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The regional dimension of smart cities in Brazil: urban networks, planning, and
inequality

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Lucas Leão Fernandes Ferreira

The regional dimension of smart cities in Brazil: urban networks, planning, and inequality

Tese apresentada ao Programa da Pós Graduação em Economia da Universidade Federal de Juiz de Fora como requisito parcial à obtenção do título de Doutor em Economia Aplicada. Área de concentração: Economia

Orientador: Prof. Dr. Fernando Salgueiro Perobelli

Coorientador: Prof. Dr. Admir Antonio Betarelli Junior

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"The future is already here – it's just not very evenly distributed."

William Gibson

ABSTRACT

The urban future is not confined to large metropolitan areas but is organised through networks of cities of different sizes, functions, and territorial positions. From this premise, this Thesis analyses how the smart city agenda is distributed, incorporated into municipal planning, and related to intra-regional economic inequality in Brazil. The argument brings the smart cities literature into dialogue with regional and urban economics by situating this agenda within Brazilian federalism, in which autonomous and heterogeneous municipalities form networks of centralities, dependencies, and economic and social flows. The first empirical stage constructs a composite urban smartness index for all 5,570 municipalities, based on 25 indicators covering the economy, society, environment, governance, and technology. The dimensions are estimated using Confirmatory Factor Analysis and generalised structural equation models, aggregated through Principal Component Analysis, and examined spatially. The second stage examines 1,236 Master Plans adopted or revised between 2010 and 2020, using dictionary-based textual analysis to measure the diversity of content associated with urban smartness. The third combines this documentary measure with a multi-period Difference-in-Differences design for 2013–2020, distinguishing between the initial adoption and revision of the Master Plan. The outcome is the municipal additive contribution to the intra-regional component of GDP per capita inequality, obtained through a nested decomposition of the Theil T index. The results show heterogeneous municipal profiles and spatial clustering in the selected smart-city-related conditions. The documentary analysis identifies uneven thematic coverage and different combinations of content across Master Plans. The econometric exercise provides suggestive evidence of a negative association between intensive new thematic incorporation in revised plans and the signed municipal contribution to GDP per capita inequality within Immediate Geographic Regions. This result does not establish a reduction in aggregate regional inequality or the effect of implemented smart city policies. Auxiliary outcomes describe changes in relative economic position, but do not identify the underlying transmission mechanisms. By integrating multidimensional measurement, documentary analysis, and regional evaluation, the study proposes a shift in scale for understanding the smart city not only through conditions observed within municipalities, but also through the institutional capacities associated with planning and the territorial relations in which municipalities are embedded.

Keywords: smart cities; urban networks; intra-regional economic inequality.

RESUMO

O futuro urbano não se restringe às grandes áreas metropolitanas, mas se organiza por meio de redes de cidades com diferentes portes, funções e posições no território. A partir dessa premissa, este estudo analisa como a agenda de cidades inteligentes se distribui, é incorporada ao planejamento municipal e se relaciona com a desigualdade econômica intrarregional no Brasil. O argumento aproxima a literatura de cidades inteligentes da economia regional e urbana ao situar essa agenda no federalismo brasileiro, em que municípios autônomos e heterogêneos integram redes marcadas por centralidades, dependências e fluxos econômicos e sociais. A primeira etapa empírica constrói um índice composto de inteligência urbana para os 5.570 municípios brasileiros, com base em 25 indicadores distribuídos entre as dimensões Economia, Sociedade, Meio Ambiente, Governança e Tecnologia. As dimensões são estimadas por meio de Análise Fatorial Confirmatória e modelos generalizados de equações estruturais, agregadas por Análise de Componentes Principais e examinadas espacialmente. A segunda etapa analisa 1.236 Planos Diretores adotados ou revisados entre 2010 e 2020, utilizando análise textual baseada em dicionário para mensurar a diversidade de conteúdos associados à inteligência urbana. A terceira combina essa medida documental com um desenho de Diferenças em Diferenças com múltiplos períodos para 2013–2020, distinguindo a adoção inicial da revisão do Plano Diretor. O desfecho corresponde à contribuição aditiva municipal para o componente intrarregional da desigualdade do PIB per capita, obtida por meio de uma decomposição aninhada do índice de Theil T. Os resultados mostram perfis municipais heterogêneos e padrões de concentração espacial nas condições selecionadas associadas às cidades inteligentes. A análise documental identifica cobertura temática desigual e diferentes combinações de conteúdos entre os Planos Diretores. O exercício econométrico fornece evidências sugestivas de uma relação negativa entre a incorporação mais intensa de novos conteúdos temáticos em planos revisados e a contribuição aditiva municipal para a desigualdade do PIB per capita nas Regiões Geográficas Imediatas. Esse resultado não permite concluir pela redução da desigualdade regional agregada, nem identificar o efeito de políticas de cidades inteligentes efetivamente implementadas. Desfechos auxiliares descrevem mudanças na posição econômica relativa dos municípios, mas não permitem identificar os mecanismos de transmissão subjacentes. Ao integrar mensuração multidimensional, análise documental e avaliação regional, o estudo propõe uma mudança de escala na compreensão das cidades inteligentes, situando essa agenda não apenas nas características internas dos municípios, mas também nas capacidades institucionais associadas ao planejamento e nas relações territoriais em que esses municípios estão inseridos.

Palavras-chave: cidades inteligentes; redes urbanas; desigualdade econômica intrarregional.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANATEL	Agência Nacional de Telecomunicações (National Telecommunications Agency)
ANEEL	Agência Nacional de Energia Elétrica (National Electric Energy Agency)
ANS	Agência Nacional de Saúde Suplementar (National Supplementary Health Agency)
ATT	Average Treatment Effect on the Treated
BACEN	Banco Central do Brasil (Central Bank of Brazil)
BRL	Brazilian real (ISO currency code)
BRT	Bus Rapid Transit
CBCI	Carta Brasileira para Cidades Inteligentes (Brazilian Charter for Smart Cities)
CDC	Centro de Difusão do Conhecimento (Knowledge Dissemination Centre)
CEDES	Centro de Estudos e Debates Estratégicos da Câmara dos Deputados (Centre for Strategic Studies and Debates of the Chamber of Deputies)
CFA	Confirmatory Factor Analysis
CFI	Comparative Fit Index
CI	Citation Index (Chapter 5); confidence interval (Chapter 6)
CNPq	Conselho Nacional de Desenvolvimento Científico e Tecnológico (National Council for Scientific and Technological Development)
CSO	Civil Society Organisation
DiD	Difference-in-Differences
ECOIndex	Economy Index
ENVIndex	Environment Index
ESDA	Exploratory Spatial Data Analysis
FIB	Felicidade Interna Bruta (Gross National Happiness)
FINEP	Financiadora de Estudos e Projetos
GCCSA	Greater Capital City Statistical Area
GDP	Gross Domestic Product
GDP _{pc}	Gross Domestic Product per capita
GE	Generalised Entropy
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (German Agency for International Cooperation)
GOVIndex	Governance Index
GPS	Global Positioning System
GSEM	Generalised Structural Equation Modelling
HHI	Herfindahl–Hirschman Index
IBC	Índice Brasileiro de Conectividade (Brazilian Connectivity Index)
IBGE	Instituto Brasileiro de Geografia e Estatística (Brazilian Institute of Geography and Statistics)

ICT	Information and Communication Technology (plural: ICTs)
IDEB	Índice de Desenvolvimento da Educação Básica (Basic Education Development Index)
ImGR	Immediate Geographic Region
INEP	Instituto Nacional de Estudos e Pesquisas Educacionais Anísio Teixeira (Anísio Teixeira National Institute for Educational Studies and Research)
IntGR	Intermediate Geographic Region
IPCA	Índice Nacional de Preços ao Consumidor Amplo (Extended National Consumer Price Index)
Ipea	Instituto de Pesquisa Econômica Aplicada (Institute for Applied Economic Research)
IPS	Índice de Progresso Social (Social Progress Index)
IPW	Inverse Probability Weighting
IQM	Índice de Qualidade Mercadológica (Market Quality Index)
ISO	International Organization for Standardization
LGA	Local Government Area
LISA	Local Indicators of Spatial Association
MCID	Ministério das Cidades (Ministry of Cities)
MCom	Ministério das Comunicações (Ministry of Communications)
MCTI	Ministério da Ciência, Tecnologia e Inovação (Ministry of Science, Technology and Innovation)
MDR	Ministério do Desenvolvimento Regional (Ministry of Regional Development)
MDS	Ministério do Desenvolvimento e Assistência Social, Família e Combate à Fome (Ministry of Development and Social Assistance, Family and Fight against Hunger)
MTE	Ministério do Trabalho e Emprego (Ministry of Labour and Employment)
MUNIC	Pesquisa de Informações Básicas Municipais (Survey of Basic Municipal Information)
NABERS	National Australian Built Environment Rating System
NACE	Statistical Classification of Economic Activities in the European Community, Revision 2
NBN	National Broadband Network
NBR	Norma Brasileira (Brazilian Standard)
NTIA	National Telecommunications and Information Administration
OECD	Organisation for Economic Co-operation and Development
OCR	Optical Character Recognition
PCA	Principal Component Analysis
PDTCI	Plano Diretor de Tecnologias da Cidade Inteligente (Master Plan for Smart City Technologies)

PDF	Portable Document Format
PECCI	Plano Estratégico de Cidades Inteligentes (Strategic Smart Cities Plan)
PIB	Produto Interno Bruto (Gross Domestic Product)
PNAD Contínua	Pesquisa Nacional por Amostra de Domicílios Contínua (Continuous National Household Sample Survey)
PNCI	Política Nacional de Cidades Inteligentes (National Smart Cities Policy)
PQ-CNPq	Bolsa de Produtividade em Pesquisa do CNPq (CNPq Research Productivity Grant)
R&D	Research and Development
RAIS	Relação Anual de Informações Sociais (Annual Social Information Report)
REGIC	Regiões de Influência das Cidades (Regions of Influence of Cities)
RMSEA	Root Mean Square Error of Approximation
RNP	Rede Nacional de Ensino e Pesquisa (National Education and Research Network)
SCIndex	Smart City Composite Index
SD	Standard Deviation
SE	Standard Error
Sebrae	Serviço Brasileiro de Apoio às Micro e Pequenas Empresas (Brazilian Micro and Small Business Support Service)
SEM	Structural Equation Modelling
SENATRAN	Secretaria Nacional de Trânsito (National Traffic Secretariat)
SMS	Short Message Service
SOCIndex	Society Index
SRMR	Standardised Root Mean Square Residual
TECHIndex	Technology Index
TKI	Total Knowledge-Intensive Activities
TU Wien	Vienna University of Technology
TWFE	Two-Way Fixed Effects
UFJF	Universidade Federal de Juiz de Fora
UN-Habitat	United Nations Human Settlements Programme
VLP	Veículo Leve sobre Pneus
VLT	Veículo Leve sobre Trilhos (light rail transit)

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1 INTRODUCTION

The future of the world's population is urban, but it will not be lived only in large metropolises. Between 1950 and 2018, the world's urban population increased from around 750 million to 4.2 billion people, raising the share of inhabitants living in urban areas from approximately 30% to 55%. By 2050, this share may reach 68%, with an estimated increase of 2.5 billion urban residents, concentrated mainly in Asia and Africa (UNITED NATIONS, 2019). At the same time, almost half of the world's urban population still lives in settlements with fewer than 500,000 inhabitants, and small, medium-sized and secondary cities are expected to absorb a substantial share of future growth, especially in developing countries (UN-HABITAT, 2022). Contemporary urban transformation therefore combines demographic expansion, changes in the spatial distribution of the population and the reorganisation of relations among centres of different sizes and functions.

Cities concentrate economic activities, knowledge, infrastructure, public services and opportunities for interaction. This concentration may favour productivity gains, innovation, economic diversification and access to jobs, education and specialised services (Duranton; Puga, 2004; Glaeser, 2011; UNITED NATIONS, 2019). The same processes, however, also produce or intensify agglomeration diseconomies, such as congestion, pressures on land use, rising housing costs, pollution, high resource consumption, precarious housing conditions and the unequal distribution of urban services (Lee, 2016; Wheeler, 2003). Urbanisation may expand the possibilities for development, but its benefits are not automatically distributed across people, neighbourhoods, cities and regions (Chauhan; Agarwal; Kar, 2016; Sharifi et al., 2023).

From an economic perspective, the issue is not whether a city possesses a particular technology, but whether changes in infrastructure, information and institutions improve the conditions under which households and firms interact. Agglomeration gains can arise through sharing, matching and learning, while congestion, housing costs and environmental externalities limit those gains (Duranton; Puga, 2004; Brueckner, 2011). Initiatives associated with the smart city agenda may influence these margins, but the label itself is neither an economic mechanism nor evidence of improved performance. Their consequences depend on which costs are reduced, which opportunities become accessible and how households, firms and public authorities respond.

This tension acquired new contours over the first decades of the twenty-first century. Climate change, biodiversity loss, ageing infrastructure, health crises, economic inequalities, territorial asymmetries and digital divides became increasingly interdependent elements of the urban planning agenda (Toli; Murtagh, 2020; UN-HABITAT, 2022; Yigitcanlar et al., 2019). At the same time, the rapid diffusion of information and communication technologies expanded the possibilities for monitoring, coordination and service provision, offering

new instruments for the management of transport, energy, waste, security, health and social participation. These transformations brought together two movements that, initially, did not always advance in tandem: the pursuit of more sustainable and inclusive cities, and the incorporation of digital technologies into urban administration and functioning (Ahvenniemi et al., 2017; Huovila; Bosch; Airaksinen, 2019).

The academic, policy and business response to this set of transformations produced a wide variety of concepts and urban positioning strategies. Sustainable, resilient, digital, green, creative, inclusive, connected, low-carbon and knowledge-intensive cities became part of the vocabulary of researchers, local governments and international organisations (De Jong et al., 2015; Janik; Ryszko, 2018). These labels seek to assign identities to territories, signal specific capacities and organise intervention programmes associated with the attraction of investment, human capital and economic activities (Ashton; Emmendoerfer; Emmendoerfer, 2018; Crippa et al., 2023). Although they are not necessarily competing terms, they reflect different interpretations of urban problems and of the appropriate means to address them.

Among these labels, the term smart city gained particular prominence after 2010, surpassing in frequency some of the expressions previously used to describe contemporary urban development strategies (Crippa et al., 2023; De Jong et al., 2015). The smart city has been framed, at different moments, as a response to rapid urbanisation, environmental constraints, inefficiencies in public management and the diseconomies produced by agglomeration (Ojo; Dzhusupova; Curry, 2016; Toli; Murtagh, 2020; Vanli; Akan, 2023). As a result, the concept came to acquire the contours of a possible panacea for urban problems of very different kinds, although there is still no consensus on what would characterise a genuinely smart city or on which outcomes should be expected from its policies (Kummitha; Crutzen, 2017; Yigitcanlar et al., 2018).

The roots of this agenda can be traced back to the first experiences in the use of databases and computational technologies in urban management, as early as the second half of the twentieth century (Caragliu; Del Bo, 2022; Vallianatos, 2015). The more explicit use of the smart city concept, in turn, spread from the 1990s onwards, influenced by the smart growth movement and by the expectation that new technologies could support planning, the operation of infrastructure systems and the administration of urban services (Ahvenniemi et al., 2017; Albino; Berardi; Dangelico, 2015; Pratama, 2021; Yigitcanlar et al., 2018). In its early formulations, urban smartness was strongly associated with the availability of digital infrastructure, sensors, connectivity and systems capable of integrating information and making the city more efficient and responsive (Hall et al., 2000; Harrison; Donnelly, 2011; Washburn et al., 2010).

The centrality assigned to technologies also reflected the role played by large technology, engineering and consulting companies in defining and disseminating the Smart City agenda. Monitoring solutions, integrated control centres, sensor networks, digital

platforms and data analytics systems came to be presented as instruments of urban modernisation, at times without sufficient consideration of institutional capacities, social inequalities and existing territorial conditions (Vanolo, 2014; Yigitcanlar et al., 2018). This orientation prompted criticism of the corporatisation of urban management, the private production of public data, technological dependence and the risk that digital transformation would disproportionately benefit groups already endowed with the resources and skills needed to use its tools (Kitchin, 2014).

Subsequent conceptual and applied work broadened the concept. Urban smartness ceased to be treated solely as a technological attribute and came to involve the articulation of infrastructure, human capital, innovation, environmental sustainability, quality of life, citizen participation and institutional capacity (Albino; Berardi; Dangelico, 2015). The definition proposed by Caragliu, Del Bo and Nijkamp (2011), influenced by the model developed by Giffinger et al. (2007), associates smart cities with investment in human and social capital, traditional and digital infrastructure, sustainable growth, quality of life, the management of natural resources and participatory governance.

Nam and Pardo (2011) organised this shift around three components – technology, people and institutions – whereas Yigitcanlar et al. (2018) proposed a multidimensional framework in which community, policy and technology are articulated with outcomes related to productivity and innovation, sustainability and accessibility, liveability and well-being, governance and planning.

The multidimensional approach became one of the main reference points in this literature. Economy, mobility, governance, environment, people and living conditions appear as articulated dimensions whose joint performance is more informative than the isolated presence of digital devices (Batty et al., 2012; Caragliu; Del Bo, 2022; Giffinger et al., 2007). Subsequent studies expanded these categories by incorporating education, health, energy, security, buildings, inclusion and basic infrastructure, without eliminating technology, but repositioning it as a means of urban transformation rather than as an end result (Aldegheishem, 2019; Toli; Murtagh, 2020; Vanli; Akan, 2023). This shift also brought smart cities closer to debates on sustainable urban development and quality of life, although the relationship between the two concepts remains subject to tensions and differences in measurement (Ahvenniemi et al., 2017; Yigitcanlar et al., 2019).

The absence of a universal definition of the smart city does not imply a lack of analytical convergence. Recent literature makes it possible to identify a common core formed by the integration of technological resources, social and institutional capacities, urban infrastructure and development objectives. What varies is the combination of these components, their relative importance and the way they are translated into policies, indicators and projects. This variation is not merely a conceptual problem. It stems from the diversity of cities themselves, their trajectories, fiscal constraints, governance

structures and social priorities. For this reason, definitions and assessment instruments need to be situated within the contexts in which they are applied (Caragliu; Del Bo, 2022; Toli; Murtagh, 2020; Vanli; Akan, 2023).

This issue is particularly sensitive when models formulated in high-income countries are used to examine cities in the Global South. A substantial share of international indicators presupposes the existence of basic infrastructure, fiscal capacity, consolidated administrative systems and widespread access to digital technologies. In many Latin American cities, by contrast, the urban agenda still involves deficits in sanitation, housing, mobility, security, connectivity and service provision, combined with persistent economic inequalities and governance weaknesses. Replicating successful solutions from cities in the Global North does not guarantee similar outcomes in territories with different institutional and socio-economic conditions (Marchetti; Oliveira; Figueira, 2019). Urban smartness needs to be interpreted in relation to the problems that each city seeks to address and the capacities available to it.

Although the literature on smart cities has expanded rapidly, quantitative applications aimed at identifying economic, social, environmental and distributive effects still occupy a relatively limited space. In Europe, the work of Caragliu and Del Bo forms one of the most sustained empirical strands in this field. Caragliu and Del Bo (2016) show that the adoption of Smart City policies is more likely in cities that already display high levels of smartness, density and development, a result that reveals the selection of treated locations and calls for caution in the causal attribution of the observed effects. Subsequently, Caragliu and Del Bo (2019) find an association between greater policy intensity and patent production, especially in high-technology segments; Caragliu and Del Bo (2020) advance the discussion of their mechanisms and evaluation criteria; and Caragliu and Del Bo (2022) identify a relationship between smart characteristics and lower levels of income inequality in European cities.

Since the early 2020s, evaluations of China's smart city policy have offered a distinct empirical setting, in which the staggered implementation of pilot projects has been explored as a quasi-natural experiment. These applied studies examine effects on innovation, economic growth, green productivity, pollution, population dynamics and territorial inequalities (e.g., Chu, Cheng and Yu, 2021; Chen et al., 2023; Chen, Deng and Schneider, 2024). Other applied studies connect the agenda to spatial issues, such as urban sprawl, economic expansion and regional coordination, although they do not always rely on identification strategies comparable to those used in evaluations of the Chinese pilots (e.g., Hao, Chen and Min, 2021).

These advances have expanded knowledge about the outcomes associated with smart cities, but they have not substantively changed the predominant scale of analysis. The city, the metropolitan area or the functional urban area remains the central unit of

observation, while innovation, growth, inequality, population and environmental quality are generally assessed as outcomes of that unit itself. Even when references to regional coordination or regional inequality appear, space tends to operate as a frame for comparison or aggregation, rather than as a structure of relations among urban centres. It therefore remains underexplored how smart city policies may modify intermunicipal flows, hierarchical positions and the composition of inequalities within regional systems.

This gap becomes more evident when set against a consolidated tradition in regional and urban economics. Cities are not autonomous units randomly distributed across space. They are part of systems of relations through which people, goods, services, information, investment and decisions circulate (Pred, 1977; Pumain, 2001). Some centres concentrate management functions and specialised services, while others depend on them to meet demands related to work, consumption, health or education. The positions occupied by cities result from cumulative processes, agglomeration economies, interaction costs, accessibility, functional specialisation and the capacity to connect with other places (Capello, 2015; Fujita; Thisse, 2002; Krugman, 1991).

The move from the isolated city to the system of cities changes the interpretation of urban policies. An intervention that improves connectivity, infrastructure, governance, environmental quality or service provision may alter the attractiveness of a locality for households, firms and workers. This change may reinforce a pre-existing centrality, stimulate the diffusion of activities, reorganise flows or deepen relations of dependence in the surrounding area. The effect observed in one city may therefore be accompanied by changes in other localities with which it maintains functional links. The region is not merely a scale of aggregation, but the relational space in which centralities, complementarities and inequalities are formed (Camagni; Salone, 1993; Galindo; Tavares, 2020; Taylor; Hoyler; Verbruggen, 2010).

At this point, there remains an underexplored point of convergence between the smart cities literature and regional economics. The dimensions usually associated with urban smartness also correspond to locational attributes capable of influencing the net benefits perceived by economic agents. Infrastructure, connectivity, human capital, innovation, institutional quality, access to services and living conditions affect location choices and may modify the relative position of centres within an urban network (Capello, 2015; Roback, 1982; Thite, 2011). Smart city policies may act upon these attributes, but their regional effects will depend on the territorial structure, implementation capacity and initial position of the locality. The same strategy may produce diffusion in one context, concentration in another, or remain confined to the discursive level when it does not encounter the institutional conditions required for execution.

The gap guiding this study lies less in the absence of research on the effects of smart cities than in the scale and nature of the outcome analysed. The empirical literature

reviewed has asked whether smart cities grow more, innovate more, attract population or display lower internal inequality. It remains underexplored whether the incorporation of this agenda alters the way a city participates in the economic structure of its region, either through changes in its relative economic position or through its contribution to intra-regional inequality. This is the shift that organises the argument of this study: the urban is not abandoned, but observed through the relations that constitute it.

Brazil offers particular analytical conditions for this investigation. The country combines an extensive and hierarchical urban network, high economic concentration in specific centres, persistent territorial inequalities and a large number of small municipalities. The study *Regiões de Influência das Cidades* (Regions of Influence of Cities, REGIC) identifies metropolises, regional capitals, sub-regional centres, zone centres and local centres on the basis of management functions, the supply of goods and services and population movements, revealing relations of centrality and dependence that extend beyond municipal boundaries (IBGE, 2019b). The Immediate and Intermediate Geographic Regions seek to capture part of these functional articulations, organising the territory according to nearby centres, daily flows and urban functions of different levels of complexity (IBGE, 2017).

At the same time, Brazilian federalism grants municipalities political, administrative and normative autonomy, as well as direct responsibilities for service provision and territorial planning (Abrucio, 2005; Arretche, 2004; BRASIL, 1988). This autonomy coexists with marked differences in fiscal, technical and institutional capacity, so that municipalities subject to similar responsibilities have very different conditions for formulating and implementing policies (Abrucio; Sano, 2013). The smart city agenda, therefore, does not diffuse across a homogeneous structure. It encounters metropolises with specialised resources, intermediate centres that articulate regions, and thousands of small municipalities whose provision of services and opportunities depends on supramunicipal relations.

The municipality is adopted as the unit of observation because the empirical questions concern municipal conditions and the content of a municipal planning instrument. This is an institutional choice, not a claim that municipal boundaries coincide with the built-up city, the urban population or the functional labour market. The City Statute, enacted by Federal Law No. 10,257/2001, requires the Master Plan to cover the municipality as a whole and links its guidelines to the municipal planning and budgetary process (BRASIL, 2008b, Article 40). Observing this jurisdiction therefore preserves the correspondence between the legal instrument, the public authority responsible for its formulation and the territorial information used in the analysis.

The choice also entails losses. Municipal aggregates may combine urban and rural populations, several settlement nuclei and economic activities outside the built-up area. Conversely, a single functional city may extend across several municipalities.

These differences limit the interpretation of municipal indicators as measures of urban density, accessibility or residents' welfare. Nationwide analysis based on urban areas is possible, but matching a consistent urban delineation to the documentary corpus and to the economic and institutional variables used here would require additional spatial allocation assumptions. Data availability is therefore a constraint on the joint empirical design, not an argument that urban-area analysis is intrinsically impossible.

The gain is the inclusion of small and non-metropolitan jurisdictions and the ability to connect municipal planning to a broader regional reference. The analysis retains municipalities as observations while using geographic regions and urban hierarchy to contextualise their positions. This combination does not directly identify intermunicipal flows or spillovers. It provides a way to examine an institutional unit whose economic relations need not stop at its boundary.

The general question guiding this study may be formulated as follows: how is urban smartness distributed and incorporated into the planning of Brazilian municipalities, and to what extent is this incorporation associated with changes in municipalities' relative economic position and in the composition of intra-regional inequality? This question brings together three levels of analysis. The first concerns the observable attributes of urban smartness. The second examines its inscription in formal planning instruments. The third investigates possible repercussions for the economic relations established among municipalities embedded within the same regional structure.

The overall aim is to analyse the distribution, institutional incorporation and regional implications of the smart city agenda in Brazilian municipalities, with particular attention to relations of centrality, hierarchy and intra-regional economic inequality. The study seeks to understand the phenomenon beyond large cities, considering municipalities of different sizes and positions within the urban network. The proposal is not to replace urban analysis with regional analysis, but to recognise that the outcomes of a municipal policy may depend on the functional relations that connect the locality to its surroundings.

The analytical path followed in this Thesis is deliberately sequential. First, it defines the theoretical basis capable of explaining why changes in urban attributes may produce regional effects. It then delimits a concept of the smart city that is compatible with the Brazilian context. The third stage measures how its dimensions are manifested across the set of municipalities. The fourth identifies how this agenda appears in formal planning instruments. The final stage brings these foundations together to examine their relationship with intra-regional economic inequality. In this way, the study moves from concept to measurement, from measurement to institutional incorporation, and from institutional incorporation to the regional outcome.

The three empirical exercises are complementary, but they are not successive estimates of a single causal chain. Chapter 4 measures municipal conditions associated

with the multidimensional smart city framework. Chapter 5 measures the presence of related themes in planning documents. Chapter 6 examines the relationship between the documentary event and a regional economic outcome. The structural indicators in Chapter 4, compiled from different and generally later reference years, are not interpreted as pre-treatment conditions or as identified mediators of the 2013-2020 econometric relationship. Keeping these objects separate prevents observed municipal performance, documented priorities and implemented policy from being treated as interchangeable evidence.

The first contribution stems from the dialogue between two literatures that have, to a large extent, advanced along parallel paths. The smart cities literature offers concepts, dimensions and evidence on urban policies, while regional economics provides mechanisms for understanding concentration, diffusion, hierarchies and territorial interdependencies. By bringing these fields together, the study proposes that urban smartness should be analysed not only as an internal attribute of the city, but also as a possible component in the reorganisation of regional systems. This shift in perspective makes it possible to formulate questions about centrality, dependence and inequality that do not arise when each city is treated as an isolated observation.

The second contribution lies in adapting this discussion to Brazil's institutional and territorial structure. Rather than restricting the analysis to state capitals, metropolises or municipalities above a given population threshold, the study considers the country's 5,570 municipalities at the measurement stage. This expansion makes it possible to incorporate small localities that perform their own administrative functions and participate in regional networks, but remain absent from much of the smart city rankings and diagnostics. The procedure also offers a reference for other countries in which local governments of different sizes have urban responsibilities and are embedded in hierarchical territorial systems.

The third contribution lies in the construction of a multidimensional urban smartness dataset for all Brazilian municipalities. The indicator combines 25 variables distributed across Economy, Society, Environment, Governance and Technology, adapting international models to data availability conditions and national specificities. In methodological terms, the measurement combines factor models to estimate the latent dimensions and multivariate aggregation across dimensions, reducing reliance on purely additive procedures with equal weights, which are common in urban benchmarking exercises. The analysis is not limited to classifying localities. It examines the composition of the results and their spatial distribution, making it possible to identify clusters, regional contrasts and smaller municipalities whose performance would be less visible in applications concentrated on large cities.

The fourth contribution is institutional and methodological. The research brings together 1,236 municipal Master Plans and develops a dictionary of terms organised into economic, social, environmental, institutional, technological and urban positioning

dimensions. The textual analysis allows for the construction of a comparable measure of the thematic diversity with which the smart city agenda appears in these documents. In a context in which local policies are decentralised, heterogeneous and often not identified by a common nomenclature, this strategy offers a way to observe their normative incorporation without assuming that textual presence automatically corresponds to implementation.

The fifth contribution lies in the analysis of regional implications. The outcome variable is constructed from the decomposition of generalised entropy measures (Akita, 2003; Shorrocks, 1980; Theil, 1967), allowing the additive contribution of each municipality to the intra-regional component of GDP per capita inequality to be identified. This measure is combined with a multi-period Difference-in-Differences design (Callaway; Sant’Anna, 2021), which distinguishes between initial adoption and revision of the Master Plan and considers the intensity of incorporation of the Smart City agenda. The strategy shifts the outcome of interest from aggregate regional inequality to the way each municipality participates in its composition.

Although the empirical application focuses on Brazilian municipalities, the analytical design adopted here should not be confused with a purely national specificity. The combination of multidimensional indicators of urban smartness, documentary evidence of institutional incorporation and an outcome measure defined by the position of the locality within its functional region makes it possible to observe the Smart City agenda in its territorial dimension. This analytical structure is especially informative in the Brazilian case, because of municipal fragmentation, the heterogeneity of local capacities and the hierarchical organisation of the urban network, but it also speaks to problems found in other urban systems in which unequal local governments share interdependent regional functions.

The results reveal heterogeneous municipal profiles and a clear spatial organisation of the selected conditions associated with urban smartness. Master Plans likewise differ in the breadth and composition of the agenda they record. In the econometric exercise, intensive new thematic incorporation in revised plans is associated with a negative estimate for the signed municipal contribution to intra-regional GDP per capita inequality in some specifications, whereas initial adoption shows no consistent detectable pattern. Comparisons by urban hierarchy and prior documentary content remain exploratory and do not establish differences in causal effects across groups. The evidence thus connects municipal conditions, planning documents and regional economic positions without establishing a general inequality-reducing effect of smart city policies.

From a public policy perspective, this reading suggests that the smart city agenda should not be treated as a uniform catalogue of technological solutions. The same guideline may take on different meanings in a metropolis, in a regional centre or in a small municipality dependent on urban functions located in its surrounding area. The analysis

developed here makes it possible to identify where capacities are concentrated, how the agenda appears in municipal planning and in which contexts its incorporation is associated with changes in municipalities' relative economic position. These elements may inform policies for technical support, funding, monitoring and intermunicipal cooperation that are better adjusted to Brazil's territorial heterogeneity.

In addition to this introduction, the Thesis is organised into five chapters. Chapter 2 establishes the regional and urban economics basis required to formulate the central question. The discussion begins with the evolution of the concept of space, moves through theories of location, uneven growth, agglomeration and systems of cities, and arrives at urban networks as structures of interdependence. The chapter examines innovation, infrastructure, institutions, information technologies and quality of life as locational channels capable of altering the choices of firms and individuals. Its role is to show why attributes generally associated with smart cities may modify not only the internal functioning of a locality, but also its relative position within a regional system. Without this construction, the move from the urban to the regional would remain merely an intuition not linked to the mechanisms of spatial economics.

Chapter 3 delimits the concept employed in the remainder of the study. The plurality of definitions of the smart city requires distinguishing technocentric approaches from multidimensional interpretations and explaining why technology, governance, people, environment and quality of life are treated jointly. The chapter also contextualises the discussion for Brazil, differentiating city, municipality and the urban, characterising territorial heterogeneities and examining the Brazilian Charter for Smart Cities and the proposal for a National Smart Cities Policy. Its position follows from the need to avoid applying indicators and strategies designed in other contexts to the country without conceptual and institutional adaptation. The definition constructed in this chapter guides both the measurement exercise in Chapter 4 and the textual dictionary used in Chapter 5.

Chapter 4 transforms this conceptual delimitation into a comparable empirical base. To this end, it constructs multidimensional indicators of urban smartness for Brazil's 5,570 municipalities, combining economic, social, environmental, institutional and technological data. The analysis examines dimensional scores, the composition of the aggregate index, the position of municipalities and their spatial distribution. This chapter provides a national diagnosis with full municipal coverage, supporting the subsequent stages of the analysis. Before investigating policies or effects, it is necessary to understand how the conditions associated with urban smartness are distributed across the territory and whether the observed patterns are restricted to capitals and large centres or also appear in small and intermediate municipalities.

Chapter 5 shifts the analysis from observed conditions to the institutional incorporation of the agenda. A municipality's performance in the indicators does not, in itself,

reveal whether certain dimensions have been recognised or formalised as planning priorities. For this reason, the chapter examines Master Plans, reconstructs the fragmented trajectory of Brazilian initiatives and develops a textual analysis strategy to measure the presence of content associated with smart cities. The documentary database and the citation index perform two functions. First, they make it possible to observe how the agenda is appropriated by municipalities with different characteristics. Second, they produce the treatment measure required for the impact exercise developed in the following chapter.

Chapter 6 brings together the previous analytical steps. The regional framework of Chapter 2 provides the interpretative mechanisms. The definition developed in Chapter 3 delimits the content of the agenda. The indicators constructed in Chapter 4 characterise observed urban smartness. The textual index from Chapter 5 identifies the intensity of its normative incorporation. Based on this sequence, the chapter investigates whether the incorporation of the Smart City agenda in processes of adoption or revision of Master Plans is associated with changes in municipalities' contribution to intra-regional inequality. The analysis uses Immediate Geographic Regions as the functional reference and Intermediate Geographic Regions as the decomposition structure, distinguishing effects by intensity, urban hierarchy, documentary maturity and thematic composition.

The organisation of the Thesis thus follows the research problem itself. Smart cities are first situated within a structure of spatial relations, then defined for the context under analysis, measured across the territory, identified in planning instruments and examined in terms of their possible regional implications. This sequence makes it possible to understand urban smartness as a multidimensional, institutionally mediated and territorially interdependent phenomenon. Rather than adding a new dimension to smart city studies, the proposal is to reposition the scale at which its empirical questions may be formulated.

2 SPACE, URBAN NETWORKS AND REGIONAL ECONOMIC INEQUALITY

2.1 Introduction

Regional economic inequality is one of the persistent issues in the literature on regional development (Iammarino; Rodriguez-Pose; Storper, 2019). Understanding it requires not only a careful definition of the spatial units of analysis, but also an account of the mechanisms through which people, firms, information, services and decisions are distributed across, and move through, the territory (Redding; Rossi-Hansberg, 2017). In this sense, the region cannot be treated merely as an administrative unit or a homogeneous surface. It corresponds to a form of spatial organisation marked by internal interdependencies that are more intense than those established with the rest of the territory (Lima; Simões, 2010).

The urban dimension occupies a particular position in this discussion. The city concentrates population, productive activities, infrastructure, services and command functions, but its dynamics are not exhausted within the physical or administrative limits of urbanised space. Cities are connected through flows of labour, consumption, information, capital, public services and business decisions (Pumain, 2001). For this reason, the analysis of the urban, when observed through its external relations, moves closer to regional analysis (Taylor; Hoyler; Verbruggen, 2010). Urban space is, at once, a node of concentration and a point of articulation for relations that extend beyond the city considered in isolation.

This perspective shifts the problem of regional inequality beyond the comparison between rich and poor areas. What matters is to understand how territorial differences are formed, reproduced and reorganised through structures of centrality, hierarchy and dependence among cities (Pumain, 2001). Urban centres endowed with more extensive economic, administrative and informational functions tend to attract people, firms and investment, while less central localities may occupy subordinate positions within the regional network. This process is not static. It results from equilibria continuously adjusted by forces of attraction and dispersion, associated with agglomeration economies, transport costs, accessibility, quality of life, institutions, information and economic opportunities (Redding; Rossi-Hansberg, 2017).

The literature in regional economics offers tools for understanding this dynamic. From classical location theories to the approaches of New Economic Geography, space has ceased to be treated merely as physical distance or transport cost and has come to be understood as an active dimension of economic organisation (Capello, 2015). The location of firms and households, the spatial diffusion of knowledge, the provision of infrastructure, institutional quality and well-being differentials form part of the mechanisms through which certain places become more attractive than others, producing unequal trajectories

of growth and development (Fujita; Thisse, 2002; Krugman, 1991).

The contribution of this chapter is to organise this discussion from an urban-regional perspective. Its central argument is that cities should be understood as components of interdependent urban systems. Within these systems, changes in a city's locational attributes may alter its relative position in the network, affecting flows, centralities and regional equilibria. The region, therefore, does not appear merely as a scale of aggregation, but as a relational space in which urban dynamics produce economic effects that are unevenly distributed.

In addition to this introduction, the chapter is organised into five sections. Section 2.2 revisits the evolution of the concept of space in regional economics, with emphasis on the shift from location as distance to space as a relational and cumulative structure. Section 2.3 discusses systems of cities, urban networks and regional hierarchies. Section 2.4 brings this discussion closer to the Brazilian case, drawing on the national urban network, centralities and the supra-municipal scale. Section 2.5 examines the main locational channels that condition movements of attraction and dispersion among firms and individuals. Section 2.6 discusses the net benefits of urbanisation, the optimal size of cities and the reconfiguration of regional equilibria. The final section synthesises the argument and prepares the transition to the conceptual discussion developed in the following chapter.

2.2 Space, location and uneven development

Economic activity is unevenly distributed because firms and households do not choose among equivalent locations. Places differ in market access, infrastructure, labour availability, amenities, institutions and inherited productive structures, while the value of these attributes is itself affected by the spatial distribution of economic activity. Location is therefore not only a response to geographical conditions, but also an outcome of interactions between transport and interaction costs, increasing returns, factor mobility and market access (Krugman, 1991; Fujita; Thisse, 2002; Redding; Rossi-Hansberg, 2017). From this perspective, space enters the economic problem through the incentives faced by agents and through the way their individual location decisions collectively shape the distribution of production and population.

Agglomeration provides one of the main mechanisms through which these interactions become cumulative. Duranton and Puga (2004) organise the microeconomic foundations of urban agglomeration around three broad mechanisms: sharing, matching and learning. Larger and denser markets may allow firms and workers to share specialised inputs and infrastructure, improve the quality and probability of matches in labour and input markets, and facilitate the generation and diffusion of knowledge. The empirical literature reviewed by Rosenthal and Strange (2004) provides evidence consistent with these mechanisms and also indicates that agglomeration effects tend to weaken with

geographical distance. Concentration may therefore generate locally specific productivity advantages rather than benefits that diffuse uniformly across space.

These mechanisms help explain why spatial disparities may persist even when firms and workers are mobile. In the core-periphery formulation of Krugman (1991), increasing returns, transport costs and the location of demand can reinforce one another, generating cumulative concentration of economic activity. Fujita and Thisse (2002) place this mechanism within a broader treatment of agglomeration, factor mobility and urban systems, showing how the same forces that favour concentration can also interact with dispersion forces and produce different spatial configurations. More recent quantitative spatial economics similarly treats the observed geography of economic activity as the outcome of both geographical heterogeneity and endogenous interactions among agents in goods and factor markets Redding and Rossi-Hansberg (2017).

The implication is not that concentration necessarily increases indefinitely or that regional convergence is impossible. Changes in transport and interaction costs, infrastructure, technology, institutions and local amenities may alter the relative attractiveness of places and modify previous spatial equilibria. At the same time, regional trajectories need not converge automatically, since accumulated advantages, productive structures and local capabilities affect how places respond to these changes. Evidence on European regions, for example, shows persistent and differentiated development trajectories rather than a single convergence path Iammarino, Rodriguez-Pose and Storper (2019). The relevance of this literature to the present argument lies less in predicting a specific direction of regional change than in showing that spatial outcomes depend on how agglomeration and dispersion forces operate in particular territorial contexts.

Once development is understood in these terms, the economic position of a locality cannot be interpreted only from its internal characteristics. Market access, labour mobility, service provision, knowledge flows and locational alternatives connect urban centres to other places, so that a change in the attributes of one centre may affect both its own attractiveness and the relative position of other centres. This relational dimension provides the link between location and the system of cities. The following section develops this argument by examining urban networks and regional hierarchies as structures through which these spatial interdependencies are organised.

2.3 Systems of cities, urban networks and regional hierarchies

The shift from the isolated city to the system of cities changes the way regional dynamics are understood. A city may be observed through its internal attributes, such as population, density, productive structure, infrastructure and living conditions. However, its economic position also depends on the relations it maintains with other urban centres. This relational dimension is particularly important for regional analysis, since the flows

that organise the territory articulate urban centres, areas of influence and regions through functional relations that go beyond the understanding of the city as an isolated unit (Camagni; Salone, 1993; Meijers, 2007).

Central place theory, formulated by Christaller (1933) and later developed by Lösch (1940), offers one of the first systematic interpretations of the urban hierarchy. Within this tradition, urban centres differ according to the supply of goods and services, the reach of their market areas and the position they occupy within a hierarchical structure of localities (Getis; Getis, 1966). Although its formal assumptions are restrictive, the contribution of this literature remains relevant because it makes explicit that cities do not perform the same functions within the territory. Some localities concentrate more complex services and radiate influence over smaller centres, while others serve more proximate and less specialised demands.

This hierarchical interpretation, however, does not exhaust the relations between cities. Pred (1977) defines a system of cities as a national or regional set of interdependent urban centres, in which relevant changes in the economic activity, occupational structure, income or population of one city may produce direct or indirect changes in other cities within the system. Economic interdependence, in this case, has an interactional counterpart, expressed in flows of goods, services, capital, people and information. The city ceases to be merely a point of supply for an area of influence and becomes part of an open system of relations.

Pumain (2001, 2020) develops this perspective by treating systems of cities as evolving and open sets, structured by processes of co-evolution, functional differentiation and path dependence. The size of cities and their position within the system do not result only from decisions internal to each locality, but from accumulated interactions among urban centres, economic actors and institutions. This interpretation is compatible with a dynamic understanding of the region, in which urban hierarchies are not merely a reflection of pre-existing differences, but also mechanisms through which these differences are reproduced and reorganised.

Taylor (2004, 2019) deepens this critique of the excessive attention given to cities' internal relations. For the author, external relations are not a complement to urban theory, but a constitutive dimension of cities. The distinction between central place theory and central flow theory is useful in this regard. The former describes vertical relations between the city and its area of influence, associated with the supply of goods and services. The latter describes horizontal, non-local relations among cities connected by flows of information, specialised services, business decisions and organisational networks (Taylor; Hoyler; Verbruggen, 2010). The city, therefore, combines relations of proximity and network relations, with different weights according to its position in the urban hierarchy.

In the context of regional economics, this distinction makes it possible to interpret

the urban network as a form of spatial organisation. Cities concentrate activities, but they also distribute functions, connect markets, mediate flows and structure dependencies, so that the region can be understood as a space of relations among urban centres of different sizes, functions and capacities (Capello, 2000). Regional equilibrium does not correspond to a static situation, but to a provisional configuration of centralities, flows and hierarchies, continuously tensioned by forces of concentration and dispersion associated with increasing returns, interaction costs and cumulative market effects (Krugman, 1991).

2.4 Brazilian urban network, centrality and the supra-municipal scale

The discussion of urban networks takes on specific contours in the Brazilian case. The national urban network is marked by strong territorial heterogeneity, the concentration of functions in particular centres and the broad presence of small municipalities. This configuration means that the analysis of cities, when restricted to internal attributes, is insufficient for understanding the mechanisms of regional development. The position of each municipality also depends on its insertion into relations of influence, dependence, complementarity and articulation with other centres (IBGE, 2016, 2019b).

The Brazilian tradition of studies on the urban network provides a relevant basis for this interpretation. Corrêa (2004) distinguishes three structural dimensions of the urban network: the dimensional, associated with the size of centres; the functional, related to the activities and functions performed by each locality; and the spatial, referring to the way in which centres and flows are distributed across the territory. These dimensions are inseparable. Differences in size, function and location help to explain why certain centres concentrate command capabilities, while others are inserted into the network in subordinate or specialised ways.

Mendes (2009) observes that the city occupies a central position in understanding the hierarchy of the urban network and the configuration of regions or territories of influence. The distinction between homogeneity and polarity is useful for this argument. While the former defines regions by similar characteristics, the latter emphasises interaction among differentiated urban cores, in which certain centres function as poles of supply, decision-making and territorial articulation. For a regional analysis guided by the urban network, polarity makes it possible to observe not only where inequalities lie, but how they are produced through relations among urban centres.

This perspective is operationalised in the study *Regiões de Influência das Cidades* (Regions of Influence of Cities, REGIC), produced by the *Instituto Brasileiro de Geografia e Estatística* (Brazilian Institute of Geography and Statistics, IBGE). REGIC identifies the hierarchy of Brazilian urban centres and their areas of influence based on management functions, the supply of goods and services, and population mobility flows (IBGE, 2019b). The unit of analysis combines municipalities and population arrangements, recognising

that the functional city may extend beyond the individual municipality when there is conurbation or strong integration through daily commuting. In this way, the Brazilian urban network is treated as a structure of centralities and territorial linkages, rather than merely as a distribution of localities across space.

Galindo and Tavares (2020) advance this perspective by arguing that the urban network should not be treated as yet another scale, but as an approach applicable across different scales. This distinction is important for this chapter. Observing the urban network does not mean abandoning the regional scale, but understanding how interactions among cities organise spillovers, impacts and effects across the territory. The network is the medium through which production, circulation, consumption, services and decisions are articulated in space.

The supra-municipal scale reinforces this argument. Marguti et al. (2020) argue that relations among municipalities involve complementarities, asymmetries of capacity, flows of access to services and the formation of networks of cities. In a federal country, where municipalities have political and administrative autonomy but highly unequal capacities, this dimension is particularly sensitive. Policies, investments or institutional changes in one municipality may produce effects on nearby localities, especially when that municipality performs regional centrality functions.

From this perspective, the Brazilian urban network provides the territorial framework needed to analyse regional economic inequality at the municipal level. Municipalities are not merely administrative units that can be compared with one another. They occupy distinct positions within systems of relations that condition their capacity to attract population, firms, services, investment and public functions. Thus, regional inequality can be interpreted as the result of internal differences among municipalities and also of the positions they occupy within the urban networks that structure the territory.

2.5 Locational forces and regional equilibria

This section organises five locational channels around a common economic question: how might a change in municipal conditions alter the costs and benefits of locating, working or producing in a place? Innovation and human capital may affect productivity and learning. Infrastructure and mobility may change access to employment, suppliers and services. Institutions may alter regulatory predictability and coordination costs. Digital technologies may reduce information and administrative costs, conditional on skills and access. Amenities and public services may affect residential attractiveness and the compensation households require to live in different locations (Duranton; Puga, 2004; Roback, 1982).

These channels do not imply a common regional outcome. Lower interaction costs can strengthen a central location or facilitate activity in its surroundings. Better amenities

can attract residents without proportionate growth in locally recorded output. Changes in land-use rules can affect the supply and price of housing, modifying the incidence of urban gains. The empirical chapters observe selected municipal conditions, documentary content and changes in relative economic position, rather than all intermediate decisions. The mechanisms discussed here therefore organise the interpretation and its limits; they are not claimed to be separately identified by the estimates.

2.5.1 Spatial diffusion of innovation

Innovation is one of the channels through which economic dynamics are reorganised across space. By shifting the locus of growth among sectors, firms and localities, it changes locational advantages and influences the way different regions participate in development processes (Malecki, 2021). Although innovation is often treated as the outcome of decisions at the firm or individual level, its production and diffusion have a strong territorial dimension, as they depend on environments capable of combining knowledge, infrastructure, human capital, interaction and access to markets (Florida; Adler; Mellander, 2018; Johansson, 2021).

This territorial dimension is particularly visible in the geography of innovation. Knowledge-intensive activities tend to concentrate in urban and regional spaces endowed with greater economic density, a larger supply of skilled workers and a more diverse set of organisations, such as specialised firms, universities, research centres and support institutions (Brunow; Hammer; McCann, 2020; Johansson, 2021). Proximity does not preclude the circulation of knowledge at broader scales, but it favours frequent interactions, informal exchanges and learning processes that may reinforce the advantage of particular centres. For this reason, location remains a relevant factor for firms seeking to expand their innovative and competitive capacity (Doloreux; Shearmur, 2012).

The spatial concentration of innovation also helps to explain the persistence of regional inequalities. The literature on the geography of innovation has shown that knowledge-intensive activities are not distributed randomly across the territory, but tend to accumulate in areas that already have denser productive, institutional and relational resources (Tunes, 2020). This movement is consistent with the logic of the spatial diffusion of innovation, formalised by Hägerstrand (1967), according to which ideas, production methods and new products spread unevenly across space, with greater intensity in proximity to their centres of origin.

Innovation therefore operates simultaneously as a force of concentration and as a potential mechanism of diffusion. Denser urban centres may expand their capacity for attraction by bringing together knowledge, infrastructure and skilled labour. At the same time, the effects of innovation may reach other localities through information flows, worker mobility, productive linkages and institutional networks. The predominant direction of

this process depends on the regional structure in which the centres are embedded. In some contexts, innovation may reinforce pre-existing centralities; in others, it may expand the articulation capacity of intermediate centres and favour the reorganisation of the regional network.

2.5.2 Infrastructure, accessibility and territorial productivity

Infrastructure constitutes another relevant channel in the formation of locational advantages. In a broad sense, it comprises capital-intensive systems that support the circulation of people, goods, information and services, such as transport, communication, sanitation and energy networks, as well as urban facilities (Gramlich, 1994). In regional economics, its importance stems from the fact that development depends not only on private factors of production, such as capital and labour, but also on the territorial conditions that make it possible to increase productivity, reduce interaction costs and improve accessibility to markets (Capello, 2015; Rietveld, 1989).

Greater infrastructure provision can increase factor productivity, reduce logistics costs and expand the effective area of interaction of a locality. These effects make certain centres more attractive to firms and workers, while also potentially generating positive externalities for nearby localities, depending on the scale and type of infrastructure and on existing regional connections (Capello; Nijkamp, 2009). Infrastructure should therefore not be seen merely as a physical stock, but as a condition that changes the possibilities for economic articulation across the territory.

This interpretation brings the discussion of infrastructure closer to spatial equilibrium theory. In Roback's (1982) model, firms choose their locations on the basis of the relationship between productivity, wages and land-use costs, while households consider wages, living costs and local amenities. A change in variables that affect productivity or well-being, such as infrastructure investment, may alter prices, population and locational decisions, thereby modifying the net benefits associated with each region (Grimes, 2021). In this sense, infrastructure affects both the productive and the residential dimensions of location.

The regional effect of these investments, however, is not necessarily homogeneous. Infrastructure improvements may reinforce the centrality of already dynamic centres by expanding their command capacity and market reach. In other cases, they may reduce access costs for less central areas, creating conditions for the dispersion of activities or for the strengthening of intermediate centres. The literature therefore suggests that infrastructure investment may influence the level of agglomeration, the development trajectory and the spatial distribution of income, but its effects depend on the pre-existing territorial structure and on the functional relations among urban centres (Siatan; Gustiyana; Nurfitriani, 2024).

The economic consequences of improved accessibility depend on the response of

land and housing markets. A reduction in commuting costs can expand residential choice and access to employment, but may also encourage more dispersed development. Its welfare effect cannot be inferred from the urban footprint alone. The distinction is between spatial expansion reflecting households' choices and expansion influenced by unpriced congestion, environmental costs or restrictions on housing supply. Land-use regulation and transport policy matter because they shape these trade-offs, not because either more regulation or a more compact city is necessarily preferable in every setting (Brueckner, 2011).

2.5.3 Institutional environment and territorial coordination

The institutional environment conditions the way economic agents make decisions, coordinate expectations and organise their interactions across space. North (1990) defines institutions as socially constructed rules that shape human behaviour. These may be formal, when expressed in laws, contracts and norms, or informal, when linked to habits, conventions and social practices. By establishing incentives and constraints, institutions influence investment decisions, productive organisation, transaction costs and forms of cooperation, with effects on the development trajectory of regions (Acemoglu; Johnson; Robinson, 2005).

At the regional level, institutional quality affects the predictability of contracts, the definition of property rights, access to finance and the capacity for coordination between public and private agents. These elements shape the way externalities are produced, appropriated or mitigated within the territory (Fiani, 2011). Since the institutional matrix results from the interaction between economic and political organisations, different regions may develop distinct institutional arrangements, reflecting their own interests, capacities and trajectories (Lakshmanan; Button, 2009; Santana; Candéa, 2016).

The relationship between institutions and regional development should not be read in a single direction. Institutions that are more conducive to reducing uncertainty and transaction costs may stimulate economic growth, but more developed economies also tend to demand and sustain more complex institutional arrangements (Naritomi, 2007). In economies in which competitiveness, learning and innovation become more dependent on coordination among actors, the quality of formal and informal rules begins to affect the regional capacity to organise productive systems, absorb knowledge and sustain growth trajectories (Capello, 2015).

This institutional dimension also has locational implications. Formal rules affect contracts, regulation, finance and legal certainty, while informal institutions influence trust, cooperation and the social acceptance of economic activity (Melo et al., 2020). In the labour market, effective regulations may reduce uncertainty and improve contractual efficiency, favouring the agglomeration of workers and firms in particular centres (Guan; Zhang; Zhu,

2021). Thus, the institutional environment may reinforce or constrain agglomerative forces, influencing the way economic opportunities and income are distributed across regions.

In this thesis, the Master Plan is one formal institution through which these incentives may be shaped. It can establish land-use guidelines, provide a framework for subsequent regulation and coordinate public decisions, while firms and households continue to respond to prices, opportunities and constraints. The institutional argument therefore does not presume that planning replaces market allocation. Nor does it presume that a more elaborate document improves allocation. That depends on the content, implementation and enforcement of its provisions, as well as on the interests represented in the planning process. Chapter 5 examines this institutional setting in detail.

2.5.4 Information and communication technologies

Information and communication technologies (ICTs) affect regional dynamics by changing interaction costs, forms of production, access to information and possibilities for connection among agents. Their adoption may foster innovations in products, processes, organisation and distribution, increasing the competitiveness of local production systems and facilitating the circulation of market information, employment opportunities, ideas and business services (Cooke et al., 2015; Czernich et al., 2011; Habibi; Zabardast, 2020; Mashadihasanli; Zülfiyar, 2024; Pradhan; Mallik; Bagchi, 2018). Even so, the presence of these technologies does not, by itself, produce regional development. Their effectiveness depends on their combination with knowledge, skills, institutional capabilities and productive bases that are not evenly distributed across space (Capello; Lenzi, 2015; Capello, 2015).

The literature usually organises this debate around two interpretations. The first suggests that ICTs may reduce the marginalisation of peripheral areas by expanding access to productive information, remote training, external markets, professional services, teleworking opportunities and new sources of finance (Battino; Lampreu, 2019; Chen et al., 2018; Kolko, 2012; Mack et al., 2024; Paunov; Rollo, 2016; Richardson; Gillespie, 1996; Zhao; Zheng; Fang, 2024). In this argument, connectivity would weaken part of the disadvantages associated with physical distance and allow firms and workers located in less central areas to become integrated into broader economic circuits.

A second interpretation is more cautious regarding the “death of distance” hypothesis. Although ICTs restructure relations between time and space, geography continues to influence technological diffusion, knowledge production and the location of economic activities (Dadashpoor; Yousefi, 2018). Central regions tend to have better digital infrastructure, a higher density of users, a larger stock of human capital and greater technological absorptive capacity, which may also make ICT diffusion a centripetal process (Capello, 2015; Zhao; Zheng; Fang, 2024). Moreover, even when digital technologies facilitate the

circulation of codified knowledge, tacit knowledge continues to depend on interaction, trust and, in many cases, face-to-face contact (Gertler, 2003).

Thus, the relationship between ICTs and regional inequality remains ambiguous. In some contexts, these technologies may expand the integration capacity of peripheral areas; in others, they may reinforce the advantages of centres that already concentrate infrastructure, knowledge and advanced economic functions. The persistence of transport costs for physical goods and the empirical evidence against the hypothesis of the disappearance of distance reinforce this caution (Jakobi, 2013; Rietveld; Vickerman, 2004).

The discussion of digital exclusion makes this point even more sensitive. Initially associated with inadequate access to information technologies, the notion of the digital divide has, since the 2000s, come to encompass differences in usage capacity, frequency of use, quality of access and the socio-economic effects of connectivity (NTIA, 1999; Özcan Alp; Baycan, 2024). The gap between individuals and territories with adequate access to ICTs and those with precarious or no access may affect economic capital, social capital, civic participation and well-being, contributing to the reproduction of social and regional inequalities (Chen; Deng; Schneider, 2024; Ferreira et al., 2021; Lythreatis; Singh; El-Kassar, 2022; Ragnedda, 2018).

2.5.5 Well-being, quality of life and locational choices

The locational decisions of firms and individuals do not depend only on productivity, costs and access to markets. They are also influenced by attributes associated with well-being, quality of life and territorial amenities. While New Economic Geography emphasises economies of scale, increasing returns and transport costs, New Urban Economics incorporates residential and productive choice more explicitly as the outcome of preference maximisation under different combinations of wages, prices, amenities and living costs (Thite, 2011). This approach is connected to a broader literature that has come to treat well-being as a complement to conventional measures of economic performance (Morrison, 2014).

The literature distinguishes two main ways of treating well-being. The first emphasises its objective dimension, bringing it closer to aggregate indicators of quality of life, such as income, access to services, housing, transport, education, safety and environmental conditions. This tradition is connected to the works of Rosen (1979) and Roback (1982), in which local attributes are incorporated into the analysis of wages, prices and locational choices. The second emphasises subjective well-being, understood as individuals' evaluation of their own lives, including satisfaction, engagement and positive or negative experiences (Diener, 2006; Diener; Lucas; Oishi, 2018). These approaches are not mutually exclusive, since the spatial patterns of well-being depend both on the objective conditions of the territory and on the way individuals perceive and evaluate their living contexts (Lenzi;

Perucca, 2019; Morrison, 2021).

At the urban-regional level, quality of life involves a broad set of attributes. Donald (2001) identifies dimensions such as social cohesion, human services, learning, safety, affordable housing, public transport, environmental quality, culture, recreation and lifestyle. These elements affect the attractiveness of places for households and workers, but may also influence the choices of firms that depend on skilled labour. In knowledge-based economies, in which telecommunications, computing, biotechnology and entertainment gain weight, the capacity to attract and retain workers becomes part of firms' own locational strategy (Salvesen; Renski, 2003; Thite, 2011).

This argument is particularly important for knowledge-intensive activities. In their early stages, high-technology firms tend to seek environments with adequate infrastructure, proximity to sources of knowledge and the availability of skilled human capital, attributes more frequently found in metropolises and in some key cities (Doloreux; Shearmur, 2012; Frenkel, 2012; Shearmur; Doloreux, 2021). As these firms mature and part of their activities becomes more standardised, rental, labour and space costs may gain importance, favouring the relocation of segments less dependent on agglomeration externalities to peripheral areas or lower-cost centres (Shearmur; Doloreux, 2008). Even in these cases, research and development activities remain sensitive to access to skilled workers and to quality-of-life attributes that affect their attraction and retention (Harding, 1989; Ritter, 1990).

Knowledge workers tend to display greater mobility and more specific locational preferences (Malecki; Bradbury, 1992). When wage differentials do not fully compensate for local disadvantages, factors such as amenities, environmental quality, urban services, cultural diversity and leisure opportunities may influence residential choice, except where firms offer sufficient compensation for local disamenities (Power, 1980). This logic helps to explain why localities with universities, consumption amenities, openness to diversity and a more active cultural life tend to attract and retain talent (Clark et al., 2002; Florida, 2014).

The relationship between well-being and location is also expressed in migration flows. Localities undergoing economic expansion tend to attract workers from other regions, and this movement is usually selective, more often involving young and relatively more skilled individuals (Feres; Lemos, 2005; Laskiene; Zykiene; Verdnikovaite, 2020). At the same time, urban centres may exert attraction by combining well-paid jobs, a high density of opportunities and a culturally active environment, attributes that may be fostered by appropriate urban policies (Caragliu; Del Bo, 2012). For knowledge-intensive firms, workers' well-being also affects performance, turnover, absenteeism, loyalty and productivity, making quality of life an indirect component of territorial competitiveness (Love; Crompton, 1999; Thite, 2011).

This interpretation, however, does not imply that greater agglomeration automatically translates into higher well-being. The urban paradox described by Morrison (2021) suggests that large cities may combine production and consumption advantages with lower average levels of subjective well-being, especially when congestion, long commutes, housing costs, lower real income and less available time reduce the satisfaction of most residents. Similarly, economic progress may attract population, but disorderly urban growth, pollution, pressure on natural resources and obstacles to mobility may generate forces of repulsion (De Lima, 2016).

For this reason, well-being and quality of life should be incorporated into the analysis of regional equilibria. They affect residential decisions, firm location and migration, and may operate as both centripetal and centrifugal forces. Since migration responds, to a large extent, to the search for better living conditions, the regional dynamics of urban and residential location must take into account household preferences and the costs associated with different territorial alternatives (Laskiene; Zykiene; Verdnikovaite, 2020; Straszheim, 1987). These movements, accumulated over time, influence the relative size of cities and help to prepare the discussion on the net benefits of urbanisation and the theory of optimal city size, addressed in the following section.

2.6 Net benefits of urbanisation and reconfiguration of equilibria

The discussion of locational forces leads to the issue of city size. If firms and individuals respond to differentials in productivity, costs, accessibility and well-being, the distribution of population and economic activity across urban centres can be understood as the result of relative net benefits. Larger cities tend to offer agglomeration economies, denser markets, specialised services and a greater diversity of interactions. These gains, however, coexist with rising costs associated with congestion, land prices, environmental pressure, the scarcity of urban space and the coordination difficulties that accompany denser environments (Duranton; Puga, 2020).

The theory of optimal city size is grounded in this tension. Urban growth may expand agglomeration benefits up to a certain point, but beyond particular thresholds, diseconomies begin to reduce the net gains from location (Camagni; Capello; Caragliu, 2013). The decisions of economic agents depend not only on the absolute size of the city, but on the relationship between perceived advantages and costs in comparison with other available localities within the urban system. When a central city reduces its diseconomies or expands its attractive attributes, it may prolong its capacity for concentration. When urban costs rise without an equivalent compensation in benefits, intermediate or peripheral centres may gain relative attractiveness. The redistribution of population, firms and economic functions among cities therefore depends on the way net benefits are reorganised within the regional urban system.

This approach rests on an understanding of the city as a privileged space for the generation of agglomeration economies. When space ceases to be treated merely as distance or physical support and comes to be understood as a source of productivity and well-being advantages, the urban becomes central to explaining regional development. Cities concentrate fixed capital, infrastructure, advanced services, diversified labour markets and opportunities for interaction, elements that favour firms' productivity and expand the range of choices available to individuals (Capello, 2015).

Glaeser (2011) defines cities by the reduction of physical distance between economic agents, emphasising that their vitality depends on the demand for connection. Fujita and Thisse (2002), in a similar way, treat the city as an institution favourable to the development of social contacts. In Capello (2015), this interpretation is associated with urbanisation economies, expressed in the presence of transport and telecommunications infrastructure, the supply of advanced services to firms, the diversity of intermediate and final goods, and the greater density of productive interactions. Taken together, these elements help to explain why an increase in urban size may raise the benefits associated with location.

The problem of optimal city size arises when these benefits begin to be confronted with rising costs. The literature on the economics of urban size has addressed this issue since the late 1960s, starting from the idea that increasing net returns exist only up to a certain limit (e.g., Mills, 1967; Alonso, 1971). Beyond this point, mechanisms associated with congestion, rising land prices, environmental costs and pressures on urban infrastructure and services may transform agglomeration economies into diseconomies (Camagni; Capello; Caragliu, 2013; Capello, 2004).

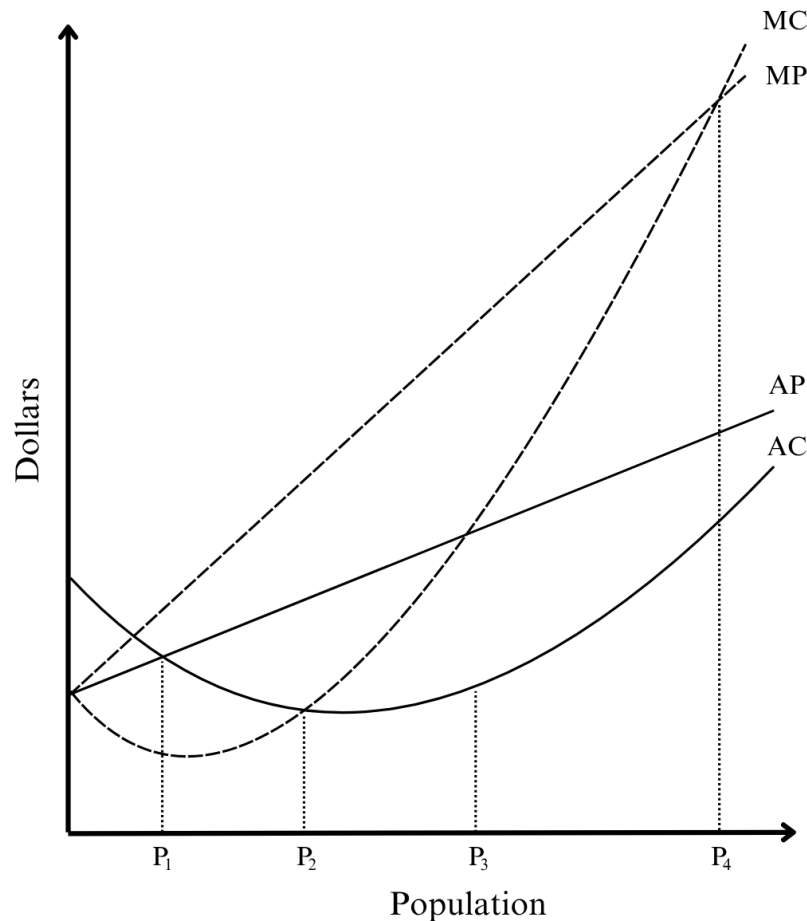
Part of this literature focused on the scale advantages generated by the greater availability of productive inputs in large urban centres, such as fixed capital, public and private infrastructure, and labour supply, relating city size to productivity gains (Beeson, 1992; Henderson, 1986; Segal, 1976). This perspective recognises, however, that urbanisation also generates costs. In its simplest formulation, the ideal size of the city could be defined by the point at which marginal costs and marginal benefits are equal. Alonso (1971), however, argues that an approach based only on minimising the costs of urban inputs is limited, since it assumes that per capita output is constant. The evidence mobilised by the author indicates that per capita output tends to increase with urban size, which requires inputs, outputs and social costs to be considered simultaneously.

The aggregate theory proposed by Alonso (1971) treats the city as a productive unit, whose scale should be assessed through the relationship between costs and output. The author shows that, in cities where costs increase, a new firm or a new resident tends to decide where to locate on the basis of existing average costs. The problem is that their arrival may raise the marginal costs borne by the community, such as congestion,

commuting time and pressure on infrastructure. The difference between private costs and social costs helps to explain why cities may grow beyond the size that would be considered optimal under certain criteria. This problem remains relevant in a context of increasing urbanisation and continuous pressure on urban systems (UNITED NATIONS, 2019).

Figure 2.1 illustrates this formulation. Point P_2 represents the population level associated with the lowest average cost per capita. This point, however, does not correspond to the optimal city size. The maximum local contribution to national income occurs at P_4 , where marginal product equals marginal cost. Alonso (1971) observes that a national government interested exclusively in maximising total output, under unlimited labour supply, could take this point as a reference. In practice, since labour supply is limited and there are locational alternatives in other cities, the size that maximises national output tends to be smaller, defined by the comparison between the city's marginal net gain and the opportunity cost in other localities.

Figure 2.1 – Urban costs and product curves with city size



Source: Adapted from Alonso (1971).

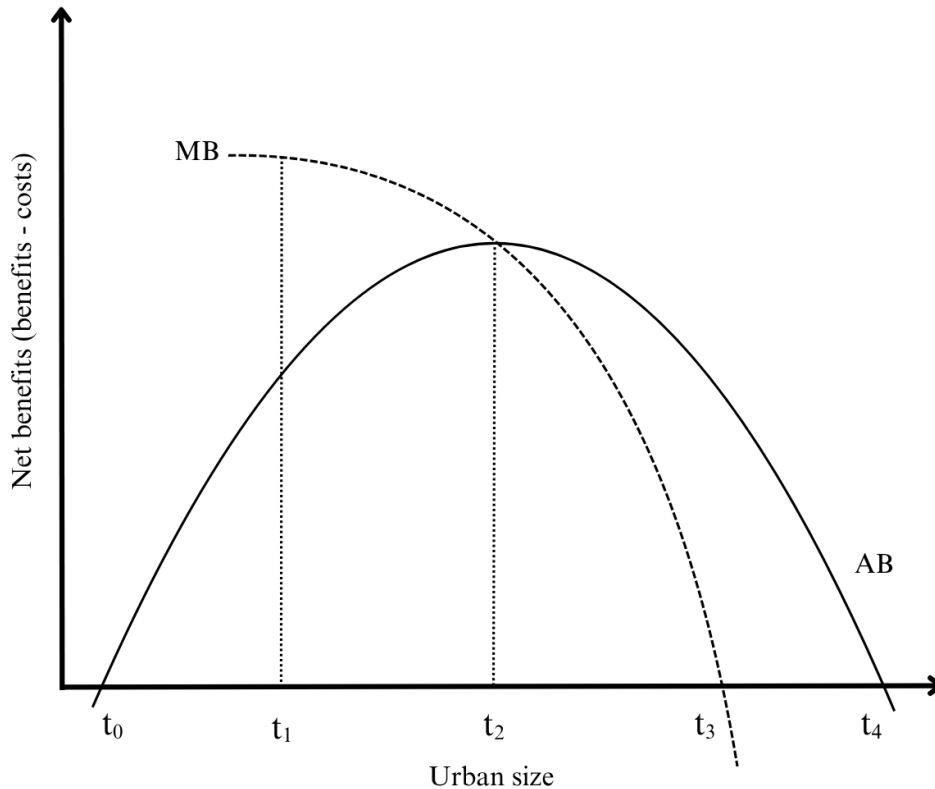
Note: MC denotes marginal cost per capita; AC denotes average cost per capita; MP denotes marginal product per capita; and AP denotes average product per capita.

From the inhabitants' point of view, the criterion is different. The objective is

no longer to maximise the city's contribution to national income, but to maximise the difference between average product and average cost per capita. In this case, the ideal size corresponds to $P3$. The main implication is that the optimal size of the same city varies according to the point of view adopted. For Alonso (1971), in none of these cases does the optimum necessarily coincide with the minimum-cost point, which weakens interpretations that associate urban efficiency only with the minimisation of average costs.

Capello (2015) reorganises this discussion through the notion of net urban benefits, presented in Figure 2.2. The minimum urban size, indicated by t_0 , occurs at the point where average benefits and average costs are equal. Point t_1 represents the greatest net benefit for newcomers, associated with the largest difference between average benefit and marginal cost. Point t_2 corresponds to the preferred size for inhabitants, equivalent to the maximisation of the difference between average product and average cost. Point t_3 indicates the ideal size for the system, associated with the equality between marginal product and marginal cost, while t_4 represents the upper limit of urban growth.

Figure 2.2 – Net urban benefits



Source: Adapted from Capello (2015).

Note: MB denotes marginal net benefit; AB denotes average net benefit.

The interpretation based on net benefits makes it possible to explain why cities may exhibit diminishing returns even when gross benefits continue to increase. Like any intensively exploited resource, the city may generate additional gains up to a certain limit,

but the intensified use of urban space tends to raise marginal costs and reduce the net benefit of location (Alonso, 1971; Camagni; Capello; Caragliu, 2013). Thus, when urban net benefit guides locational decisions, an optimal city size may exist even in contexts in which gross benefits continue to increase (Capello, 2015).

The dynamics observed in real urban systems, however, do not always follow the theory of optimal size in a direct way. Capello (2004) observes that declining rates of population growth may appear in both large and small cities, suggesting that physical size is not the only determinant of agglomeration economies. Richardson (1972) had already pointed to this contrast by arguing that elements other than population scale interfere with the relationship between urban growth, productivity and costs. The quality of urban management, productive structure, the level of infrastructure, position within the regional network and governance capacity may alter the point at which net benefits begin to decline.

Camagni, Capello and Caragliu (2013) reinforce this interpretation by indicating that the actual population of some cities may be below or above the equilibrium size predicted by traditional models. Part of these discrepancies may stem from the way urban managers deal with agglomeration externalities. Cities capable of reducing congestion, expanding accessibility, preserving environmental quality, organising public services and coordinating land uses may shift their efficiency limits. Conversely, governance weaknesses may bring diseconomies forward and reduce the net gains associated with urban growth.

This discussion repositions optimal city size as a regional problem, rather than only an urban one. If net benefits vary across cities, economic agents compare locational alternatives within a network of centres. A city does not grow or lose attractiveness in isolation; its position depends on how its advantages and costs change in relation to the other localities in the urban system. Changes in infrastructure, institutional quality, connectivity, service provision and living conditions may alter this comparison and, in doing so, reconfigure flows of population, firms and investment.

The contemporary challenge of urban management lies precisely in dealing with this tension. Clark, Harrison and Miguelez (2018) observe that urban managers need to respond to rapid transformations in cities while seeking to mitigate the negative effects of urbanisation. From a regional perspective, this issue takes on an additional layer of complexity. Urban policies that reduce diseconomies or expand attractive attributes may alter not only the internal functioning of the city, but also its relative position within the regional network. The equilibrium among urban centres should therefore be understood as a shifting outcome of the net advantages that each locality offers to firms and individuals within a system of interdependent alternatives.

2.7 Conclusion

The discussion developed throughout this chapter began from the premise that space is not merely the support on which economic activities are located. It organises interactions, conditions locational choices and participates in the formation of regional inequalities. The literature in regional economics indicates that the location of firms and individuals depends on transport costs, accessibility, increasing returns, infrastructure, institutions, knowledge and well-being. These elements are not distributed homogeneously across the territory. They tend to combine unevenly, producing localised advantages and distinct development trajectories.

The incorporation of urban networks made it possible to advance this interpretation. Cities concentrate population, resources, services and command functions, but they also connect markets, mediate flows and organise relations that extend beyond their own boundaries. For this reason, the city should not be treated merely as an isolated urban unit. It is part of systems of cities in which hierarchies, areas of influence, horizontal relations and functional linkages shape the way people, firms, information and decisions circulate across the territory. The region, in this sense, can be understood as a relational space, structured by urban centres that occupy distinct positions within a network of interdependencies.

In the Brazilian case, this perspective takes on its own specific contours. The national urban network combines strong economic and demographic concentration in particular centres, the broad presence of small municipalities, asymmetries in administrative capacity and supra-municipal relations formed through daily flows of work, consumption, public services and management. Municipalities are not merely administrative units that can be compared with one another. They occupy different positions within structures of centrality and dependence that condition their capacity to attract investment, organise services, retain population and participate in regional development processes.

The locational forces discussed throughout the chapter help to explain how these positions may change. Innovation, infrastructure, accessibility, the institutional environment, information and communication technologies, quality of life and well-being affect the net benefits perceived by firms and individuals. When these attributes are strengthened in a given urban centre, its relative attractiveness may increase. When urban costs, congestion, environmental pressures, institutional weaknesses or service deficits reduce the gains from location, other centres in the network may become more favourable alternatives. Regional dynamics therefore result from the continuous comparison between the advantages and costs offered by different localities.

The theory of optimal city size reinforces this argument by showing that the gains from urbanisation do not grow indefinitely. Agglomeration economies, diversity of services, density of interactions and productivity coexist with diseconomies associated with

congestion, rising land prices, pressure on infrastructure and loss of well-being. Regional equilibrium therefore does not correspond to a fixed composition of larger and smaller cities, but to a shifting configuration of net benefits, centralities and flows. Changes in urban attributes may alter this configuration, shifting the relative position of centres within the regional system.

This theoretical framework prepares the discussion that follows. Many contemporary urban agendas seek to act precisely on the attributes that affect the attractiveness of cities: infrastructure, connectivity, innovation, governance, sustainability, mobility, public services, quality of life and social participation. When these agendas are understood beyond an exclusively technological interpretation, they come to engage directly with the locational channels discussed in this chapter. The question is no longer only how to improve the internal functioning of cities, but also how these changes may affect urban networks, hierarchies and regional equilibria.

It is at this point that the concept of the smart city comes into the analysis. The following chapter discusses the evolution of this agenda in the international literature and its contextualisation for Brazil, starting from the shift from a technocentric view to a broader approach associated with governance, sustainability, human capital, quality of life and digital transformation. This discussion makes it possible to understand why urban smartness, when taken up in a territory marked by intermunicipal inequalities and asymmetric regional relations, should not be examined only as a local urban policy, but also as a potential vector for reorganising municipal positions within the networks that structure regional space.

3 THE CONCEPT OF SMART CITIES: INTERNATIONAL APPROACHES AND CONTEXTUALISATION FOR BRAZIL

3.1 Introduction

Against a backdrop of accelerated urbanisation, the expansion of large urban agglomerations and the intensification of the socio-environmental, economic and infrastructural challenges that characterise twenty-first-century cities, Crippa et al. (2023) observe that many urban centres have begun to adopt territorial branding strategies as a way of addressing urban management problems, promoting more sustainable environments and strengthening their capacity to attract investment and human capital. According to Ashton, Emmendoerfer and Emmendoerfer (2018), these labels seek to confer an identity on the territory, operating as mechanisms for recognising and projecting its urban capacities.

Terms such as digital cities, virtual cities, cyber cities, network cities, intelligent cities, knowledge cities, ubiquitous cities, real-time cities and hybrid cities (Janik; Ryszko, 2018), as well as sustainable cities, resilient cities, green cities, low-carbon cities, eco-cities, inclusive cities and knowledge cities, have been widely used in the international literature and in the discourse of urban managers around the world (Crippa et al., 2023).

Over the years, however, especially after 2010, the term smart city began to eclipse the others in popularity, even surpassing the term sustainable city in its frequency of occurrence in academic studies (De Jong et al., 2015; Myeong; Park; Lee, 2022).

According to Kummitha and Crutzen (2017), smart city branding has increasingly been framed as a panacea for the problems associated with rapid urbanisation and as a pathway towards sustainable development. Piciorogă, Eremia and Sănduleac (2018) add that the term smart city emerged as an innovative concept that encourages economic development, improved quality of life and environmental preservation, based on smart, integrated and adaptive infrastructures.

However, despite the high expectations surrounding smart cities as a solution to contemporary challenges in urban management, the literature does not offer a single, stable definition of the term (Yigitcanlar et al., 2018). What can be observed instead is a plurality of conceptualisations (Toli; Murtagh, 2020), which vary according to the dimension of smartness considered or according to the convenience of the analytical purpose (Caragliu; Del Bo, 2020).

In view of this, this chapter presents a literature review which, in Section 3.2, discusses the conceptual evolution of the term smart city, with emphasis on its more recent approach, which is less technocratic and more closely oriented towards debates on sustainability and quality of life, and is regarded here as the most appropriate for the Brazilian context. In Section 3.3, the debate is contextualised for Brazil along three complementary lines: first, the distinction between municipality, city and the urban is

discussed, justifying the centrality of the municipality as the unit of analysis; next, the country's territorial, demographic, economic and institutional heterogeneities are presented; finally, the main recent initiatives aimed at structuring a national smart city agenda are examined, with particular emphasis on the *Carta Brasileira para Cidades Inteligentes* (Brazilian Charter for Smart Cities) and the proposal for the *Política Nacional de Cidades Inteligentes* (National Smart Cities Policy).

3.2 The concept of the smart city

Although, in essence, actions associated with urban smartness date back to the beginning of the second half of the twentieth century, with roots in the first wave of diffusion of information and communication technologies (ICTs) in the United States (Caragliu; Del Bo, 2022; Vallianatos, 2015), the concept of the smart city only began to be used more explicitly in the 1990s (Ahvenniemi et al., 2017; Albino; Berardi; Dangelico, 2015; Ismagilova et al., 2019; Yin et al., 2015). It was influenced by the “smart growth” movement (Yigitcanlar et al., 2018) and emerged as an alternative to traditional planning approaches, using new technologies, especially ICTs, to address problems related to agglomeration diseconomies (Fernandez-Anez; Fernández-Güell; Giffinger, 2018; Harrison; Donnelly, 2011; Nam; Pardo, 2011).

Since 2010, academic interest in the study of urban smartness has grown rapidly (Pratama, 2021). However, the literature offers neither a single framing model nor a single, consistent definition of smart cities (Albino; Berardi; Dangelico, 2015). In fact, several definitions and approaches have been proposed since the late twentieth century, each differing in relation to the main characteristics considered relevant for determining smartness (Albino; Berardi; Dangelico, 2015; Anthopoulos, 2015; Caragliu; Del Bo, 2020; Toli; Murtagh, 2020; Vaquero-García; Álvarez-García; Peris-Ortiz, 2017; Yigitcanlar et al., 2018).

For its first two decades, definitions of smart cities placed strong emphasis on technology-based innovation applied to urban planning, operation and management (Yigitcanlar et al., 2018). ICTs emerged as the main pillar in the construction of urban smartness (e.g., Hall et al., 2000; Partridge, 2004; Eger, 2009; Belissent, 2010; Washburn et al., 2010) and as a means of improving the population's quality of life by increasing urban efficiency (Kummitha; Crutzen, 2017).

According to Graham and Marvin (2002), ICTs would play a structuring role in cities by reconfiguring infrastructures, services and forms of circulation. By highlighting the role of these technologies in the integration, control and differentiation of urban networks, the authors anticipated the core of the discourse on urban smartness.

For Odendaal (2003), a smart city or region would be one that capitalises on the opportunities provided by ICTs to increase its prosperity and influence. Similarly,

Paskaleva (2009) argued that these cities would take advantage of ICTs to enhance local competitiveness and dynamism, while Belissent (2010) maintained that they would use these technologies to make the city’s infrastructure components and services more aware, interactive and efficient.

Partridge (2004) viewed smart cities as those that adopt new technologies to facilitate citizen participation, broaden access to services and provide information in a simpler and more cost-effective way. Washburn et al. (2010), in turn, argued that these cities would use smart computing technologies to make their critical infrastructure and services more efficient, integrated and responsive.

This ICT-centred view of smartness encouraged several academic projects and research initiatives, especially in the first decade of the twenty-first century, although it was not without criticism of the concept’s strong corporate orientation (Caragliu; Del Bo, 2020). This is because the growing popularity of this agenda resulted largely from the aggressive funding and promotion efforts of major global technology, development and consulting companies, as well as their programmes (Yigitcanlar et al., 2018).

Caragliu and Del Bo (2016) point out that research on smart cities initially developed around the need for ICT infrastructure as the main driver of urban development. Subsequently, this focus began to incorporate the role of e-government technologies, broadening the analysis to issues of governance and, later, to debates on environmental sustainability.

This multidimensionality in the concept of smartness reflects a more recent trend in this literature, especially after 2010, when the view became consolidated that smart cities integrate the triad¹ of technology, government and society to promote smarter economies, mobility systems, environments, people, urban living and governance processes (Ahvenniemi et al., 2017; Kummitha; Crutzen, 2017; Pratama, 2021).

Known in the literature as the “holistic” approach to smart cities (Caragliu; Del Bo, 2022; Chauhan; Agarwal; Kar, 2016; Ismagilova et al., 2019; Neirotti et al., 2014), this perspective derives from the seminal work of Giffinger et al. (2007), which organises the concept around six main dimensions:

- Smart economy: strategies aimed at economic development, innovation, entrepreneurship and strategic planning;
- Smart mobility: accessibility and safe, interconnected and efficient transport systems;

¹ Nam and Pardo (2011) organised the different definitions of smart cities into three groups, according to the tools they had in common: (1) technology, with emphasis on the role of digital technologies in transforming and strengthening the urban system; (2) human resources, focused on people, education, learning and knowledge; and (3) institutions, oriented towards government action and public policies.

- Smart governance: transparency, citizen participation, social policies and commitment to democratic values;
- Smart people: the existence of qualified, creative human capital capable of innovation;
- Smart living: urban quality of life based on health, safety, education and well-being; and
- Smart environment: environmental protection linked to conditions of liveability and sustainability.

According to Vanolo (2014), the definition proposed by Giffinger et al. (2007), which extends the concept of smartness to the categories mentioned above, is the most established and reliable in the literature. Purnomo, Meyliana and Prabowo (2016) revisit these dimensions in a systematic review and identify a set of indicators associated with them. These indicators include entrepreneurship and innovation, economic productivity, environmental sustainability, pollution monitoring, energy management, ICTs and e-government, transparent governance and open data, citizen participation in decision-making processes, health services, safety and social protection, public transport systems, ICT infrastructure, cultural and social plurality, and creativity.

In another study based on a systematic review, Aldegheishem (2019) expands the six original dimensions and proposes a model composed of twelve indicator domains, classified as follows:

- Smart living: recreational facilities, such as stadiums, theatres, public libraries and cultural facilities, as well as decent housing and diversity;
- Smart economy: ICT infrastructure, labour market flexibility, ICT-based production processes, productivity, use of applications and high-tech industries;
- Smart environment: low levels of carbon dioxide emissions, green spaces, efficient water use and water quality, effective waste management and recycling, and pollution control;
- Smart education: educational institutions, share of research funding provided by the private sector and remote access to educational programmes;
- Smart governance: e-government services, research and development centres in the city, smart administration, participation in decision-making processes and transparency;
- Smart energy: renewable energy projects, efficiency of energy systems, share of electricity generation and total energy consumption;

- Smart safety: individual safety, tracking through urban sensors, warning systems and emergency response systems;
- Smart mobility: ICT-based transport, ICT-driven logistics, advanced driver assistance systems, smart maintenance, safe transport, sustainable transport systems and electronic monitoring of the transport system;
- Smart technology: internet infrastructure, home internet access, high-tech training and software engineering;
- Smart buildings: housing quality, including solid waste management and reduced construction costs, smart heating, smart air conditioning, smart monitoring, smart lighting and smart socket charging;
- Smart hospitals: health conditions, health services, electronic home patient monitoring, connections between hospitals, biomedical sensors and smart hospital architecture;
- Smart people: innovative solutions to urban problems, participation in sustainable development, involvement in public life, access to training courses and online learning, a skilled workforce and the employment rate in knowledge sectors.

Batty et al. (2012) argue that integrating these multiple dimensions is essential for a more complete understanding of smart cities. In addition, Caragliu and Del Bo (2022) emphasise that the holistic approach has the advantage of bringing together several drivers of smartness that the literature has identified separately, even though it does not privilege any specific dimension.

This perspective also broadens the dialogue with debates on sustainability and quality of life. Yigitcanlar et al. (2019) argue that a city can only be considered smart when it invests simultaneously in the social, human and environmental capital that underpins sustainable urban development. In this direction, the authors maintain that only a holistic view of the concept can guide the construction of truly smart cities.

Along the same lines, Anschütz, Ebner and Smolnik (2024) argue that the smart city should adopt a holistic approach, with an integrated and coordinated strategy for urban development, taking into account the importance of quality of life and culture rather than focusing solely on the development and implementation of technological solutions.

Table 3.1 presents some of the main definitions in the literature that adopt a non-purely technocratic approach to the concept of smart cities.

Table 3.1 – Definitions of smart cities in the literature

Reference	Definition
Giffinger et al. (2007)	A smart city is a city well performing in a forward-looking way in these six characteristics [economy, people, governance, mobility, environment, and living], built on the ‘smart’ combination of endowments and activities of self-decisive, independent and aware citizens
Caragliu, Del Bo and Nijkamp (2011)	A city to be smart when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance.
Thite (2011)	Smart city experiments [...] aimed at nurturing a creative economy through investment in quality of life which in turn attracts knowledge workers to live and work in smart cities. The nexus of competitive advantage has [...] shifted to those regions that can generate, retain, and attract the best talent.
Kourtit and Nijkamp (2012)	Smart cities are the result of knowledge-intensive and creative strategies aiming at enhancing the socio-economic, ecological, logistic and competitive performance of cities. Such smart cities are based on a promising mix of human capital, infrastructural capital, social capital, and entrepreneurial capital.
Albino, Berardi and Dangelico (2015)	The term smart city is understood as a certain intellectual ability that addresses several innovative socio-technical and socio-economic aspects of growth. These aspects lead to smart city conceptions as ‘green’ referring to urban infrastructure for environment protection and reduction of CO ₂ emission, ‘interconnected’ related to revolution of broadband economy, ‘intelligent’ declaring the capacity to produce added value information from the processing of city’s real-time data from sensors and activators, whereas the terms ‘innovating’, ‘knowledge’ cities interchangeably refer to the city’s ability to raise innovation based on knowledgeable and creative human capital.
Lara et al. (2016)	A community that systematically promotes the overall wellbeing of all its members, and flexible enough to proactively and sustainably become an increasingly better place to live, work and play.

Table 3.1 – Continue

Reference	Definition
Zhuhadar et al. (2017)	Smart cities are those cities that have the greatest quality of life and economic well-being for their citizens.
Tura and Ojanen (2022)	A smart city can be viewed as an innovative urban development, aiming for sustainable development and high quality of life of its citizens.
Vanli and Akan (2023)	Smart city is an ICT-driven strategy of urban development to achieve urban efficiency, environmental sustainability, public health and safety, government transparency, economic productivity and labor market flexibility using technology, physical infrastructure, community, innovative economy, and governance mechanism through an integrated management and coordination of these drivers

Source: Author's own elaboration based on Albino, Berardi and Dangelico (2015) and Yigitcanlar et al. (2018).

Caragliu and Del Bo (2022) emphasise that, depending on the region, both the conceptual definition and the forms of financing of smart cities may take on different meanings, reinforcing the need to situate analyses within their appropriate institutional contexts.

According to Marchetti, Oliveira and Figueira (2019), many Latin American cities face significant structural deficiencies, such as insufficient infrastructure, lack of basic services, weak governance and limited appreciation of citizen participation in local decision-making. In a context marked by deep economic inequalities, the authors observe that smart tools tend to be appropriated unevenly across urban space, contributing to widening disparities between rich and poor.

Although the purpose of the smart city is to offer the highest possible quality of life to its inhabitants (Bakıcı; Almirall; Wareham, 2013), the priorities associated with this objective vary according to the stage of urban development. In more developed cities, the quality-of-life agenda often involves issues such as urban greenery, public leisure spaces and urban amenities. In less developed contexts, however, it depends above all on ensuring universal access to sewerage, waste collection, adequate urban mobility, social protection and other basic services.

For this reason, Marchetti, Oliveira and Figueira (2019) emphasise that it is not straightforward to transfer successful technological solutions from cities in the Global North to the Global South. Similarly, it is not simple to replicate, in Brazilian cities with

their own specificities, conceptions of urban smartness and quality of life formulated in contexts with greater institutional maturity and more consolidated federal arrangements (Andrade, 2023).

In this sense, since the mid-2010s, efforts have emerged to define the concept of the smart city as applied to the Brazilian context, in a country that is among the five most unequal in Latin America (Arretche, 2018) and is marked, across multiple dimensions, by inter-municipal inequality that is even more pronounced than inter-regional inequality (Abrucio; Sano, 2013).

3.3 The definition of smart cities in Brazil

In the Brazilian context, it is particularly important to distinguish between the concepts of municipality, city and the urban. From a constitutional standpoint, municipalities are autonomous federative entities² at the local level, governed by their own organic laws and endowed with the authority to legislate on matters of local interest, while observing the principles established in the Federal Constitution and in state constitutions (IBGE, 2022d).

As Funari, Lui and Ferreira Junior (2023) explain, a city is, in legal terms, the urban nucleus that contains the seat of the municipality, which may in turn include another urban category: the village, corresponding to the seat of a district, or districts, located within municipal boundaries. The authors also observe that, in several Brazilian cases, the municipal seat – formally recognised as the city – has a smaller urban scale than the village that serves as the seat of one of its districts, or even than certain neighbourhoods, which may maintain stronger relations with neighbouring municipalities.

Although the normative perspective offers a wide range of terms to define the urban and, consequently, what constitutes the city, the primacy of the *municipality* in the legal delimitation of urban territory cannot be denied (BRASIL, 2020). Under Brazil's constitutional framework, the municipality is the legal entity that represents localities. According to Law No. 10,257 of 2001, known as the Estatuto da Cidade (City Statute), it is the municipality that must promote territorial organisation through the control of the use, subdivision and occupation of urban land (BRASIL, 2008b).

Ojo, Dzhusupova and Curry (2016) emphasise that smart cities are expected to be capable of significantly improving the quality of life of their citizens, encouraging the attraction of private investment and creating a sustainable urban environment. Such actions are directly associated with the drafting of land use and occupation laws, studies of social and environmental impacts, and the formulation of programmes and incentives

² According to Meirelles (2008), the Brazilian municipality is a third-level political-administrative entity in the descending order of national federalism: Union – states – municipalities.

aimed at sustainability, all of which are constitutional responsibilities of municipalities in the Brazilian context.

Municipal data provide the common geographical reference for the institutional and economic information assembled in this study. The municipality is therefore used as the smallest observational unit, without being redefined as an entirely urban area. The existence of a legally recognised municipal seat does not establish morphological or functional equivalence between municipalities. Results refer to municipal territories and must be interpreted in light of their urban–rural composition, settlement structure and regional integration.

This section first presents an overview of the multidimensional heterogeneities that characterise Brazilian municipalities and that, in turn, underpin the efforts to conceptualise smart cities as applied to the national context, as proposed in the Brazilian Charter for Smart Cities.

3.3.1 Heterogeneities of the Brazilian territory

According to the World Bank (2024), Brazil has approximately 203 million inhabitants distributed across multiple ecosystems over its 8.5 million km². The Brazilian state is organised as a federation composed of the Union, 26 states, the Federal District and 5,570 municipalities. Since the Federal Constitution of 1988, this arrangement has given municipalities a distinctive institutional position within Brazilian federalism, ensuring them political, economic, fiscal and administrative autonomy (Abrucio, 2005; Baggio, 2006; Losada, 2008).

This autonomy increased local responsibilities in the provision of public services and in the promotion of the population’s quality of life, in a process associated with the municipalisation of public policies (Almeida, 2005). However, the expansion of responsibilities did not eliminate dependence on intergovernmental transfers, nor did it reduce capacity asymmetries among local governments (Abrucio, 2005). On the contrary, the creation of new municipalities after 1988, often encouraged by the pursuit of a larger share of the *Fundo de Participação dos Municípios*, contributed to the proliferation of small population nuclei endowed with constitutional responsibilities, but with highly unequal administrative, fiscal and technical capacities (Baldissera, 2015; Losada, 2008).

Data from the 2022 Demographic Census indicate that 69.32% of Brazilian municipalities had up to 20,000 inhabitants, while only 5.73% had more than 100,000 inhabitants (IBGE, 2023a). Although this second group is a minority, it accounted for approximately 56.96% of the country’s population, as shown in Table 3.2. This pattern reveals a population distribution strongly concentrated in a small number of municipalities, while also showing the widespread presence of small localities within Brazil’s federative structure.

Municipal heterogeneity is not limited to population size. Brazilian municipalities

also differ in terms of accessibility, integration with markets, intensity of urbanisation and the composition of urban, rural and natural areas (BRASIL, 2021). The methodological proposal developed by IBGE (2023b), presented in Figure 3.1, identifies 16 types of spaces distributed along a rural-urban-nature continuum. This classification shows that the urban in Brazil is not organised around a simple opposition between city and countryside. Across much of the territory, urban, rural and natural areas overlap, forming distinct combinations of occupation, production, circulation and access to services.

Table 3.2 – Population percentages and number of municipalities by population class

Population class	Number of municipalities	Percentage of the population
Up to 5,000 people	1324	2.19
From 5,001 to 10,000 people	1169	4.10
From 10,001 to 20,000 people	1370	9.50
From 20,001 to 50,000 people	1050	15.71
From 50,001 to 100,000 people	338	11.56
From 100,001 to 500,000 people	278	27.96
More than 500,000 people	41	28.99

Source: Author's own elaboration based on IBGE (2023a).

Figure 3.1 further reinforces the inadequacy of uniform approaches to the smart city agenda in the country. Municipalities located in large urban concentrations face challenges associated with density, pressure on infrastructure, congestion and the provision of services at scale. Municipalities with predominantly rural or natural characteristics, in turn, may present low density, higher connectivity costs, dependence on nearby urban centres and difficulties in accessing public facilities. Between these extremes, there is a wide variety of transitional localities, in which urban functions, rural productive activities and environmental areas coexist in different proportions.

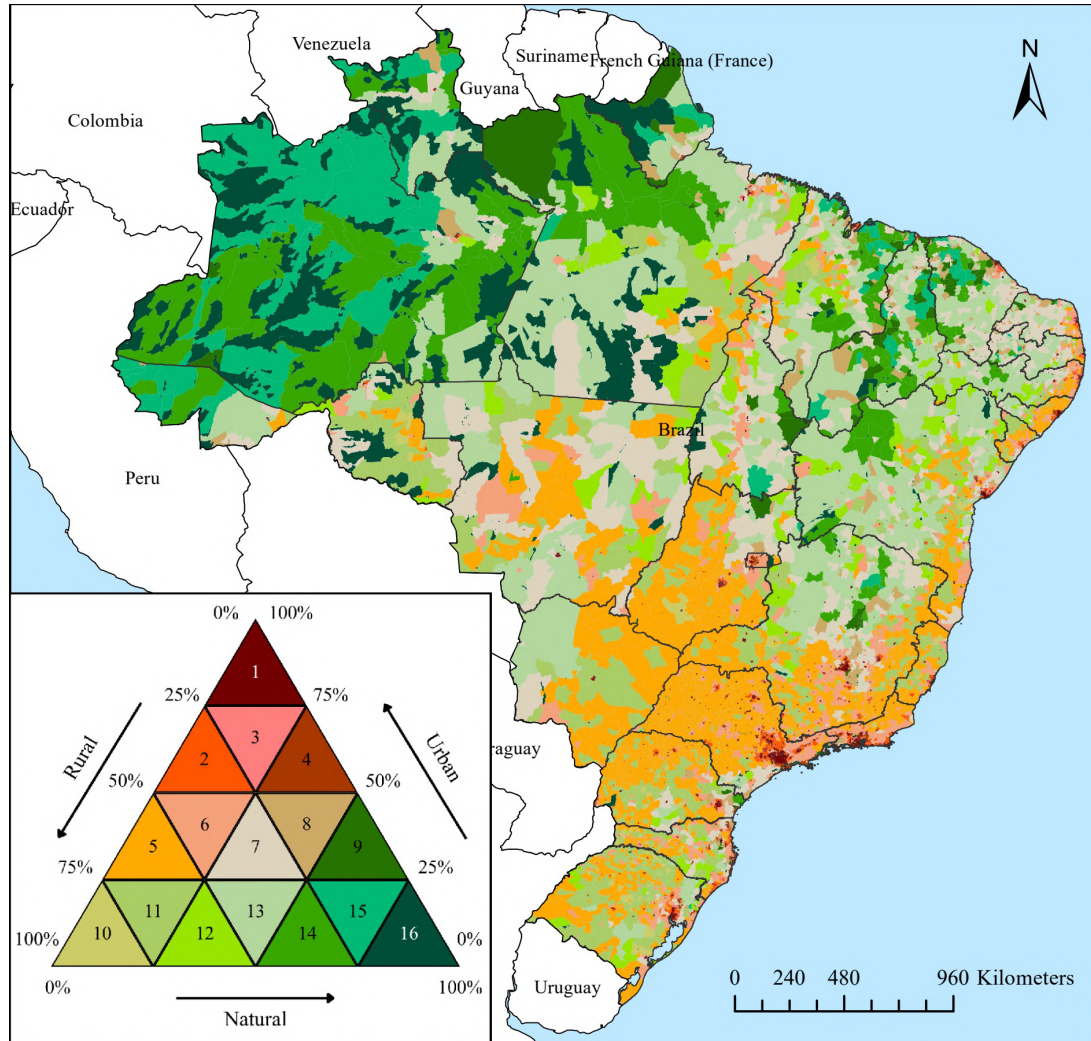
This territorial diversity is accompanied by deep social and economic inequalities. According to Ipea's Social Vulnerability Index (2015), 41.80% of Brazilian municipalities had high or very high social vulnerability, with greater concentration in the Northeast and North regions. Inequalities are also evident in the distribution of economic activity. In 2021, the Southeast region concentrated around 52% of Brazilian GDP, while the states of São Paulo and Rio de Janeiro accounted for 30.18% and 10.53% of national GDP, respectively (IBGE, 2022c).

Economic concentration is also observed when considering the distribution of GDP across metropolitan regions and municipalities. The analysis based on the Herfindahl-Hirschman Index (HHI)³ indicates that the metropolitan regions of the municipalities of São Paulo and Rio de Janeiro accounted for 66.15% and 15.84%, respectively, of the

³ The Herfindahl-Hirschman Index (HHI) is a statistical measure of concentration, calculated as

HHI value calculated for the 87 metropolitan regions identified by IBGE in 2021. Among Brazil's 5,570 municipalities, concentration was also high, especially in São Paulo, Rio de Janeiro, Brasília and Belo Horizonte, which accounted for 64.15%, 12.07%, 7.69% and 1.05%, respectively, of the municipal HHI value.

Figure 3.1 – Typology of urban, rural, and natural spaces in Brazil



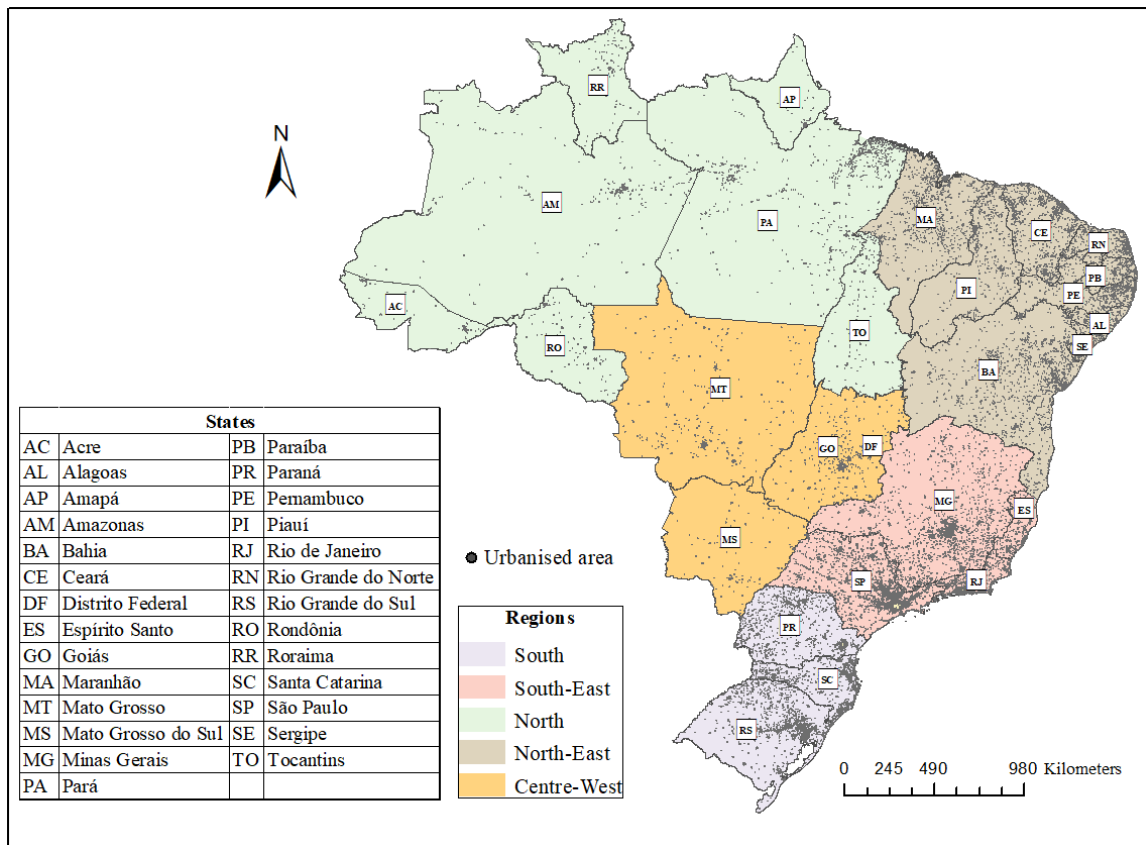
Source: IBGE (2023b). Adapted by the author.

Economic and demographic concentrations in the Southeast region reflect the country's historical trajectory of industrialisation, which began in the mid-nineteenth century and favoured the accumulation of knowledge-intensive services, attracted migratory flows and concentrated skilled labour (Tunes, 2020). This trajectory also contributed to the predominance of the population living in urban areas (BRASIL, 2020). According to the 2022 Demographic Census, around 87.41% of the Brazilian population lived in

the sum of the squared shares of each unit in the variable under analysis. In this study, the individual contribution to the HHI corresponds to the share of each metropolitan region or municipality in the total value of the index. The higher the HHI, the greater the concentration of the variable analysed (Rhoades, 1993).

urban areas (IBGE, 2023a). The distribution of urbanised areas, presented in Figure 3.2, shows the spatial concentration of urbanisation in Brazil. According to the report *Áreas Urbanizadas do Brasil: 2019* (Urbanised Areas of Brazil: 2019), the country had 45,945 km² of urbanised area in 2019, equivalent to only 0.54% of the national territory. More than one third of these areas was concentrated in the Southeast region, especially in the state of São Paulo, which accounted for 18.39% of the country's total urbanised areas (IBGE, 2022a).

Figure 3.2 – Distribution of urbanised areas in Brazil, 2019



Source: Prepared by the author based on IBGE (2019a) data.

As a result of this pattern of development and unequal urban concentration, some localities have accumulated, over time, urban deficits in infrastructure and adequate housing, limited autonomy in the provision of public services and difficulties in ensuring higher levels of quality of life for the population (Arretche, 2004; IPEA, 2021). By contrast, economically consolidated municipalities have greater financial autonomy and a stronger capacity to provide infrastructure and services, but they also face challenges typical of denser urban areas, such as air pollution, congestion, resource scarcity and rising crime (Ahvenniemi et al., 2017; Sharifi et al., 2023; Toli; Murtagh, 2020).

In addition, municipalities lower in the urban hierarchy often rely on more developed centres to access public services, jobs, health and education facilities, and other urban functions. This pattern may generate free-riding behaviour, insofar as citizens contribute

fiscally in one municipality but consume services in another (Abrucio; Sano; Sydow, 2010; Arretche, 2004; Garson; Ribeiro; Ribeiro, 2010). Associated with commuting flows for work and study, this process tends to increase pressure on the managers of more urbanised municipalities and reinforces the inter-municipal nature of many urban problems (Chiquetto et al., 2022).

Taken together, these elements show that the discussion of smart cities in Brazil must engage with a territory marked by strong municipal diversity, economic and demographic concentration, social inequalities, institutional asymmetries and functional relations between municipalities. Urban smartness, in this context, cannot be treated as a uniform package of technological solutions. It must be situated within the different territorial configurations, local capacities and positions that municipalities occupy in the national urban network. In view of this complexity, the Ministério do Desenvolvimento Regional (Ministry of Regional Development) proposed the formulation of a national smart city agenda, materialised in the Carta Brasileira para Cidades Inteligentes (Brazilian Charter for Smart Cities).

3.3.2 The Brazilian Charter for Smart Cities

The Carta Brasileira para Cidades Inteligentes (Brazilian Charter for Smart Cities, CBCI) was published in 2021, promoted by the Ministério do Desenvolvimento Regional (Ministry of Regional Development, MDR) – now incorporated into the Ministério das Cidades (Ministry of Cities, MCID) – and developed with the support of the German Cooperation Agency GIZ, in partnership with the Ministério da Ciência, Tecnologia e Inovação (Ministry of Science, Technology and Innovation, MCTI), the Ministério das Comunicações (Ministry of Communications, MCom) and civil society organisations (Andrade, 2023).

At the outset, the CBCI establishes that the smart cities envisaged for the country should be (BRASIL, 2021):

- Diverse and fair: they recognise territorial conflicts and act, while respecting diversity, to reduce socio-spatial inequalities;
- Vibrant and people-centred: they place people at the centre of development and promote improvements in quality of life for all, balancing nature, the built environment and the digital environment;
- Connected and innovative: they use technologies to make government and public services more efficient, while recognising that there are forms of connection and innovation beyond digital solutions, especially in less dense urban areas;

- Inclusive and welcoming: they adopt broad and transparent governance, encourage social engagement and embrace diversity;
- Safe, resilient and self-regenerative: they use technologies suited to their own realities to address urban, environmental and social problems and conflicts;
- Economically fertile: they promote economic and social development in a sustainable way, taking into account their technological stage;
- Environmentally sustainable: they adopt responsible patterns of production and consumption and seek to strengthen the resistance and resilience of socio-ecological systems in the face of climate change and extreme events, using solutions and technologies suited to the local context;
- Articulators of different notions of time: they recognise differentiated rhythms of digital transformation suited to each person, reality and territory;
- Articulators of different notions of space: they understand their territory and act in an integrated and multi-scalar way, considering urban, intra-urban, rural, natural and regional dimensions;
- Conscious and guided by reflection: they plan, organise themselves and act through the responsible and integrated use of data, grounded in indicators, diagnoses, research and evidence-based evaluations;
- Attentive and responsible towards their principles: they understand that urban smartness is also expressed in the way urban and environmental development is managed.

The CBCI presents itself as a political document that expresses a public agenda aimed at supporting the promotion of sustainable urban development patterns, considering the Brazilian context of digital transformation⁴ in cities (BRASIL, 2021). The efforts involved in its preparation resulted in the formulation of a concept of smart cities for Brazil, the definition of five guiding principles and six orienting guidelines, as well as the establishment of eight strategic objectives accompanied by 163 recommended actions. The CBCI defines smart cities as:

cities committed to sustainable urban development and digital transformation, in their economic, environmental and socio-cultural aspects, which act in a planned, innovative, inclusive and networked

⁴ Digital transformation is defined, in the context of the CBCI, as the historical phenomenon of socio-cultural changes arising from the dissemination of the use of information and communication technologies in people's everyday lives, in environmental practices, in politics and in the economy (BRASIL, 2021).

manner, promote digital literacy, collaborative governance and management, and use technologies to solve concrete problems, create opportunities, provide services efficiently, reduce inequalities, increase resilience and improve the quality of life of all people, ensuring the safe and responsible use of data and information and communication technologies (BRASIL, 2021, p. 26, author's translation).

The strategic objectives presented in the Charter are aimed at different actors in the governmental, business, academic, financial, development-funding and civil society spheres. They are as follows (BRASIL, 2021):

1. Integrate digital transformation into sustainable development programmes, policies and actions, taking into account the inequalities and diversities present in Brazilian cities;
2. Ensure equitable access to quality internet for all people;
3. Establish technology and data governance systems based on security, transparency and privacy protection;
4. Adopt innovative and inclusive models of urban governance and strengthen the role of the public sector in managing the impacts of technological transformation in cities;
5. Foster local economic development in the context of technological transformation;
6. Encourage financing models and instruments aimed at sustainable urban development amid digital transformation;
7. Promote a broad and innovative movement of education and public communication, expanding society's engagement in digital transformation and sustainable urban development; and
8. Build means to continuously and systemically assess the impacts of digital transformation on cities.

Based on the CBCI's strategic objectives and the recommendations associated with each of them, the document can be seen as essentially strategic and operational in nature, oriented towards future guidelines for digital transformations in Brazilian cities. Although it recognises the economic, demographic, socio-political and managerial inequalities and diversities present across the national territory, the Charter tends to place greater emphasis on inequality and precariousness in internet access in some regions – which it refers to as “digital exclusion” (BRASIL, 2021, p. 16) – than on inequalities in urban infrastructure and on the dilemmas faced by cities in ensuring and providing public services, for example.

3.3.3 The proposed National Smart Cities Policy

Between 2019 and 2020, the Centro de Estudos e Debates Estratégicos da Câmara dos Deputados (Centre for Strategic Studies and Debates of the Chamber of Deputies, CEDES) conducted a study that culminated in the drafting of Bill No. 976 of 2021. The bill aims to establish the Política Nacional de Cidades Inteligentes (National Smart Cities Policy, PNCI) in Brazil, with a view to improving the quality of life of municipal residents, setting out principles, guidelines, objectives and actions for its implementation (BRASIL, 2021b).

The study conducted by CEDES indicates that, although some Brazilian municipalities have begun projects related to smart cities, there is a lack of regulatory support to ensure their sustainability (BRASIL, 2021a). In addition, the report highlights the need to regulate support from the Union, so as to enable strategic and coordinated action in the development of smart cities in Brazil.

In item I of Article 2, the PNCI Bill defines the concept of a smart city as:

Article 2. For the purposes of this Law, the following terms shall mean:

I – smart city: an urban space oriented towards investment in human and social capital, sustainable economic development and the use of available technologies to improve and interconnect city services and infrastructure, in an inclusive, participatory, transparent and innovative manner, with a focus on raising citizens' quality of life and well-being (BRASIL, 2021b, author's translation).

The Bill also establishes a set of dimensions and their respective components, which are positioned as drivers of smart city development (Table 3.3). The dimensions correspond to areas of action for management, investment and governance aimed at fostering urban smartness, while the components constitute elements associated with each dimension, through which the adherence of cities to the concept of a smart city is to be assessed (BRASIL, 2021a).

Andrade (2023) observes that, although the Bill refers to the components as material elements for incorporating the smart city into Brazilian municipalities, the proposed policy does not provide an objective basis for defining and operationalising measurable indicators for these elements. Thus, should the bill be approved⁵ in these terms, the measurement and monitoring of such components will depend on complementary regulations.

⁵ As of the finalisation of this study, in 2026, Bill No. 976/2021 had not yet been approved by the National Congress.

Table 3.3 – Dimensions and components proposed in the PNCI Bill

Dimension	Components
Innovative and highly qualified society	Basic education with quality learning. Digital and innovative education. Promotion of creativity, transformation, and the development of the creative class. Workforce qualified according to demand. More accessible higher education.
Economy	Integration with local productive arrangements. Development of local vocations. Innovation ecosystems, including ICT.
Government	Participatory governance and co-creation. Public services. City management and administration. Institutional arrangements.
Sustainability	Natural environment and ecological sustainability. Built environment and city infrastructure. Urban resilience.
ICT and other technologies	Software infrastructure and equipment. Digital services. Data and information.

Source: Adapted from Brasil (2021b). Author's translation.

Note: ICT: Information and Communication Technologies.

Based on this argument and in line with the guidelines of the Brazilian Charter for Smart Cities, this study argues that the formulation of more consolidated and operational recommendations, capable of guiding the planning and implementation of urban and regional policies, first requires an accurate diagnosis of the profile of municipalities within the thematic area of interest.

Thus, before proposing an agenda or policy guidelines for urban smartness in Brazil, it is necessary to diagnose the level of urban smartness of municipalities, identifying weaknesses and guiding strategies more efficiently. This diagnosis can be constructed through the calculation of indicators.

3.4 Conclusion

This chapter discussed how the concept of the smart city became consolidated internationally, moving from a technocentric view anchored in ICTs towards a broader approach that integrates technology, governance, people, the environment and quality of life. By bringing this debate into the Brazilian context, the chapter argued for the centrality of the municipality as a unit of analysis and action, both because of the legal-

institutional definition of territory and because of data availability and the constitutional responsibilities related to urban planning and the provision of public services.

The characterisation of Brazil's demographic, economic, territorial and institutional heterogeneities suggests that addressing smart cities in the country entails dealing with highly diverse realities, ranging from major metropolises with strong income concentration to small municipalities with high social vulnerability and limited administrative capacity. In this context, the Carta Brasileira para Cidades Inteligentes (Brazilian Charter for Smart Cities, CBCI) and the proposal for the Política Nacional de Cidades Inteligentes (National Smart Cities Policy, PNCI) represent efforts to structure a public agenda for the issue in the country, by establishing principles, guidelines, objectives and guiding dimensions for urban development associated with digital transformation.

However, although these initiatives contribute to the consolidation of a normative and strategic framework for smart cities in Brazil, there remains a lack of clear operational instruments for measuring and monitoring the level of urban smartness in Brazilian municipalities in a broader manner and in a way that is adapted to the realities of the country's localities. In particular, both the CBCI and the proposed PNCI recognise existing territorial diversity and inequalities, but are limited in terms of defining and operationalising comparable indicators.

It is in this context that the objective of the next chapter is situated: to construct and analyse smart city indicators for Brazilian municipalities, in order to provide a more precise and comparable diagnosis of different territorial realities.

4 MEASUREMENT AND SPATIAL DISTRIBUTION OF URBAN SMARTNESS IN BRAZILIAN MUNICIPALITIES

4.1 Introduction

The adoption and diffusion of smart city strategies in the Brazilian context are far from straightforward. In a country marked by deep territorial, demographic, economic and institutional heterogeneities, as well as by a complex constitutional design (Abrucio, 2005), the demand for smart cities involves much more than the mere incorporation of technological solutions to address the contemporary challenges of urbanisation. It requires an understanding of how different municipalities, with uneven capacities and distinct positions in the urban network, can mobilise infrastructure, technology, governance, sustainability, public services and quality of life within their urban development strategies.

This issue is particularly sensitive because the municipality occupies a central position in the institutional organisation of the Brazilian territory. Even small localities have direct responsibilities for the provision of social services, within an arrangement marked by decentralisation and the municipalisation of public policies (Almeida, 2005; Arretche, 2004). In addition, municipalities have constitutional competences related to urban and spatial planning, including the formulation of instruments such as the Municipal Master Plan, where required by law (BRASIL, 1988). At the same time, the widespread presence of small municipalities, often organised around small settlement nuclei in close spatial proximity, coexists with strong asymmetries in administrative, fiscal and technical capacity. This arrangement creates coordination challenges that go beyond municipal administrative boundaries (Abrucio; Sano, 2013).

The provision of public services through integrated national systems, such as the Sistema Único de Saúde (Unified Health System), reinforces this intermunicipal dimension (Teixeira, 2007). Better-structured municipalities tend to concentrate facilities, services and urban functions that are also used by residents of neighbouring localities, without there necessarily being fiscal or administrative correspondence between the place of residence and the place where these services are accessed (Abrucio; Sano; Sydow, 2010). This configuration shows that the discussion of urban planning in Brazil cannot be restricted to the internal performance of each municipality, since many urban challenges are supra-municipal in nature (Marguti et al., 2020).

From an urban-regional perspective, smart city strategies may affect attributes that influence the relative attractiveness of municipalities. Investments in connectivity, mobility, environmental management, governance, public services, innovation and quality of life may alter how households, workers and firms perceive the net benefits of locating in a given territory (Thite, 2011). More recent evidence indicates that smart cities may experience higher urban population growth, partly due to the reduction of environmental externalities

and the wider diffusion of information through the internet, factors associated with a lower propensity to leave and greater migratory attractiveness (Chen et al., 2023). These findings should not be transposed automatically to the Brazilian case, but they suggest a plausible channel between urban smartness, location choices and the reorganisation of municipal positions within regional contexts.

For this reason, the smart city approach needs to move beyond large cities and metropolitan regions. The urban smartness agenda encompasses dimensions that are also decisive for small and medium-sized municipalities, such as access to basic services, connectivity, institutional capacity, local economic development, sustainability, digital inclusion and quality of life. Restricting the assessment to more populous urban centres means excluding from the analysis a substantial part of the institutional and territorial structure that organises the Brazilian urban system.

This is where the contribution of this chapter lies. Its objective is to construct and analyse multidimensional measures of urban smartness for the 5,570 municipal-level units represented in the national statistical databases, making it possible to compare highly diverse territorial realities within a common analytical framework.¹ This proposal broadens the scope of existing measurement initiatives, which typically focus on cities with populations above 50,000 inhabitants or on state capitals, as is the case in part of the applied literature and in national smart city rankings (e.g., Fachinelli et al., 2022; Urban Systems, 2024).

Extending the analysis to all municipalities makes it possible to examine urban smartness from a regional perspective. In a country marked by relations of centrality, dependence and complementarity among municipalities, different levels of urban smartness may be associated with uneven territorial patterns, reflecting both local capacities and positions within the national urban network. The proposed assessment, therefore, does not merely rank municipalities. It allows us to examine how urban smartness is distributed across the Brazilian territory and how this distribution relates to the spatial composition of municipal inequalities.

In addition to this introduction, the chapter is organised as follows. Section 4.2 discusses the role of small and medium-sized cities in the smart cities debate. Section 4.3 presents different approaches and metrics used in the literature to assess urban smartness. Section 4.4 describes the construction of the smart city index for Brazilian municipalities, including the definition of the dimensions, indicators and data sources, as well as the statistical methods employed. Section 4.5 presents the empirical results of the composite

¹ For statistical purposes, the national municipal-level databases used in this application comprise Brazil's 5,568 municipalities together with the Federal District and the State District of Fernando de Noronha, yielding 5,570 observational units (IBGE, 2026). For expositional simplicity, the term municipality is used throughout the empirical discussion as shorthand for this statistical universe when the distinction in legal status is not substantively at issue.

index and analyses its territorial distribution and spatial patterns across the national territory. Finally, Section 4.6 concludes the chapter.

4.2 Urban smartness in the context of small and medium-sized cities

Based on the degree of urbanisation, the OECD (2020) distinguishes between cities, towns and semi-dense areas, and rural areas using harmonised criteria grounded in thresholds of population density and minimum cluster size. Cities correspond to contiguous clusters with a minimum density of 1,500 inhabitants per km² and at least 50,000 inhabitants. Towns and semi-dense areas have a minimum density of 300 inhabitants per km² and a population of at least 5,000, whereas rural areas comprise localities with densities below this threshold.

Although this classification is based on internationally harmonised morphological and demographic criteria, the literature shows that definitions of towns and cities remain heterogeneous across countries and regions. In general, national definitions in Europe and the Americas tend to classify towns as urban, whereas in Africa and Asia they tend to be classified as rural (UN-HABITAT, 2022).²

Within the category of cities itself, the literature also distinguishes, in heterogeneous ways, categories of localities according to population size (UN-HABITAT, 2022).³ Anschütz, Ebner and Smolnik (2024) adopt the German institutional definition, which classifies small cities as those with between 5,000 and 20,000 inhabitants and medium-sized cities as those with between 20,000 and 100,000 inhabitants. Based on this classification, the authors argue that these urban categories still remain relatively neglected in research on smart cities.

According to the authors, smaller localities face specific challenges associated with their scale, such as the outmigration of young skilled people due to the limited supply of economic opportunities and quality of life. In this context, they argue that the adoption of smart city initiatives, conceived from a holistic, integrated and multidimensional understanding of the concept, may help these localities modernise their infrastructure, promote economic development and position themselves as more attractive places for firms and talent.

This perspective is also found in UN-Habitat's *World Cities Report 2022* (UN-HABITAT, 2022), which argues that although all world regions are undergoing urbanisation, highly urbanised and more developed regions tend to stabilise or even experience a decline

² The report notes that towns are treated as urban in some countries in Europe and the Americas, such as Brazil, France, Mexico and the United States, but as rural in countries such as Egypt, India, Uganda and Viet Nam (UN-HABITAT, 2022, p. 33).

³ According to UN-Habitat (2022), small cities have populations between 50,000 and 250,000 inhabitants; medium-sized cities have populations between 250,000 and 1 million inhabitants; and large cities have populations between 1 and 5 million inhabitants.

in urban growth relative to regions that are currently less urbanised. Thus, although humanity's future is undeniably urban, this process is not restricted to large metropolitan areas.

UN-Habitat (2022) highlights that, in developing countries, future urban priorities include, among others, the provision of adequate infrastructure, affordable housing and investment in secondary cities. These cities, typically small and medium-sized and often with populations below one million, account for a significant share of the urban population and show high growth rates, although they remain relatively marginal in planning agendas when compared with major metropolises. According to the report, with adequate planning, management and governance, such cities can strengthen urban-rural linkages, reduce territorial disparities and ease pressures observed in large urban centres, such as informal settlements, environmental degradation and long commutes.

In the Brazilian case, characterised by an urban network mostly composed of small and medium-sized municipalities⁴, this discussion is particularly relevant. The formulation and implementation of smart city projects, programmes and strategies within an integrated regional context, encompassing localities of different population sizes, depend on the construction of accurate and comparative assessments capable of guiding public policies and territorial planning strategies.

In this context, the construction of urban indicators and rankings constitutes an analytical tool frequently used to assess the relative performance of cities. In examining the smartness of small and medium-sized cities, Dall'O et al. (2017) propose the use of a set of indicators specifically adapted to these less dense urban contexts. Similarly, in analysing medium-sized cities in Europe, Giffinger et al. (2007) highlight that indicator-based rankings are frequently used as positioning tools in interurban competition. A prominent position in these rankings can help strengthen a city's image and influence strategies of territorial marketing and regional development. The authors also note that such instruments stimulate public debate on urban development strategies.

Against this background, the following section presents a set of metrics and indicators identified in the international and Brazilian literature for constructing a ranking of cities according to their degree of smartness or related characteristics of their urban management.

⁴ In this study, following Veiga (2003), Brazilian municipalities are classified by population size into three categories: small municipalities, with populations of up to 50,000 inhabitants; medium-sized municipalities, with populations between 50,000 and 500,000 inhabitants; and large municipalities, with populations above 500,000 inhabitants.

4.3 Approaches and metrics for assessing urban smartness

As the debate on smart cities advanced over the first decades of the twenty-first century, several public and private organisations began to develop metrics and assessment systems designed to measure and compare the performance of cities according to their smart attributes (Toh, 2022). The growing diffusion of these tools is associated with the need to produce comparative assessments that support public policy formulation, urban planning and the competitive positioning of cities in contexts of increasing territorial interdependence (Santos, 2022).

Against this background, the literature has developed indicator-based methodological procedures aimed at the systematic assessment of urban smartness. As Dall’O et al. (2017) observe, such systems allow both partial analyses, centred on specific dimensions such as economy, mobility or the environment, and aggregate assessments of the overall smartness of cities.

One of the urban smartness ranking metrics most frequently cited in the literature derives from the European Smart Cities project, developed by Giffinger et al. (2007), whose objective was to assess the performance of medium-sized European cities. Conducted by the Vienna University of Technology (TU Wien), in collaboration with the University of Ljubljana and Delft University of Technology, the project defined and applied a classification tool that made it possible to compare attributes associated with urban smartness in cities with populations between 100,000 and 500,000 inhabitants, resulting in a final sample of 70 localities.

The smartness dimensions proposed in the study were Smart Economy, Smart People, Smart Governance, Smart Mobility, Smart Environment and Smart Living, operationalised through 74 indicators distributed across these categories (Giffinger et al., 2007). To ensure comparability among the cities analysed, the indicators were standardised using z-score transformation. Aggregation was additive, with no differentiated weights assigned to the dimensions; the standardised values were summed and divided by the number of indicators considered at each hierarchical level of the analysis.

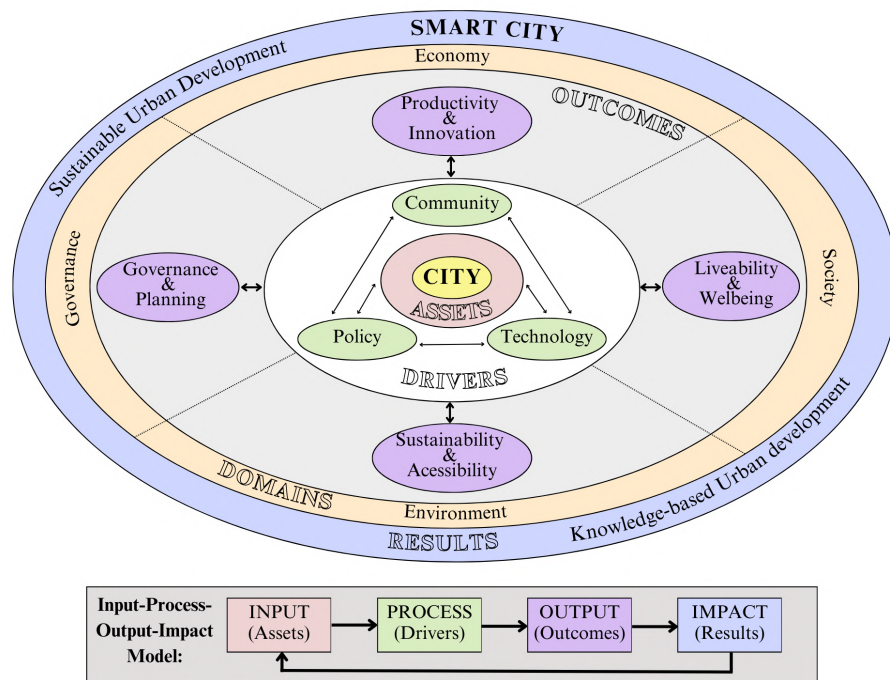
In a similar vein to Giffinger et al. (2007), who structure urban smartness around multiple interrelated dimensions, Yigitcanlar et al. (2018) developed an equally holistic conceptual model for assessing the performance of smart cities, anchored in an integrated perspective of sustainable, knowledge-based urban development. This framework was later applied to the Australian context in the report *Smart Cities Down Under* (Yigitcanlar et al., 2020), in which the model was operationalised according to an input-process-output-impact logic (Figure 4.1).

Unlike strictly technocentric approaches, the smart city is conceived as an organic system in which assets, drivers, intermediate outcomes and final results interact dynamically.

In this framework, urban smartness emerges from the articulation between community, public policy and technology, oriented towards the promotion of productivity, innovation, sustainability, accessibility, quality of life and good governance (Yigitcanlar et al., 2020).

The framework is organised into four main domains – Economy, Society, Environment and Governance – which unfold into result areas such as Productivity and Innovation, Liveability and Wellbeing, Sustainability and Accessibility, and Governance and Planning. The model was operationalised through the construction of a composite index based on multiple indicators selected according to criteria of measurability, comparability, data availability and theoretical relevance. The data were normalised using a min-max technique, converting the values to a standardised scale between 0 and 1, and were subsequently aggregated with equal weights across indicators (Yigitcanlar et al., 2020).

Figure 4.1 – Smart cities conceptual framework



Source: Adapted from Yigitcanlar et al. (2018, 2020).

The empirical application of this model focused on 180 Local Government Areas (LGAs), covering all local government areas within the Greater Capital City Statistical Areas (GCCSAs) and those located outside these areas with populations above 50,000 inhabitants (Yigitcanlar et al., 2020). These LGAs accounted for approximately 85% of the Australian population in 2016, indicating that the analysis was concentrated mainly on metropolitan areas and medium- and large-sized urban centres.

Building on this conceptual framework, Fachinelli et al. (2022) adapted the model to the Brazilian context in the report *Smart Cities of Brazil: Performance of Brazilian Capital*

Cities. The study can be understood as an extension of the Australian application, retaining the structural input-process-output-impact logic and the multidimensional character of the framework, while adjusting the set of indicators to Brazil's institutional and socioeconomic specificities.

Unlike the original application, the authors explicitly incorporate Technology as a distinct analytical domain, alongside Economy, Society, Environment and Governance, resulting in five structuring domains. These domains are operationalised through a set of 25 indicators selected on the basis of availability, comparability and relevance to the national context, forming a synthetic index of urban smartness calculated using min-max normalisation and equal-weight aggregation across indicators.

The empirical application focused on Brazil's 27 state capitals, which the authors argue play a strategic role in the country's federative structure and in the organisation of its urban network (Fachinelli et al., 2022). The sample scope therefore privileges medium- and large-sized urban centres with high economic and administrative centrality, which delimits the territorial reach of the analysis and suggests caution when generalising the results to small municipalities.

In the Brazilian context, in addition to academic initiatives, international measurement standards have also been incorporated, such as the ABNT NBR ISO 37122 (2020) standard, part of the ISO 37120/37122/37123 family, which establishes standardised indicators for monitoring the performance of smart cities, with a focus on urban services and quality of life.⁵ However, Andrade (2023) argues that a significant share of the indicators in this standard contributes little to a more substantive appropriation of the concept of smart cities oriented towards the fulfilment of the social functions of the city. According to the author, several indicators are based on realities that have little connection with the conditions of many Brazilian municipalities, especially smaller ones, which still face structural problems related to the securing of social rights and the equitable distribution of urban resources.

Private initiatives, such as the Bright Cities platform, developed by BrasilLAB, also offer tools for self-assessment and the diagnosis of smart city maturity (BRIGHT CITIES, 2026). However, this tool is predominantly normative in character and does not constitute a systematised empirical database with broad territorial coverage and longitudinal comparability across municipalities.

Among the ranking initiatives periodically applied in Brazil, the Connected Smart Cities Ranking, developed by the consultancy Urban Systems, stands out. Published annually since 2014, the ranking aims to map Brazilian municipalities with the greatest

⁵ ABNT NBR ISO 37122 (2020) establishes 80 indicators for smart cities, of which 46 are core indicators and 34 are supporting indicators, organised across different dimensions of urban services and quality of life.

potential for smart development based on the so-called “connectivity concept”, understood as the systemic articulation among different urban sectors (URBAN SYSTEMS, 2024).

The index is composed of 74 indicators distributed across 11 thematic axes: mobility, urbanism, environment, energy, technology and innovation, economy, education, health, safety, entrepreneurship and governance. Until 2024, the methodology employed was based on the so-called Índice de Qualidade Mercadológica (Market Quality Index, IQM), which starts from the relative standardisation of the values observed among cities and applies specific relevance weights to each indicator, allowing an aggregate score to be constructed for each municipality (URBAN SYSTEMS, 2024).

In the 2024 edition, the ranking covered 656 Brazilian municipalities with populations above 50,000 inhabitants, according to estimates from the Instituto Brasileiro de Geografia e Estatística (Brazilian Institute of Geography and Statistics, IBGE). These municipalities are distributed as follows: 41 with more than 500,000 inhabitants, 278 with between 100,000 and 500,000 inhabitants, and 337 with between 50,000 and 100,000 inhabitants (URBAN SYSTEMS, 2024). This population cut-off means that only around 11.8% of Brazilian municipalities are considered in the analysis, excluding approximately 88% of localities, most of them small municipalities.

Although the Connected Smart Cities Ranking represents a systematic effort to compare urban conditions in the Brazilian context, its sample scope restricts the analysis to more populous municipalities, which also include a large share of the country’s major economic and administrative centres. This delimitation tends to concentrate the assessment on more structured urban centres, producing a partial view of the territorial distribution of urban smartness and limiting the possibility of examining how these conditions vary across the diversity of the Brazilian municipal system and relate to different positions within the urban hierarchy.

For this reason, the following section proposes and develops, based on the conceptual model of Yigitcanlar et al. (2018, 2020) and as an extension of the application carried out by Fachinelli et al. (2022), the calculation of smartness metrics for ranking all Brazilian municipalities, regardless of population size. The method employed in the Australian and Brazilian applications is adopted as the reference, rather than the methodology used by Urban Systems, given the need for broader territorial coverage and the availability of homogeneous data for small municipalities. While Fachinelli et al. (2022) base their analysis on 25 indicators, the Connected Smart Cities Ranking uses 74 indicators, many of which are not systematically available for localities with smaller population sizes.

4.4 Construction of the smart city index for Brazilian municipalities

This section describes the data and methods used to calculate the smartness indices for Brazilian municipalities, as well as their respective rankings and patterns of spatial

distribution across the national territory. Before doing so, however, it is necessary to discuss the question that underpins the proposed exercise, which is presented in the following subsection.

4.4.1 Why extend the metrics to all Brazilian municipalities?

As discussed in the previous sections, internationally comparable definitions of cities do not rely solely on the total population of administrative units. The Degree of Urbanisation adopted by the OECD and the European Commission first identifies spatial clusters from population-grid cells according to density, contiguity and population thresholds. Urban centres are defined from contiguous high-density cells with at least 1,500 inhabitants per km² and an aggregate population of at least 50,000, after which small spatial units are classified according to the share of their population living in these clusters (OECD, 2020). This procedure differs conceptually from the eligibility rule adopted by the Connected Smart Cities Ranking, which restricts its Brazilian municipal sample according to total municipal population (URBAN SYSTEMS, 2024). The two criteria therefore should not be interpreted as equivalent simply because both involve a reference value of 50,000 inhabitants.

This distinction is important for the empirical scope adopted here. The purpose of this study is not to reproduce a morphological classification of Brazilian cities, nor to infer urban status directly from municipal population. Rather, the objective is to examine the distribution of conditions associated with urban smartness across the country's institutional and territorial structure, including municipalities of markedly different population sizes, settlement patterns and degrees of urbanisation. Restricting the exercise to municipalities above a population threshold would exclude a large share of the local governments through which public services, territorial regulation and development strategies are organised in Brazil.

Accordingly, the municipality is adopted as the unit of observation without being treated as synonymous with the built-up city, the urban centre or the functional urban area. A municipality may contain urban, semi-dense, rural and natural spaces in different proportions, while functional urban relations may extend beyond its administrative boundaries. The common municipal scale is therefore used to ensure nationwide comparability of institutional and socioeconomic information, not to assume equivalent degrees of urbanisation, density or service demand across jurisdictions.

This distinction is revisited empirically below through a descriptive comparison between the Smart City Index and the share of the municipal population classified as urban in the 2022 Demographic Census.

Data from IBGE (2022b) indicate that, in 2021, 2,919 Brazilian municipalities (52.41%) reported having a Master Plan, the main instrument of municipal urban planning

in Brazil,⁶ of which 2,253 (40.45%) had populations below 50,000 inhabitants and 1,324 (23.77%) had fewer than 20,000 inhabitants.

Moreover, UN-Habitat (2022) emphasises that, in developing countries, small cities and towns are crucial to achieving sustainable urban futures, given their high growth rates. The report argues that adequate territorial planning and the strengthening of capacities in these localities can consolidate the role they play in building sustainable futures in their countries.

In parallel, Jakobsen, Mikalsen and Lilleng (2023) argue that new social demands, opportunities associated with the green economy, the effects of the Covid-19 pandemic and the expansion of teleworking have renewed interest in rural and non-metropolitan areas as spaces of wellbeing and new possibilities for socio-economic renewal. In a similar vein, Lopes and Oliveira (2017) show, in the Portuguese context, that living in a small or medium-sized inland city may constitute a smart alternative from a quality-of-life perspective.

Such evidence reinforces the role of smaller cities as relevant components of a hierarchical urban system and suggests that urban planning guided by a multidimensional approach to smartness may influence the centripetal and centrifugal forces that shape economic and demographic equilibria within regions.

In the Brazilian context, the discussion of urban hierarchies and regional configurations is supported by the study *Regiões de Influência das Cidades* (Regions of Influence of Cities, REGIC), conducted by IBGE (2019b), which identifies and classifies urban centres according to their functional centrality and areas of territorial influence.⁷ REGIC reveals the existence of an urban network structured hierarchically, in which certain cities perform more complex functions and radiate services and flows towards a set of subordinate municipalities. This structure reflects processes of spatial concentration and diffusion that are consistent with the regional discussion developed in this study.

In this regard, incorporating multidimensional metrics of urban smartness for all Brazilian municipalities makes it possible to examine whether municipalities with different levels of urban smartness also occupy distinct positions within the national urban network, revealing possible associations with patterns of centrality and territorial dependence.

⁶ Although the Master Plan is commonly understood in Brazil as an urban planning instrument, under the Estatuto da Cidade (City Statute) it is a municipal instrument: it must cover the municipality as a whole and define the social function of different areas of the municipal territory, whether urban or rural, public or private (Santos Junior; Montandon, 2011).

⁷ REGIC classifies Brazilian urban centres into categories such as metropolises, regional capitals, sub-regional centres, zone centres and local centres, highlighting different degrees of centrality and territorial influence (IBGE, 2019b).

4.4.2 Dimensions, indicators and data sources

This section describes the variables used to construct the multidimensional smartness metrics for the 5,570 municipal-level observational units defined above. The composite smart city indicator comprises 25 indicators, organised into five dimensions, drawing on the works of Yigitcanlar et al. (2020) and Fachinelli et al. (2022) as methodological references. The systematisation of these metrics makes it possible to assess the territorial heterogeneity of urban smartness and its implications for regional organisation and intermunicipal inequalities.

For the calculation of the indices, data are drawn from several different sources, including:

- Instituto Brasileiro de Geografia e Estatística (Brazilian Institute of Geography and Statistics, IBGE);
- Agência Nacional de Energia Elétrica (National Electric Energy Agency, ANEEL);
- Agência Nacional de Telecomunicações (National Telecommunications Agency, ANATEL);
- Agência Nacional de Saúde Suplementar (National Supplementary Health Agency, ANS);
- Ministério do Trabalho e Emprego (Ministry of Labour and Employment, MTE);
- Ministério do Desenvolvimento e Assistência Social, Família e Combate à Fome (Ministry of Development and Social Assistance, Family and Fight against Hunger, MDS);
- Ministério das Cidades (Ministry of Cities, MCID);
- Secretaria Nacional de Trânsito (National Traffic Secretariat, SENATRAN);
- Instituto Nacional de Estudos e Pesquisas Educacionais Anísio Teixeira (Anísio Teixeira National Institute for Educational Studies and Research, INEP); and
- Instituto de Pesquisa Econômica Aplicada (Institute for Applied Economic Research, Ipea).

Table 4.1 presents the set of indicators used, their respective dimensions and categories, as well as a comparison with the variables employed by Yigitcanlar et al. (2020) for Australian Local Government Areas and by Fachinelli et al. (2022) for Brazilian state capitals.

Due to the high spatial granularity adopted in this study, some methodological adaptations were necessary in relation to the model applied by Fachinelli et al. (2022).

Table 4.1 – Comparative framework of smart city indicators across empirical applications

Composite Indicator	Indicator Category	Indicator Area	Indicator	Yigitcanlar et al. (2020) Australian LGAs	Fachinelli et al. (2022) Brazilian Capital Cities	Brazilian Municipalities
Smart City	Economy	Sustainable Economy, Productivity, and Entrepreneurship	Economic output per resident	Median income in \$	Gross domestic product (GDP) per capita at current prices	Gross domestic product (GDP) per capita at current prices
			Formal Employment Intensity	% in labour force population (15-85+)	% of formal workers in working population	% of formal workers in working-age population (14+)
			Talent Pool	% of labour forces as knowledge workers	% of labour force with university education	% of formal workers with tertiary education
			Innovation Industries	% of industries categorised as knowledge intensive	% of companies categorised as knowledge-intensive	% of companies categorised as knowledge-intensive
			Income		Average monthly salary of formal workers	Formal wage bill per capita (monthly average)
	Society	Well-Being and Liveability	Health Status	% of taxable population with private health insurance	% of the population covered by a health insurance according to data from National Health Agency	% of the population covered by a health insurance according to data from National Health Agency (ANS)
			Education		Basic Education Development Index (IDEB) score	Basic Education Development Index (IDEB) score
			Safety and Security	Offence per 100,000 people	Deaths from external cause (i.e., accidents, violence) per 100,000 people	Homicide rate (per 100,000 inhabitants)
			Housing Conditions	% of households that pay less than 30% of household income as rent	% of households in irregular settlements	Average percentage of households in inadequate housing conditions
			Socioeconomic Progress	% of individuals categorised as low income	% of individual categorised as low income	% of beneficiaries whose per capita income exceeds the poverty line after Bolsa Família transfers
	Environment	Environmental Sustainability, Urban Mobility, and Basic Infrastructure	Sustainable Commuting	% of workforce using public transport for commuting	Bus fleet per 100,000 people	Bus fleet per 1,000 people

Table 4.1 – Continue

Composite Indicator	Indicator Category	Indicator Area	Indicator	Yigitcanlar et al. (2020) Australian LGAs	Fachinelli et al. (2022) Brazilian Capital Cities	Brazilian Municipalities
Smart City	Governance	Governance and Planning	E-government			Number of remote service options for citizens
			Transparency			Number of channels for interaction between the municipality and the population
	Technology	Technology, R&D, Connectivity, and Innovation	Broadband Internet	% of area covered by the National Broadband Network (NBN)	Broadband internet coverage	Whether the municipality provides information on the budget and financial execution
			Connectivity			% of residents covered by broadband internet
			Innovation		Patents registered per 100,000 people	Brazilian Connectivity Index (IBC) score
			Research Capacity		Research grants per 100,000 people (PQ-CNPq)	
			Public Wi-Fi	Free Wi-Fi spots per 100,000 people	Free Wi-Fi spots per 100,000 people	Existence of free Wi-Fi access in the municipality
			Media		Local digital press media per 100,000 people	
			Digital Inclusion			Existence of a digital inclusion program or action
			Digital Systems			Number of digital systems present in people's daily lives

Source: Author's own elaboration based on Yigitcanlar et al. (2020) and Fachinelli et al. (2022).

The Economic Output per Resident index corresponds to municipal gross domestic product (GDP) per capita at current prices, based on IBGE data. The indicator measures locally recorded economic output relative to the resident population and should not be interpreted as a direct measure of labour productivity, household income or locally retained income. In municipalities characterised by productive specialisation or substantial commuting flows, locally generated output may differ considerably from the economic resources received by residents. GDP per capita is nevertheless retained as an indicator of the scale of economic activity recorded in the municipality, consistent with its use in the economic dimension of urban smartness (Caragliu; Del Bo, 2015).

The Formal Employment Intensity index corresponds to the ratio between formal employment records in the municipality and the resident working-age population,⁸ combining data from the *Relação Anual de Informações Sociais* (Annual Social Information Report, RAIS) (MTE, 2023) and the 2022 Demographic Census (IBGE, 2023a). The numerator refers to formal employment recorded at establishments located in the municipality, whereas the denominator refers to its resident working-age population.

The ratio therefore measures the concentration of formal employment relative to residents, rather than the probability that a resident holds a formal job. It may exceed one because workplace and residence do not necessarily coincide and because an individual may hold more than one formal employment contract. Labour market formalisation is related to the local productive structure and the quality of economic opportunities (Chen; Deng; Schneider, 2024).

The Talent Pool index represents the proportion of formal workers who have completed tertiary education, based on information obtained from RAIS (MTE, 2023) for 2022. The literature indicates that cities with higher levels of urban smartness tend to attract and retain skilled workers (Caragliu; Del Bo, 2015; Chen; Deng; Schneider, 2024; Nam; Pardo, 2011).

The Innovation Industries index corresponds to the ratio between firms classified as knowledge-intensive, according to the Eurostat (2009) typology,⁹ and the total number of firms registered in RAIS (MTE, 2023). Urban ecosystems based on knowledge-intensive activities are considered central elements of urban smartness (Zygiaris, 2013).

The Income index is represented by the municipality's average monthly formal wage bill in 2022, obtained by summing the wages paid to formal workers over the year, according to RAIS data (MTE, 2023), and dividing this amount by the municipal population recorded in the 2022 Demographic Census (IBGE, 2023a). The formal wage bill per resident is an

⁸ According to the *Pesquisa Nacional por Amostra de Domicílios Contínua* (Continuous National Household Sample Survey, PNAD Contínua), conducted by IBGE, the working-age population comprises persons aged 14 or over, that is, those who may participate in labour market activities.

⁹ See Table A.4.1 in the Appendix.

indicator of employment-based income generated at local establishments relative to resident population. Commuting and the exclusion of informal work prevent its interpretation as average labour income received by municipal residents. The measure is therefore used here as an indicator of the economic intensity of formal employment relative to municipal population, consistent with the economic dimension of urban smartness (Kumar; Dahiya, 2017).

The second smartness category for Brazilian municipalities is termed Society, corresponding closely to the Smart Living and Smart People dimensions proposed by Giffinger et al. (2007).¹⁰ This dimension emphasises the central role of people in urban development. Bouskela et al. (2016) argue that smart cities are those that place citizens at the centre of development strategies. In a similar vein, Lara et al. (2016) define the smart city as a community capable of systematically promoting overall wellbeing and of continuously adapting to become a more favourable environment for living, working and taking advantage of urban opportunities.

Along the same lines, Nam and Pardo (2011) conceptualise the smart city as a human space that expands opportunities for individual development and the construction of creative trajectories. Thite (2011) complements this perspective by highlighting that investments in quality of life and the creative economy contribute to attracting and retaining knowledge workers, thereby reinforcing urban dynamism.

The Society dimension is operationalised through five indicators, beginning with the Health Status index, which corresponds to the proportion of the municipal population covered by private health insurance in December 2023, based on ANS data (2024). Private health insurance coverage captures one dimension of access associated with employment, income and the organisation of private provision. It does not measure the quality of the municipal public health system, universal access to care or health outcomes directly. Health nevertheless constitutes a central component of quality of life and of the smart city agenda, which motivates its inclusion within the Society dimension (Solanas et al., 2014).

The Education index is represented by the 2021 Basic Education Development Index (IDEB), released by INEP (2022). The quality of the education system is widely recognised as a central element in human capital formation and in the consolidation of smart urban environments (Dumančić, 2019).

The Safety and Security index is measured by the homicide rate per 100,000 inhabitants in 2022, according to Ipea's *Atlas da Violência* (Atlas of Violence) (2024). Public safety is a key condition for urban liveability and for the proper functioning of economic and social activities (De Marco; Magno; Zenezini, 2015).

The Housing Conditions index corresponds to the simple average of three indicators from the 2022 Demographic Census (IBGE, 2023a): the percentage of households without

¹⁰ See Chapter 3.

access to piped water, without a bathroom or toilet, and without waste collection. The aim is to capture the precariousness of housing conditions and household vulnerability. In developing countries, the measurement of urban smartness requires consideration of structural deficits in basic infrastructure and essential services, which have often already been overcome in many cities in the Global North (Marchetti; Oliveira; Figueira, 2019).

Finally, the Socioeconomic Progress index is calculated as the ratio between the number of Programa Bolsa Família (Bolsa Família Programme) beneficiaries whose per capita income exceeded the poverty line after receiving the benefit and the total number of beneficiaries, based on MDS information for December 2023 (MDS, 2023). This indicator describes the position of programme beneficiaries relative to the selected poverty threshold after transfers. It is not a measure of poverty incidence or income inequality among all municipal residents. Poverty reduction and socioeconomic inclusion nevertheless constitute dimensions associated with the broader social outcomes discussed in the smart city literature, which motivates the inclusion of this indicator within the Society dimension (Caragliu; Del Bo, 2022).

The third category of smartness indicators is termed Environment, in line with the Smart Mobility and Smart Environment dimensions proposed by Giffinger et al. (2007). This dimension encompasses both environmental sustainability and the organisation of urban mobility and infrastructure systems.

Vanli and Akan (2023), in reviewing the main conceptual approaches to smart cities, highlight that the environmental dimension involves combining technological solutions with traditional green interventions, such as the expansion of green areas, with the aim of reducing pollutant emissions and promoting urban sustainability. Similarly, Tura and Ojanen (2022) emphasise that smart urban development presupposes the strengthening of physical infrastructure, including energy and water networks, buildings and urban roads, as well as environmental protection through the preservation of natural resources, pollution control and improved waste management.

The Sustainable Commuting index corresponds to the municipal bus fleet per 1,000 inhabitants, using December 2023 data from SENATRAN (2024). In line with Fachinelli et al. (2022), registered bus stocks are used as a proxy for transport-related resources. However, they do not directly measure where the vehicles operate, service frequency, accessibility or commuting time. The indicator should therefore be interpreted as a limited measure of the resources potentially associated with collective transport, rather than as a direct measure of public transport provision or sustainable commuting. In particular, a higher value should not automatically be interpreted as evidence of more sustainable mobility. The strengthening of public transport is recognised as a central element in promoting sustainable mobility and mitigating the environmental externalities associated with intensive use of individual motorised transport (Zawieska; Pieriegud, 2018).

The Sustainable Vehicles index measures the proportion of registered vehicles with an electric or hybrid fuel system, also based on SENATRAN data (2024) for December 2023. The diffusion of these vehicles is part of the transition towards more sustainable urban systems, by linking mobility and renewable energy in the context of smart urban development (Oldenbroek; Verhoef; Wijk, 2017). Because this indicator is expressed as a ratio to the registered vehicle fleet, comparatively high values may arise in units with small fleet denominators. The benchmark specification retains the observed values, while the sensitivity of the composite results to a small number of upper-tail observations is examined separately in the Appendix.

The Sustainable Energy index is defined as the proportion of power generation facilities based on renewable sources in the total number of generation facilities located in the municipality.¹¹ Renewable sources are defined as solar, wind, hydro and biomass, based on ANEEL information for December 2023 (ANEEL, 2024). The measure concerns the composition of registered generation facilities, not the proportion of electricity consumed locally that comes from renewable sources. Differences in plant size and the spatial organisation of electricity supply limit its interpretation as a measure of municipal energy sustainability. The diffusion of renewable energy technologies nevertheless constitutes an important component of urban sustainability strategies and of the transition towards low-carbon energy systems (Kylili; Fokaides, 2015).

The Sanitation index corresponds to the proportion of the resident population with access to the sewerage network, based on the 2022 Demographic Census (IBGE, 2023a). The Selective Waste Collection index is measured by the recovery rate of recyclable materials, excluding the organic fraction and rejects, in relation to the total amount of municipal solid waste collected, using 2023 data from MCID (2024). Information for this indicator is available for 5,060 municipal-level units. The remaining observations are retained as missing rather than interpreted as zero recovery. The measure therefore describes reported recyclable-material recovery conditional on source coverage and should not be interpreted as a complete measure of municipal waste-management capacity. As Marchetti, Oliveira and Figueira (2019) argue, the assessment of urban smartness in developing contexts should account for differences in basic infrastructure and environmental services, including sanitation and waste management.

The fourth category of smartness indices for Brazilian municipalities is termed Governance. This dimension refers to the institutional processes and mechanisms that enable the transformation of a city into a smart city, including the coordination and

¹¹ Ideally, the relative share of energy sources should be measured on the basis of installed capacity or actual energy generation. However, due to the limited availability and comparability of these data at the municipal scale for the entire Brazilian territory, the indicator is constructed on the basis of the number of generation facilities registered in each municipality, which makes it possible to capture the territorial diffusion of renewable generation technologies.

monitoring of its different domains (Vanli; Akan, 2023). According to Nam and Pardo (2011), the institutional dimension encompasses public policies, administrative structures, interorganisational collaboration and citizen participation, and is a central element for the implementation and success of smart city initiatives.

The Governance dimension is operationalised through five indicators. The Participation index corresponds to the number of Civil Society Organisations (CSOs) registered in the municipality up to December 2022, per 1,000 inhabitants, based on Ipea data (2023). Smart governance presupposes not only the incorporation of digital technologies into public management, but also the promotion of participatory processes and cooperation between government and society (Giffinger et al., 2007; Nam; Pardo, 2011). In this sense, the density of CSOs may be interpreted as a proxy for the local institutional capacity to foster civic engagement and the co-production of public policies, aspects associated with the consolidation of smart and sustainable urban ecosystems (Durán-Sánchez et al., 2017).

The Institutions index is constructed as a count variable that records the number of legal and regulatory instruments for spatial planning, urban policy and environmental management in force in the municipality, based on the 2021 Pesquisa de Informações Básicas Municipais (Municipal Basic Information Survey, MUNIC) by IBGE (2022b). The indicator ranges from 0 to 20, as detailed in Table A.4.2. The presence of these instruments reflects the existence of institutional arrangements capable of supporting the implementation of urban policies and promoting coordination among local actors, a dimension regarded as central to the smart development of cities (Kummitha; Crutzen, 2017).

The E-government index is composed of two dimensions drawn from the 2019 MUNIC survey (IBGE, 2020). The first corresponds to the number of public services made available remotely by the municipal government, ranging from 0 to 6 (Table A.4.3). The second refers to the number of formal channels of interaction between the municipal government and citizens, ranging from 0 to 4 (Table A.4.4). The digitalisation of public services and the expansion of mechanisms for institutional interaction are recognised as central elements of governance in smart cities (Vanli; Akan, 2023). However, as Hollands (2015) argues, smart governance should not be restricted to its technological dimension, but should also consider the effective degree of citizen involvement in decision-making processes.

The Transparency index is represented by a binary variable equal to 1 if the municipality makes information on budgetary and financial execution available to citizens, according to data from the 2019 MUNIC survey (IBGE, 2020). Transparency is widely recognised as one of the pillars of smart governance, alongside participation and the quality of public services (Giffinger et al., 2007).

The fifth dimension of smartness indicators is termed Technology. Although

definitions of smart cities vary in the literature, the centrality of Information and Communication Technologies (ICTs) is a recurrent element across different conceptual approaches (Tura; Ojanen, 2022). ICTs increase the efficiency of urban systems, strengthen public management and enable new forms of interaction among government, firms and citizens.

Partridge (2004) defines the smart city as one that actively adopts new technologies and seeks to become more open, insofar as technology facilitates citizen participation, expands access to public services and improves the flow of local information. Similarly, Eger (2009) understands the smart city as a community in which residents use ICTs to strengthen the service economy, stimulate job creation and enhance quality of life.

The Technology dimension is operationalised through five indicators: Broadband Internet, Connectivity, Public Wi-Fi, Digital Inclusion and Digital Systems.

The Broadband Internet index corresponds to the percentage of the municipal population covered by broadband internet in December 2022, based on ANATEL data (2023). ICT infrastructure constitutes a necessary condition for the provision of digital services, the integration of urban systems and increased administrative efficiency (Vanli; Akan, 2023).

The Connectivity index corresponds to the Brazilian Connectivity Index, released by ANATEL (2024), using 2023 data. This is a composite indicator that measures the level of infrastructure and development of digital connectivity in municipalities. Beyond the physical availability of networks, connectivity expresses the capacity for integration among urban systems, government and society, enabling real-time information flows and greater coordination of public policies (Neirotti et al., 2014).

The Public Wi-Fi index is represented by a binary variable equal to 1 if free access to a public Wi-Fi network is available in the municipality, according to data from the 2019 MUNIC survey (IBGE, 2020). The literature highlights that the provision of municipal public Wi-Fi is a relevant element of urban digital infrastructure, expanding access to connectivity in public spaces and fostering digital inclusion and citizen participation (Ylipulli et al., 2014).

The Digital Inclusion and Digital Systems indices are constructed using information from the 2019 MUNIC survey (IBGE, 2020). The first is represented by a binary variable equal to 1 if the municipality has a programme or action aimed at digital inclusion. The Carta Brasileira para Cidades Inteligentes (Brazilian Charter for Smart Cities) establishes, among its guidelines, the promotion of digital education and inclusion, recommending continuous actions for citizenship training and digital literacy that encompass different social groups (BRASIL, 2021).

The second represents the count of different digital systems present in the everyday life of the municipal population (Table A.4.5), ranging from 0 to 6. The integration of digital systems into urban services constitutes a central element of the technological

transformation of cities, contributing to efficiency gains and improvements in quality of life (Tura; Ojanen, 2022).

Table 4.2 presents the descriptive statistics for the 25 indicators used to construct the municipal smart city index. The consolidated presentation makes it possible to jointly observe differences in scale, dispersion and variable availability before the normalisation and aggregation procedures.

Table 4.2 - Descriptive statistics of the indicators composing the Brazilian Municipal Smart City Index

Dimension	Indicator	Obs.	Mean	SD	Min	Max
Economy	Economic output per resident	5,570	36,725.22	41,251.57	6,757.48	842,004.60
	Formal Employment Intensity	5,570	20.46	13.00	0.34	147.50
	Talent Pool	5,570	19.95	9.38	1.15	92.97
	Innovation Industries	5,570	6.13	3.43	0.00	34.69
	Income	5,570	421.65	345.09	3.46	5161.08
Society	Health Status	5,570	13.26	15.72	0.10	97.19
	Education	5,556	5.71	0.72	3.75	8.10
	Safety and Security	5,561	20.38	22.90	0.00	256.63
	Housing Conditions	5,570	8.35	8.23	0.00	53.98
	Socioeconomic Progress	5,570	70.03	8.77	25.84	100.00
Environment	Sustainable Commuting	5,570	4.01	7.19	0.00	487.91
	Sustainable Vehicles	5,570	0.05	0.16	0.00	7.24
	Sustainable Energy	5,570	26.79	42.84	0.00	100.00
	Sanitation	5,545	37.57	32.94	0.02	99.90
	Selective Waste Collection	5,060	2.31	5.76	0.00	70.44
Governance	Participation	5,570	4.91	2.60	0.36	36.10
	Institutions	5,570	9.32	6.34	0.00	20.00
	Remote Service	5,570	0.55	0.92	0.00	6.00
	Interaction Channels	5,570	0.43	0.86	0.00	4.00
	Transparency	5,566	0.99	0.11	0.00	1.00
Technology	Broadband Internet	5,565	82.91	16.90	10.84	100.00
	Connectivity	5,570	52.62	13.83	11.60	81.94
	Public Wi-Fi	5,568	0.40	0.49	0.00	1.00
	Digital Inclusion	5,568	0.55	0.50	0.00	1.00
	Digital Systems	5,568	0.34	0.83	0.00	6.00

Source: Author's own elaboration.

Note: Obs. refers to the number of municipality-level observations available for each manifest indicator. Missing manifest observations were retained as missing and were not recoded as zero or replaced by deterministic values. SD denotes standard deviation. Binary indicators are reported as 0/1 variables, so their means correspond to the share of observed units with value equal to one. Values of Formal Employment Intensity above 100% may occur in municipalities that concentrate formal employment relative to their resident working-age population, due to commuting flows or multiple employment contracts.

Table 4.3 summarises the theoretical rationale for each of the indices used to construct the composite smart city indicator for Brazilian municipalities, as well as their respective units of measurement and data sources.

Table 4.3 - Indicators, data sources and theoretical rationale for the Smart City Composite Index

Indicator	Description	Unit of measurement	Source	Rationale/Reference
Economic Output per Resident	Gross domestic product (GDP) per capita at current prices	R\$/inhabitant	IBGE (2024)	GDP per capita measures locally recorded economic output relative to resident population. It is not a direct measure of labour productivity or residents' disposable income, and may reflect productive specialisation and commuting across municipal boundaries. Local economic output nevertheless constitutes one component of the economic conditions associated with urban smartness (Caragliu and Del Bo, 2015).
Formal Employment Intensity	% of formal workers in working-age population (14+)	%	MTE (2023); IBGE (2023)	Smart city policies affect urban labour market structure, promoting formalisation and local economic dynamism (Chen et al., 2024).
Talent Pool	% of formal workers with tertiary education	%	MTE (2023)	Highly educated workers are a key driver of urban competitiveness, as cities increasingly compete to attract and retain human capital (Betz et al., 2016).
Innovation Industries	% of companies categorised as knowledge-intensive	%	MTE (2023)	Knowledge-intensive industries are central to the innovation ecosystems that underpin smart cities (Zygiaris, 2013).
Income	Formal wage bill per capita (monthly average)	R\$	MTE (2023)	Labour income per capita reflects the economic prosperity and living standards that underpin smart city development (Kumar and Dahiya, 2017).
Health Status	% of the population covered by a health insurance according to data from National Health Agency (ANS)	%	ANS (2024)	Smart cities develop and implement policies to increase health conditions of their residents (Solanas et al., 2014).
Education	Basic Education Development Index (IDEB) score	Index	INEP (2022)	Human capital and education are core components of smart city development (Dumančić, 2019).
Safety and Security	Homicide rate (per 100,000 inhabitants)	Number/100,000 people	Ipea (2024)	Safety is a core component of quality of life and an essential indicator in smart city governance (De Marco et al., 2015).

Table 4.3 - Continue

Indicator	Description	Unit of measurement	Source	Rationale/Reference
Housing Conditions	Average percentage of households in inadequate housing conditions	%	IBGE (2023)	Smart city models for developing regions must incorporate basic infrastructure and service deficits as core dimensions (Marchetti et al., 2019).
Socioeconomic Progress	% of beneficiaries whose per capita income exceeds the poverty line after Bolsa Família transfers	%	MDS (2023)	Smart city characteristics are empirically associated with lower urban income inequality, indicating a potential role in fostering socioeconomic progress (Caragliu and Del Bo, 2021).
Sustainable Commuting	Bus fleet per 1,000 people. Bus fleet is used as a limited proxy for collective transport resources and does not directly measure commuting patterns or service quality.	Number/1,000 people	SENATRAM (2024)	Sustainable public transport is a key pillar of smart mobility and environmentally responsible urban development (Zawieska and Pieriegud, 2018).
Sustainable Vehicles	% of vehicles categorised as electric or hybrid	%	SENATRAM (2024)	Electric vehicles are key components of integrated low-carbon transport and energy systems in sustainable urban development (Oldenbroek et al., 2017).
Sustainable Energy	Share of renewable electricity generation establishments in the municipality	%	ANEEL (2024)	Renewable energy integration is central to energy sustainability in smart city development (Kylli & Fokaides, 2015).
Sanitation	% of people in establishments with access to a sewage system	%	IBGE (2023)	Smart city models in developing contexts should account for waste management and environmental service provision as
Selective Waste Collection	Share of recyclable materials recovered from total municipal solid waste collected	%	MCID (2024)	components of urban infrastructure (Marchetti et al., 2019).
Participation	Civil society organizations per 1,000 people	Number/1,000 people	Ipea (2023)	Governance and civic participation are core dimensions of smart city frameworks and sustainable urban development (Durán-Sánchez et al., 2017).
Institutions	Number of existing laws and planning instruments in the municipality	Count	IBGE (2022)	Smart city development requires supportive institutional and regulatory structures beyond technological infrastructure (Kummitha & Crutzen, 2017).

Table 4.3 - Continue

Indicator	Description	Unit of measurement	Source	Rationale/Reference
E-government	Number of remote service options for citizens	Count	IBGE (2020)	The digital provision of public services is a core component of smart governance, enhancing efficiency and accessibility in smart cities (Vanli & Akan, 2023).
E-government	Number of channels for interaction between the municipality and the population	Count	IBGE (2020)	Smart governance requires not only technological integration but also meaningful citizen engagement and participation in urban decision-making processes (Hollands, 2015).
Transparency	Whether the municipality provides information on the budget and financial execution	If provides=1; Otherwise=0.	IBGE (2020)	Transparency is considered a core component of smart governance, reflecting the quality, accountability and openness of public administration in smart cities (Giffinger et al., 2007).
Broadband Internet	% of residents covered by broadband internet	%	ANATEL (2023)	Broadband infrastructure indicates citizens' access to digital services and the technological maturity of urban connectivity systems (Vanli & Akan, 2023).
Connectivity	Brazilian Connectivity Index (IBC) score	Index	ANATEL (2024)	Digital connectivity facilitates integrated information flows and supports smart urban governance and services (Neirotti et al., 2014).
Public Wi-Fi	Existence of free Wi-Fi access in the municipality	If it exists=1; Otherwise=0.	IBGE (2020)	Municipal public Wi-Fi enhances digital connectivity in urban spaces and supports broader access to information and participation (Ylipulli et al., 2014).
Digital Inclusion	Existence of a digital inclusion program or action	If it exists=1; Otherwise=0.	IBGE (2020)	Digital inclusion is a guiding principle of smart cities, promoting digital literacy and equitable access across different social groups (Brazil, 2021).
Digital Systems	Number of digital systems present in people's daily lives	Count	IBGE (2020)	Digital urban systems support smart city transformation by improving integration and service efficiency (Tura & Ojanen, 2022).

Source: Author's own elaboration, following Fachinelli et al. (2022).

The composite Smart City index originally proposed by Yigitcanlar et al. (2020) and later adapted by Fachinelli et al. (2022) is based on a min-max normalisation procedure, in which the indicators are rescaled to an interval between 0 and 1, followed by aggregation using equal weighting. In this approach, each indicator receives the same weight within its dimension, and each dimension contributes equally to the formation of the final index. This is a transparent methodological strategy, easily replicable and suitable for comparative and benchmarking exercises.

However, equal-weight aggregation imposes a substantive and statistical convention: each selected indicator contributes equally to its dimension regardless of the strength of its empirical association with the other indicators assigned to the same construct. This choice remains transparent and interpretable, but it does not use the covariance structure of the data to distinguish the common variation shared by the indicators. This consideration is particularly pertinent here because the empirical framework combines continuous, count and binary variables. Equal weighting is therefore retained as an alternative benchmark, while the main specification uses model-based dimensional scores.

For the main specification, Confirmatory Factor Analysis (CFA), extended through Generalised Structural Equation Modelling (GSEM) where required by the statistical nature of the indicators, is used to construct the dimensional scores. The objective is to summarise the common variation among the indicators assigned to each dimension while allowing their empirical associations with the latent construct to differ. As discussed below, these model-based scores should be interpreted as statistical summaries of the selected measurement framework, rather than as theoretically unique measures of urban smartness.

4.4.3 Construction of the latent dimensions

The following subsection presents the foundations of Confirmatory Factor Analysis, used to estimate the latent dimensions of the smart city index.

4.4.3.1 Foundations of Confirmatory Factor Analysis

Confirmatory Factor Analysis (CFA) is part of the family of Structural Equation Models (SEM) and is used to assess whether a set of observed variables adequately represents a theoretically defined latent construct (Bartholomew et al., 2008). In SEM models, the relationship between observed indicators and latent variables is specified through a measurement model, in which the indicators are regarded as observable, and imperfect, manifestations of the underlying latent constructs (Bollen, 1989; Brown, 2015; Kline, 2016).

The confirmatory character of the exercise concerns the specification of the dimensions and the assignment of indicators to them on substantive grounds. It does not mean that factor loadings are fixed by theory or are independent of the observed data.

CFA estimates the association structure within a specified measurement model, while the subsequent PCA summarises covariation across the dimensional scores. These are distinct operations: the literature guides what is measured, and the statistical models determine how the selected observations are summarised.

This approach also imposes a substantive restriction. The reflective measurement model summarises the common variation associated with each dimension; it does not establish that every selected indicator is a consequence of a single underlying cause. Nor do smaller loadings imply that an indicator is less important for welfare or public policy. Indicators may represent distinct capabilities that do not move together, especially across heterogeneous municipalities. The scores are therefore interpreted as model-based summaries of the chosen framework, rather than as theoretically unique measures of urban smartness.

Following the usual notation in SEM, the relationships between latent variables and indicators can be represented by:

$$y = \Lambda_y \eta + \varepsilon \quad (4.1)$$

where y represents the vector of observed variables, Λ_y is the matrix of factor loadings, η corresponds to the vector of latent constructs and ε represents the measurement error terms associated with the indicators. The factor loadings express the strength of the association between each indicator and the corresponding latent factor, while the error terms represent the specific, or unexplained, variance not accounted for by the construct (Bollen, 1989; Brown, 2015). In general, higher factor loadings indicate a stronger association between the indicator and the specified latent variable.

To ensure model identification, it is necessary to define the scale of the latent variable, since latent factors have no directly observable unit of measurement. In confirmatory factor models, this is usually achieved by fixing the variance of the latent factor or by fixing one of the factor loadings to a reference value (Brown, 2015; Kline, 2016).

The adequacy of the measurement model is assessed by comparing the observed covariance matrix with the covariance matrix reproduced by the model. The degree of proximity between these matrices provides the basis for evaluating overall fit, since an empirically adequate measurement model should satisfactorily reproduce the pattern of relationships observed among the indicators (Bartholomew et al., 2008).

Among the statistics most commonly used to assess model fit is the chi-square test, defined as:

$$\chi^2 = (N - 1)F_k \quad (4.2)$$

where F_k represents the minimum value of the discrepancy function associated

with the estimated model and N corresponds to the sample size. This statistic measures the difference between the observed covariance matrix and the matrix reproduced by the model. Since the chi-square test is sensitive to sample size, especially in datasets with a large number of observations, it is usually interpreted alongside complementary fit indices (Bollen, 1989; Brown, 2015).

One of the most widely used indices is the Root Mean Square Error of Approximation (RMSEA), defined as:

$$\text{RMSEA} = \sqrt{\frac{\chi^2 - df}{df(N - 1)}} \quad (4.3)$$

where df represents the degrees of freedom of the model. The RMSEA is interpreted as a measure of approximation error in the population model, incorporating both fit discrepancy and model parsimony. Lower values indicate a smaller discrepancy between the specified model and the observed covariance structure, although its thresholds should be treated as approximate references rather than mechanical decision rules (Browne; Cudeck, 1992; Hu; Bentler, 1999; Kline, 2016).

Another widely used index is the Comparative Fit Index (CFI), which compares the specified model with an independence model, in which all observed variables are treated as uncorrelated. Its general form can be expressed as:

$$\text{CFI} = 1 - \frac{\chi_k^2 - df_k}{\chi_0^2 - df_0} \quad (4.4)$$

where the subscripts k and 0 denote, respectively, the specified model and the null model. Values closer to 1 indicate better relative fit of the specified model compared with the independence model (Bentler, 1990; Hu; Bentler, 1999).

In addition, the Standardized Root Mean Square Residual (SRMR) is used, corresponding to the standardised mean of the covariance residuals between the observed matrix and the matrix reproduced by the model:

$$\text{SRMR} = \sqrt{\frac{\sum (s_{ij} - \hat{s}_{ij})^2}{k(k + 1)/2}} \quad (4.5)$$

where s_{ij} denotes the observed covariances and $\hat{s}_{ij}$ the covariances reproduced by the model. Lower values indicate greater proximity between the data and the specified model. As a measure based on standardised residuals, the SRMR should be interpreted in conjunction with other fit indices, such as the CFI and the RMSEA, avoiding model assessment based on a single criterion (Bartholomew et al., 2008; Kline, 2016).

Although traditional SEM is formulated under assumptions associated with continuous and normally distributed observed variables, methodological extensions make it

possible to relax this restriction. Generalised Structural Equation Modelling (GSEM) extends the SEM framework by allowing different probability distributions to be specified for the observed variables, preserving the logic of the measurement model while replacing the assumption of multivariate normality with likelihood functions consistent with the statistical nature of each indicator (Muthén, 1984; Skrondal; Rabe-Hesketh, 2004).

In GSEM models, the relationships between latent variables and indicators can be expressed within the framework of generalised linear models, in which the conditional mean of the observed variable is linked to the linear predictor through a link function. Thus, continuous, binary or count indicators can be incorporated simultaneously into the confirmatory factor model by specifying different distributional families and appropriate link functions.¹²

After the measurement models have been estimated, the latent factors can be used to summarise the information contained in the observed indicators. This procedure generates factor scores that represent the relative level of the construct analysed, while preserving the estimated structure of association among indicators, factor loadings and measurement errors (Bartholomew et al., 2008).

Indicator availability is not perfectly balanced across the municipal sample. Missing manifest observations were retained as missing and were not replaced by zero, sample means or other deterministic values. Economy has complete manifest information for the full set of 5,570 observational units. For Society, 5,547 units have complete information on the five indicators used in the CFA model, while the corresponding number for Environment is 5,035. In Governance and Technology, the GSEM specification uses the full 5,570-unit universe while allowing response-specific missingness across the manifest indicators.

After estimation, factor scores were obtained from the fitted measurement models for all 5,570 observational units. Consequently, some dimensional scores are informed by a reduced set of observed manifest indicators, although the same measurement structure is applied across units. This procedure does not imply that missing manifest values are replaced by observed or predicted values. To assess whether differences in indicator coverage materially affect the resulting index, the full measurement and aggregation procedure is also re-estimated for the 5,009 units with complete information on all 25 manifest indicators. The corresponding sensitivity results are reported in Appendix Table A.4.7 and Figure A.4.2.

¹² In the GSEM framework, different distributional families may be specified according to the statistical nature of the observed indicators. Continuous variables are usually modelled using the Gaussian family with an identity link, binary indicators using the Bernoulli family with a logit link, and count variables using the Poisson family with a log link.

4.4.4 Construction of the composite smart city index

The construction of the composite smart city index is based on the aggregation of the previously estimated latent dimensions. To this end, the multivariate technique of Principal Component Analysis is used, as described below.

4.4.4.1 Foundations of Principal Component Analysis

Principal Component Analysis (PCA) is a multivariate statistical technique aimed at representing the variance-covariance structure of a set of variables through linear combinations that are uncorrelated with one another. Its objective is to reduce the dimensionality of the original set of variables while preserving the largest possible share of the information contained in the data (Johnson; Wichern, 2014; Jolliffe, 2002). In applications concerned with the construction of composite indicators, this property makes it possible to aggregate multiple dimensions into a composite score, with weights derived from the empirical structure of the variables considered (OECD, 2008).

Formally, each principal component corresponds to a linear combination of the observed variables. The j -th principal component can be represented as:

$$PC_j = a_{j1}X_1 + a_{j2}X_2 + \cdots + a_{jp}X_p \quad (4.6)$$

where $X_1, X_2, \dots, X_p$ represent the original variables and $a_{j1}, a_{j2}, \dots, a_{jp}$ correspond to the coefficients associated with the component, determined from the eigenvectors of the covariance or correlation matrix of the variables. These coefficients define the relative contribution of each variable to the formation of the component.

The principal components are constructed sequentially, so that the first component explains the largest possible share of the total variance in the dataset, while subsequent components explain the largest possible share of the remaining variance, under the constraint that they are mutually orthogonal (Manly, 2004). Thus, each component represents a specific direction of variability in the multivariate space.

The relative importance of each component is determined by its eigenvalue, which represents the amount of total variance explained by that component. Components associated with larger eigenvalues contribute more substantially to the representation of the data structure. A widely used criterion for determining the number of components to be retained is the Kaiser criterion (1958), according to which only components with eigenvalues greater than 1 should be considered in the analysis.

In addition to the eigenvalue, the proportion of variance explained by each component is an important indicator for assessing the relevance of the extracted components. In applications concerned with the construction of composite indices, the first component may be used as a synthetic indicator when it concentrates a substantial share of the

total variance and presents a coefficient structure that is substantively consistent with the phenomenon analysed. In this situation, the component synthesises the common variation present in the variables considered, providing an aggregate measure of the construct of interest (Johnson; Wichern, 2014; Jolliffe, 2002).

The coefficients associated with the principal components indicate the relative contribution of each original variable to the extracted component. In this application, the reported loadings correspond to the coefficients of the eigenvector associated with the principal component considered:

$$\text{Loading}_{ij} = a_{ij} \quad (4.7)$$

where a_{ij} represents the coefficient associated with variable i in component j . Higher absolute values indicate a greater contribution of the variable to the corresponding component.

4.4.5 Spatial analysis strategy

According to the first law of geography, proposed by Tobler (1970), all things are related to one another, but nearby things tend to exhibit stronger relationships. This principle constitutes one of the foundations of the statistical concept of spatial autocorrelation, according to which values observed in certain spatial units may display a systematic association with values observed in neighbouring units.

Exploratory Spatial Data Analysis (ESDA) brings together a set of statistical and graphical techniques designed to identify spatial patterns in the data and assess the presence of spatial dependence among observations. These techniques make it possible to investigate whether the spatial distribution of a variable exhibits a systematic pattern of clustering, dispersion or randomness across the territory (Anselin, 1988; LeSage; Pace, 2009).

A central element of this approach is the definition of the spatial weights matrix W , which formalises the neighbourhood structure among spatial units. This matrix consists of an $n \times n$ matrix whose elements w_{ij} indicate the intensity of the spatial relationship between units i and j , taking a non-zero value when two units are considered neighbours according to the adopted neighbourhood criterion. By convention, the elements of the main diagonal are equal to zero ($w_{ii} = 0$), since a unit is not considered a neighbour of itself (Anselin; Rey, 2014).

The definition of the neighbourhood structure may be based on different spatial criteria. Among the most commonly used are contiguity matrices and matrices based on distance or proximity. In the case of contiguity matrices, two spatial units are considered neighbours when they share a territorial boundary. Rook contiguity defines neighbours as

units that share a common boundary, whereas queen contiguity considers as neighbours units that share either a boundary or a vertex. The neighbourhood structure may also be extended to higher orders, incorporating indirect neighbours, or defined on the basis of a fixed number of nearest neighbours.

In addition to contiguity matrices, the neighbourhood structure may also be defined on the basis of geographic distance or spatial proximity criteria. Among the most commonly used are matrices based on a maximum distance threshold (distance band), inverse-distance matrices and matrices defined according to a fixed number of nearest neighbours (k-nearest neighbours).

The presence of global spatial autocorrelation can be measured using Moran's I. This statistic measures the degree of spatial association between the values of a variable across different spatial units and can be expressed as:

$$I = \frac{n}{S_0} \frac{\sum_i \sum_j w_{ij} (x_i - \bar{x}) (x_j - \bar{x})}{\sum_i (x_i - \bar{x})^2} \quad (4.8)$$

where n represents the number of spatial units, x_i corresponds to the value observed in unit i , $\bar{x}$ represents the mean of the variable and S_0 corresponds to the sum of all elements of the spatial weights matrix. Positive values of the index indicate positive spatial autocorrelation, characterised by spatial association among units with similar values of the variable analysed (high-high or low-low), whereas negative values indicate negative spatial autocorrelation, associated with proximity among units with dissimilar values. Under the null hypothesis of spatial randomness, the expected value of the index tends to $-[1/(n-1)]$.

The statistical significance of Moran's I can be assessed through random permutation procedures, which make it possible to compare the observed value of the statistic with the distribution obtained under the null hypothesis of spatial randomness (Anselin; Rey, 2014).

Spatial autocorrelation analysis can be conducted in both univariate and bivariate forms. In the univariate case, Moran's I assesses the degree of spatial association between the values of the same variable observed across different spatial units. In its bivariate version, the statistic measures the relationship between the values of one variable observed in a given spatial unit and the values of another variable observed in neighbouring units, as defined by the spatial weights matrix. This approach makes it possible to investigate whether high values of one variable are spatially associated with high or low values of another variable in surrounding areas (Anselin; Rey, 2014).

Complementing the global measure of spatial autocorrelation, Local Indicators of Spatial Association (LISA) make it possible to identify specific spatial patterns within

the territory. These indicators allow the global Moran's I to be decomposed into local contributions, making it possible to identify spatial clusters and potential spatial outliers. The cartographic representation of these indicators, through LISA maps, allows spatial units to be classified into four main patterns of association: high-high, low-low, high-low and low-high, revealing areas of spatial concentration or spatial contrast in the distribution of the variable analysed.

4.5 Results of the smart city index for Brazilian municipalities

This section presents the results of the construction of the latent dimensions of urban smartness for Brazilian municipalities, as well as the composition of the aggregate smart city index. It then analyses the territorial distribution of these indicators and the evidence of spatial autocorrelation associated with this phenomenon in the Brazilian context.

4.5.1 Results of the latent dimensions and the composite index

Based on the selection of the 25 indicators and the five dimensions of urban smartness, Confirmatory Factor Analysis (CFA) models were estimated to obtain municipal factor scores for Economy, Society and Environment. For Governance and Technology, the GSEM specification was used, due to the joint presence of continuous indicators, count variables and binary variables. This strategy makes it possible to preserve the multidimensional conceptual structure of the index without imposing homogeneous statistical treatment on indicators of different natures.

Table 4.4 consolidates the estimates from the five measurement models. The results for the CFA dimensions are discussed first, followed by the GSEM specifications for Governance and Technology. The standardised diagrams for the dimensions estimated by CFA/SEM are reported in Figure A.4.1 in the Appendix. Since Governance and Technology were estimated using GSEM, equivalent diagrams are not presented for these two dimensions.

The CFA results indicate that the selected indicators are statistically associated with their respective latent factors, although the strength of these associations differs within each dimension. In Economy, Income, Formal Employment Intensity and Economic Output per Resident present the largest standardised loadings, while Talent Pool and Innovation Industries display more moderate associations with the common economic factor. These coefficients describe the covariance structure of the selected indicators and should not be interpreted as measures of their normative or policy importance.

In Society, Health Status and Education present relatively strong positive loadings, whereas Housing Conditions has a large negative loading, consistent with the fact that higher values of this indicator represent greater housing precariousness. Safety and Security

also enters with a negative sign, but with a smaller loading, while Socioeconomic Progress is positively associated with the latent factor. The resulting score therefore summarises common variation across human-capital, wellbeing and vulnerability indicators rather than representing a single social outcome.

Table 4.4 - CFA/GSEM measurement-model estimates for the Smart City dimensions

Dimension	Indicator	Family/link	Estimate	Residual variance
Economy	Economic output per resident	Gaussian/identity	0.82***	0.32
	Formal Employment Intensity	Gaussian/identity	0.93***	0.13
	Talent Pool	Gaussian/identity	0.50***	0.75
	Innovation Industries	Gaussian/identity	0.39***	0.84
	Income	Gaussian/identity	0.98***	0.03
Society	Health Status	Gaussian/identity	0.71***	0.50
	Education	Gaussian/identity	0.64***	0.59
	Safety and Security	Gaussian/identity	-0.11***	0.98
	Housing Conditions	Gaussian/identity	-0.93***	0.14
	Socioeconomic Progress	Gaussian/identity	0.12***	0.98
Environment	Sustainable Commuting	Gaussian/identity	0.62***	0.61
	Sustainable Vehicles	Gaussian/identity	0.24***	0.94
	Sustainable Energy	Gaussian/identity	0.25***	0.94
	Sanitation	Gaussian/identity	0.36***	0.87
	Selective Waste Collection	Gaussian/identity	0.37***	0.86
Governance	Participation	Gaussian/identity	0.11***	0.99
	Institutions	Gaussian/identity	0.33***	0.89
	Remote Service	Poisson/log	0.89***	n.a.
	Interaction Channels	Poisson/log	1.14***	n.a.
	Transparency	Bernoulli/logit	0.81***	n.a.
Technology	Broadband Internet	Gaussian/identity	0.73***	0.46
	Connectivity	Gaussian/identity	0.84***	0.30
	Public Wi-Fi	Bernoulli/logit	0.18***	n.a.
	Digital Inclusion	Bernoulli/logit	0.41***	n.a.
	Digital Systems	Poisson/log	1.60***	n.a.
<i>Residual covariances included in the final CFA/SEM models</i>				
Dimension	Residual covariance		Estimate	
Economy	Talent Pool ↔ Income		-0.10***	
Society	Education ↔ Safety and Security		-0.24***	
Society	Safety and Security ↔ Socioeconomic Progress		0.13***	
Environment	Sustainable Commuting ↔ Sustainable Vehicles		-0.16***	

Source: Author's own elaboration.

Note: For Economy, Society and Environment, the table reports standardised CFA/SEM loadings and standardised residual variances. Governance and Technology were estimated using GSEM to accommodate Gaussian, Poisson and Bernoulli indicators. For these two dimensions, the reported coefficients are expressed on the response-specific link scales with the latent-factor variance fixed to one; their magnitudes should therefore not be compared mechanically across statistical families. Residual variances are reported only for Gaussian responses. The residual covariances shown at the bottom of the table correspond to additional error covariances included in the final CFA/SEM specifications. *** $p < 0.001$.

All five Environment indicators are positively associated with the latent factor. Sustainable Commuting presents the largest standardised loading, followed by Selective

Waste Collection and Sanitation, while Sustainable Energy and Sustainable Vehicles have smaller loadings. The residual covariance between Sustainable Commuting and Sustainable Vehicles indicates remaining association between the two measures after conditioning on the environmental factor; it should not be interpreted as evidence of a causal relationship between them.

For Governance and Technology, all estimated latent-variable coefficients are positive and statistically significant. Because these dimensions combine Gaussian, Poisson and Bernoulli responses under different link functions, coefficient magnitudes are not directly comparable across indicators. The GSEM results therefore support the expected directional association of the selected indicators with their respective latent dimensions, but they are not used to rank the relative importance of the individual governance or technology measures.

The fit statistics for the dimensions estimated by CFA indicate a satisfactory approximation to the observed covariance structure. Economy was estimated with 5,570 observations and presented an RMSEA of 0.03, a CFI of 0.99 and an SRMR of 0.01. Society was estimated with 5,547 complete observations and presented an RMSEA of approximately 0.06, a CFI of 0.99 and an SRMR of 0.02. Environment was estimated with 5,035 complete observations and also showed low residual discrepancy. Given the large sample sizes, the statistically significant chi-square statistics are interpreted jointly with the complementary fit measures. For Governance and Technology, estimated using GSEM, global fit statistics directly comparable to those of conventional CFA models are not reported.

Based on the estimation of the measurement models, municipal factor scores were obtained for each of the five dimensions of urban smartness. These scores represent the relative position of municipalities in Economy, Society, Environment, Governance and Technology, serving as the basis for the construction of the composite index. Principal Component Analysis (PCA) was then applied with the aim of synthesising the five dimensions into a single aggregate smart city indicator. Table 4.5 presents the eigenvalues, the variance explained by the extracted components and the loadings associated with the first principal component.

The results indicate that the first principal component has an eigenvalue of 2.99 and explains 59.71% of the total variance of the dimensions analysed. The subsequent components have eigenvalues below 1 and substantially smaller contributions. Based on the Kaiser criterion, only the first component was retained and interpreted as the composite smart city index.

All dimensions present positive loadings on the first principal component, suggesting that higher levels of performance in each of them are associated with higher levels of urban smartness. Society and Economy make the largest contributions, followed by Technology

and Environment. Governance presents a more moderate positive contribution, indicating a lower relative weight in the composition of the aggregate indicator. This result does not imply low conceptual relevance of governance for urban smartness, but suggests that, in the empirical structure of the Brazilian municipal data, this dimension exhibited lower covariation with the common component extracted by PCA.

Table 4.5 - Principal component analysis of the Smart City dimensions

Panel A. Eigenvalues and explained variance

Component	Eigenvalue	Variance Explained (%)	Cumulative (%)
1	2.99	59.71	59.71
2	0.89	17.75	77.46
3	0.55	11.02	88.48
4	0.38	7.63	96.11
5	0.19	3.89	100

Panel B. Loadings of the first principal component

Dimension	Loading
Economy	0.49
Society	0.53
Environment	0.43
Governance	0.27
Technology	0.47

Source: Author's own elaboration.

Note: Panel A reports the eigenvalues, the percentage of variance explained by each principal component, and the cumulative variance. Panel B reports the loadings of the five Smart City dimensions on the first principal component. Following the Kaiser criterion, only the first component was retained, as it was the only component with an eigenvalue greater than 1. This retained component is used as the Smart City composite index. The reported coefficients correspond to the eigenvector coefficients used to construct the first principal-component score.

Two alternative aggregations were examined: a second-order confirmatory factor and the simple average of the five dimensional scores. Table A.4.6 reports correlations of 0.97 between the second-order factor and PCA, 0.95 between the second-order factor and the mean, and 0.99 between PCA and the mean. These results indicate close agreement among the aggregate scores under the three procedures. They do not establish that individual ranks are identical, or that the original indicator choices are insensitive to alternative measurement assumptions.

PCA is retained as the main descriptive aggregation of the estimated dimensions. Its weights reflect their empirical covariance structure, not their social value, causal influence or normative importance. Equal weighting is a transparent alternative rather than an intrinsically inferior procedure, and the high correlation with the mean provides a useful benchmark. Because this comparison retains the estimated dimensional scores, it should not be interpreted as a test of equal weighting across the original 25 indicators.

Additional sensitivity exercises address two features of the measurement process: unequal manifest-indicator coverage and a small number of extreme observations in

the environmental indicators. Re-estimating the complete measurement and aggregation procedure for the 5,009 units with all 25 manifest indicators observed produces a Spearman rank correlation of 0.9999 with the benchmark index. Within this common sample, membership in the top 50 and top 100 is fully preserved, and 98.5% of the units remain in the same quintile. Sensitivity to the upper tail of the environmental indicators is larger for individual positions at the top of the ranking, although the overall ordering remains highly correlated with the benchmark.

A separate dimensional diagnostic excludes Economy from the aggregation and re-estimates the PCA using Society, Environment, Governance and Technology. The resulting index remains strongly associated with the benchmark, with a Spearman rank correlation of 0.980, although changes in exact positions are more pronounced: 80.4% of the units remain in the same quintile, while 13 of the benchmark top 20 and 80 of the top 100 remain in the corresponding groups. The changes are particularly visible for some municipalities with high Economy scores, including Gavião Peixoto and Confins. The exercise therefore suggests that the broader ordering is not simply a reproduction of the Economy dimension, while also showing that its direct inclusion affects the relative position of some municipalities in the composite distribution. Appendix Table A.4.7 reports these diagnostics.

The benchmark specification is retained because Economy forms part of the multi-dimensional framework defined for the Smart City Index. The sensitivity exercises instead qualify its interpretation, indicating that broad distributional patterns are more stable than some exact rank positions. Accordingly, the latter are interpreted descriptively rather than as precise performance classifications.

Table 4.6 presents the descriptive statistics for the normalised indices, defined over the interval between 0 and 1, referring to the Economy, Society, Environment, Governance and Technology dimensions, as well as to the composite Smart City Index.

Table 4.6 - Descriptive statistics of the Smart City indices

Index	Obs.	Mean	SD	Min	Max
Economy	5,570	0.58	0.11	0	1
Society	5,570	0.58	0.18	0	1
Environment	5,570	0.17	0.06	0	1
Governance	5,570	0.38	0.17	0	1
Technology	5,570	0.68	0.14	0	1
Smart City Index	5,570	0.51	0.14	0	1

Source: Author's own elaboration.

Note: Obs. refers to the number of model-based dimensional or composite scores. It should not be interpreted as indicating that every manifest indicator is observed for all 5,570 units; indicator-level availability is reported in Table 4.2. All scores were normalised separately using min-max scaling and range from 0, the lowest observed score, to 1, the highest observed score. Because normalisation is dimension-specific, mean values across dimensions should not be interpreted as directly comparable levels of substantive achievement.

Table 4.6 describes the distribution of the model-based scores after dimension-specific min–max normalisation. Technology has the highest numerical mean, at 0.68, while Environment has the lowest, at 0.17. These values locate municipalities relative to the observed range of each dimension and are not directly comparable measures of substantive achievement. The composite Smart City Index has a mean of 0.51 and a standard deviation of 0.14. Its interpretation is therefore relative to the empirical distribution of the selected dimensions rather than to an external standard of urban development.

As an additional descriptive diagnostic, the Smart City Index was compared with the share of the municipal population classified as urban in the 2022 Demographic Census. The association is positive, with a Spearman rank correlation of 0.694, and the mean composite score increases from 0.386 among units in the lowest quartile of urban population share to 0.649 in the highest quartile. The distributions nevertheless overlap across the four groups, indicating that urban population share is associated with the measured level of urban smartness without uniquely determining municipal positions in the composite distribution. Figure A.4.4 in the Appendix reports this comparison.

Table 4.7 reports the twenty municipalities with the highest values and the ten municipalities with the lowest values for the composite smart city index.

Table 4.7 - Upper and lower tails of the Smart City Index ranking

Rank	State	Urban Hierarchy	Municipality	Population	Smart City Index
1	Pernambuco	Local Centre	Fernando de Noronha	3,167	1.0000
2	São Paulo	Metropolis	Barueri	316,473	0.9606
3	Distrito Federal	Metropolis	Brasília	2,817,381	0.8964
4	Rio de Janeiro	Metropolis	Rio de Janeiro	6,211,223	0.8953
5	São Paulo	Regional Capital	Gavião Peixoto	4,702	0.8898
6	Rio de Janeiro	Metropolis	Niterói	481,749	0.8881
7	São Paulo	Metropolis	Valinhos	126,373	0.8879
8	Paraná	Metropolis	Curitiba	1,773,718	0.8794
9	Minas Gerais	Metropolis	Confins	7,350	0.8788
10	São Paulo	Local Centre	Holambra	15,094	0.8778
11	Santa Catarina	Regional Capital	Balneário Camboriú	139,155	0.8746
12	Minas Gerais	Metropolis	Belo Horizonte	2,315,560	0.8718
13	Espírito Santo	Metropolis	Vitória	322,869	0.8716
14	Goiás	Metropolis	Goiânia	1,437,366	0.8682
15	Rio Grande do Sul	Metropolis	Porto Alegre	1,332,845	0.8640
16	São Paulo	Metropolis	Santana de Parnaíba	154,105	0.8627
17	São Paulo	Metropolis	São Paulo	11,451,999	0.8614
18	São Paulo	Metropolis	Campinas	1,139,047	0.8604
19	Mato Grosso	Regional Capital	Cuiabá	650,877	0.8507

Table 4.7 - Continue

Rank	State	Urban Hierarchy	Municipality	Population	Smart City Index
20	Rio Grande do Sul	Local Centre	Tupandi	5,029	0.8471
5561	Piauí	Local Centre	Fartura do Piauí	5,284	0.0853
5562	Maranhão	Local Centre	Marajá do Sena	7,027	0.0822
5563	Amazonas	Local Centre	Uarini	14,431	0.0817
5564	Piauí	Local Centre	Campo Largo do Piauí	7,419	0.0716
5565	Roraima	Local Centre	Uiramutã	13,751	0.0432
5566	Maranhão	Local Centre	Jenipapo dos Vieiras	17,076	0.0154
5567	Amazonas	Local Centre	Pauini	19,373	0.0082
5568	Amazonas	Local Centre	Ipixuna	24,311	0.0078
5569	Maranhão	Local Centre	Cachoeira Grande	9,732	0.0021
5570	Pará	Local Centre	Limoeiro do Ajuru	29,569	0.0000

Source: Author's own elaboration.

Note: Population refers to the resident population in 2022 according to the Brazilian Demographic Census (IBGE, 2023a). Urban hierarchy follows the REGIC classification (IBGE, 2019b). REGIC treats some functionally integrated municipalities as part of population arrangements. When the hierarchy reported here derives from such an arrangement, the category refers to the urban centre represented by the arrangement and should not be interpreted as indicating that each constituent municipality individually performs all the functions associated with that hierarchical level. The Smart City Index ranges from 0 (lowest observed composite score) to 1 (highest observed composite score). Fernando de Noronha corresponds to the State District of Pernambuco and is retained because it is represented as a municipal-level statistical unit in the databases used in the analysis.

The benchmark specification produces a heterogeneous upper tail of the distribution. Fernando de Noronha records the highest composite score, followed by Barueri, Brasília and Rio de Janeiro. The first twenty positions also include considerably smaller units, such as Gavião Peixoto, Confins, Holambra and Tupandi. This composition indicates that high benchmark scores are not confined to large metropolitan centres. At the same time, the ranking should not be read as a certification of smart-city policy effectiveness or as an ordering that is invariant to every measurement choice.

Fernando de Noronha is a particularly informative case. Its benchmark position is associated with an unusually high Environment score, driven in part by the Sustainable Vehicles indicator. The observed value is retained in the main specification because the data audit did not establish that it results from a coding error. Sensitivity exercises that reduce the influence of the upper tail of the environmental indicators leave the overall Smart City Index highly correlated with the benchmark, but alter some individual positions near the top of the distribution. Exact rank differences should therefore be interpreted cautiously, particularly for units whose scores are influenced by unusually high values in

individual indicators.

Other highly ranked smaller units also require a contextual interpretation. Positions such as those of Gavião Peixoto and Confins may reflect productive specialisation, commuting patterns and integration with larger regional economies. The indicators characterise conditions recorded at the municipal level; they do not establish that these conditions are generated autonomously within each jurisdiction or that the same combination could be reproduced independently of its regional context. The dimensional sensitivity exercise reported in Appendix (Table A.4.7) is consistent with this interpretation: both municipalities experience comparatively large rank declines when Economy is excluded from the composite aggregation.

To qualify the interpretation of the ranking, Figure 4.2 presents the dimensional profiles of the nine highest benchmark scores. The figure shows that similar positions in the composite distribution may arise from markedly different combinations of dimensions. Barueri, Brasília, Rio de Janeiro, Niterói, Valinhos and Curitiba display comparatively broad profiles across Economy, Society, Governance and Technology, although their Environment scores are generally lower.

Fernando de Noronha presents a distinct configuration, with the highest observed Environment score and more moderate values in several of the other dimensions. Gavião Peixoto and Confins illustrate another pattern, combining relatively high Economy, Society and Technology scores with more modest environmental performance. The comparison reinforces that the composite index summarises heterogeneous dimensional configurations rather than a single pathway to urban smartness.

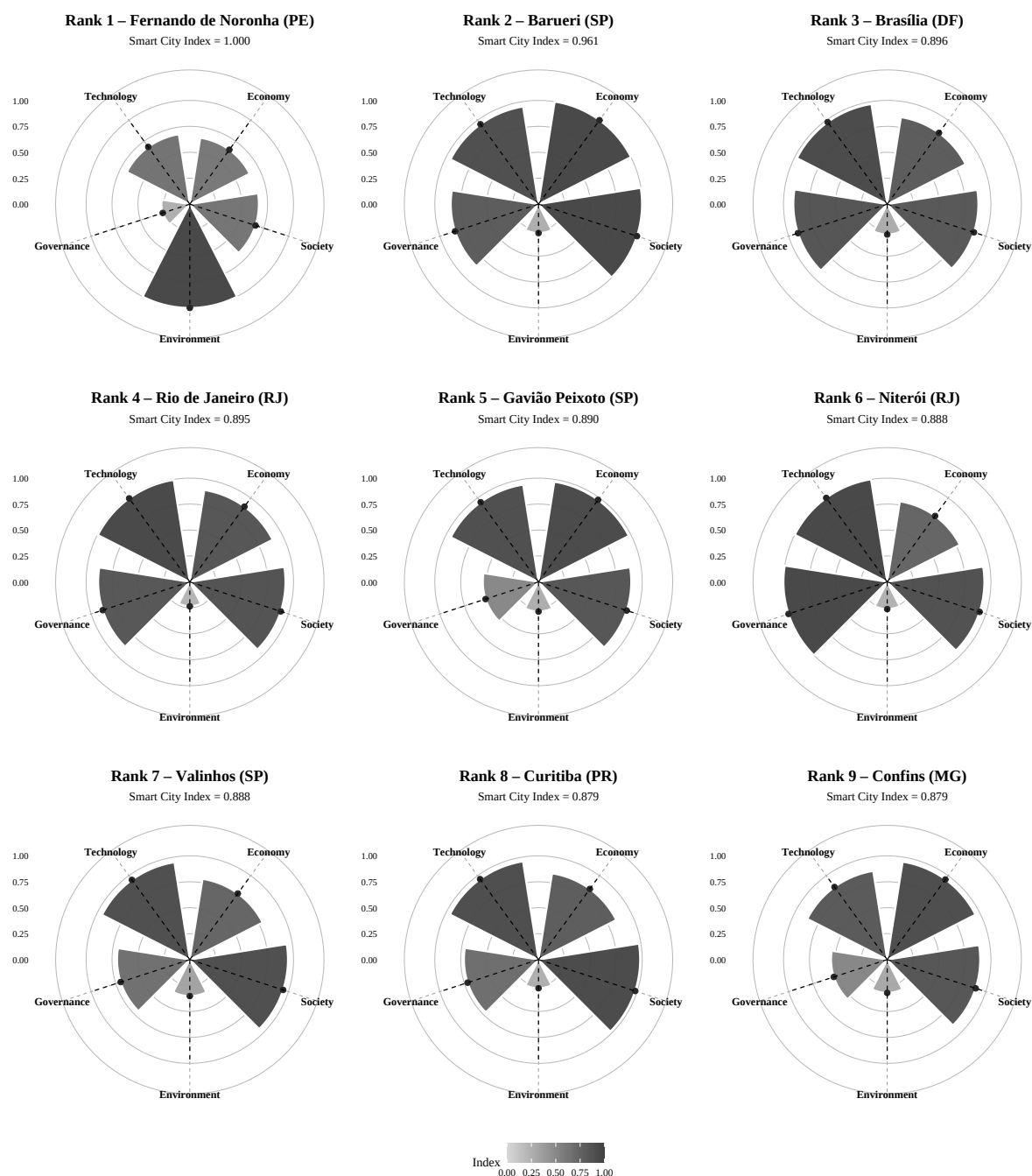
Figure 4.3 complements this reading by decomposing the weighted dimensional profiles of the twenty highest benchmark scores. For most of these units, Society, Economy and Technology account for the largest shares of the weighted profile. Governance contributes more moderately, while Environment generally represents a smaller share. Fernando de Noronha is a clear exception, with Environment accounting for a substantially larger part of its weighted profile. This contrast reinforces the heterogeneous composition of similar aggregate scores.

The decomposition helps to interpret the composite index without treating it as a homogeneous urban attribute. PCA summarises the covariance structure of the five dimensions, so municipalities with similar aggregate positions may reach them through different combinations of economic, social, environmental, institutional and technological conditions. The resulting profiles are therefore more informative for substantive interpretation than small differences in exact ranking positions.

Figure A.4.3, in the Appendix, complements this reading by restricting the display to units that are not state capitals. Fernando de Noronha, Barueri, Gavião Peixoto, Niterói, Valinhos, Confins, Holambra, Balneário Camboriú and Santana de Parnaíba

remain among the highest benchmark scores. Their presence indicates that high index values are not confined to capital cities, although this comparison does not isolate the role of metropolitan integration, productive specialisation or other regional advantages.

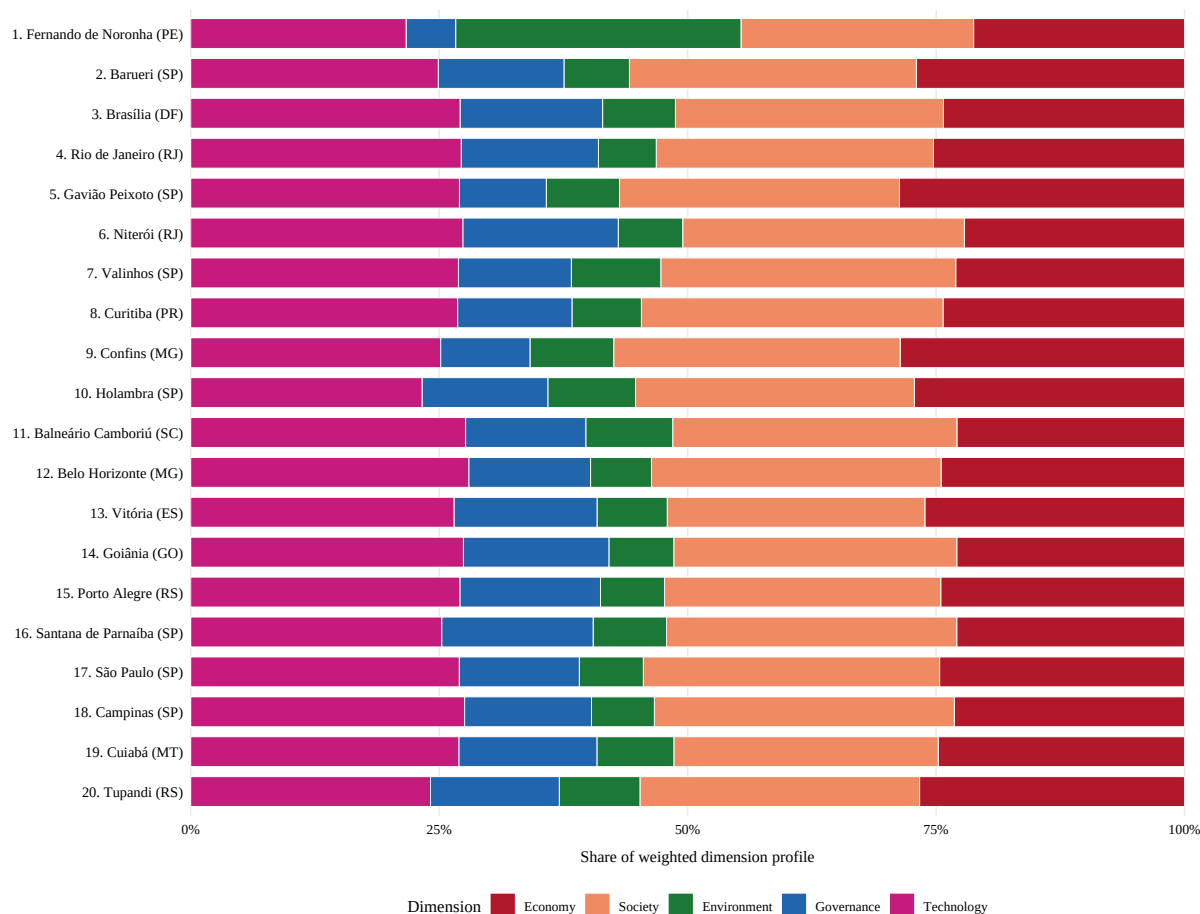
Figure 4.2 – Dimensional profiles of the top-ranked municipalities in the Smart City Index



Source: Author's own elaboration.

Note: Each radial bar reports the normalised score of the municipality in one Smart City dimension. Scores range from 0 (lowest observed dimensional score) to 1 (highest observed dimensional score). The title of each panel reports the municipality's national position in the Smart City Composite Index. Scores are relative to the observed distribution of each dimension and should not be interpreted as directly comparable levels of substantive achievement across dimensions. Exact rank positions should be read descriptively, particularly for units with singular indicator values.

Figure 4.3 - Weighted dimensional profile of the top 20 municipalities in the Smart City Index



Source: Author's own elaboration.

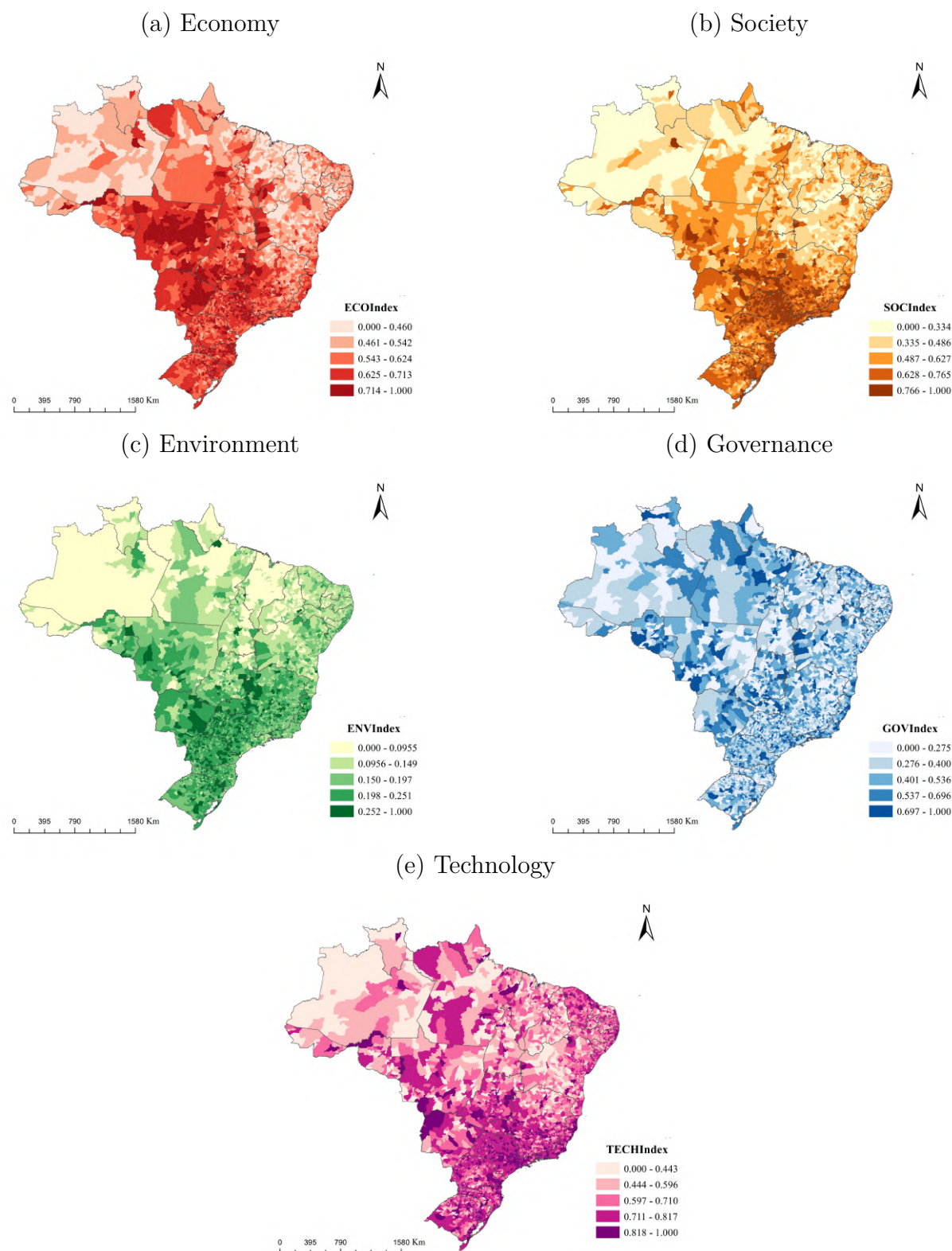
Note: The figure reports the relative share of each dimension in the weighted dimensional profile of the top 20 municipalities. Dimension scores were weighted by the PCA loadings reported in Table 4.5 and then normalised within each municipality so that the shares sum to 100%. These shares are descriptive decompositions of the composite index. They combine the normalised dimensional scores with the PCA coefficients and should not be interpreted as causal contributions or welfare weights.

4.5.2 Territorial distribution and preliminary spatial evidence

Figure 4.4 presents the spatial distribution of the normalised scores for Economy, Society, Environment, Governance and Technology. The maps provide a first descriptive view of whether the different components of the index exhibit similar territorial configurations or distinct spatial patterns.

Visual inspection suggests clearer concentrations of higher Economy, Society and Technology scores in parts of the South, Southeast and Central-West, alongside lower-score areas in substantial portions of the North and Northeast. These patterns overlap with longstanding regional differences in economic activity, infrastructure and access to services, but the maps alone do not identify the mechanisms underlying these spatial contrasts.

Figure 4.4 - Spatial distribution of Smart City dimension indices across Brazilian municipalities



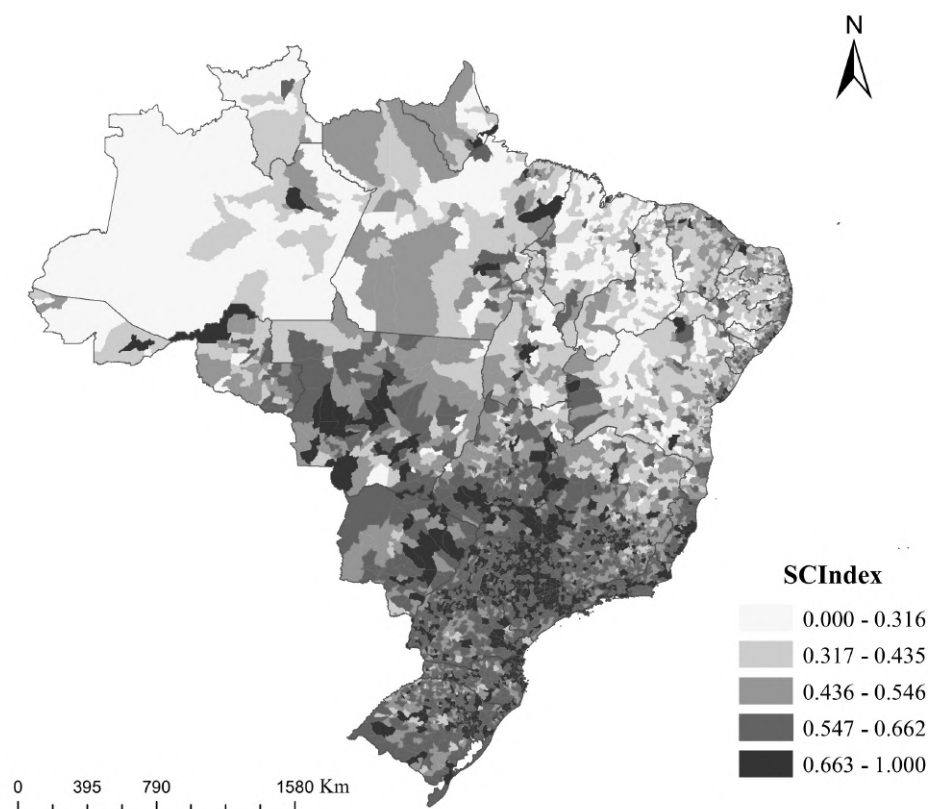
Source: Author's own elaboration.

Note: All indices were normalised separately using min-max scaling and range from 0, the lowest observed score, to 1, the highest observed score. Maps were classified using natural breaks (Jenks) and produced using ArcGIS 10.5. Class intervals were defined separately for each index and should therefore be interpreted within each panel rather than compared as common thresholds across dimensions.

Environment and Governance display comparatively more heterogeneous cartographic patterns. Higher Environment scores appear in municipalities located across different regions, while Governance shows less geographically continuous concentrations. Because each dimension is normalised separately and the Jenks class boundaries are estimated independently for each map, colours and class positions should be interpreted within each panel rather than compared as common performance thresholds across dimensions.

Figure 4.5 complements the dimensional maps by presenting the spatial distribution of the composite Smart City Index. Unlike Figure 4.4, which displays the five dimensions separately, the composite map summarises their joint variation through the first principal component.

Figure 4.5 - Spatial distribution of the Smart City Composite Index across Brazilian municipalities



Source: Author's own elaboration.

Note: SCIndex refers to the Smart City Composite Index. The index was normalised using min-max scaling and ranges from 0, the lowest observed composite score, to 1, the highest observed composite score. The map was classified using natural breaks (Jenks) and produced using ArcGIS 10.5.

The composite map suggests a broad spatial gradient, with higher Smart City Index values more frequent in parts of the South, Southeast and Central-West, and lower values more common in much of the North and Northeast. The pattern is not uniform

within regions, however, and municipalities with contrasting scores remain present outside these broader concentrations. The map should therefore be interpreted descriptively rather than as evidence of a specific regional mechanism.

This reading, however, should be interpreted as a first descriptive approximation. Cartographic visualisation makes it possible to identify apparent concentrations, regional contrasts and potential spatial clusters, but it does not allow the existence of spatial autocorrelation among municipalities to be formally assessed. To examine these patterns more systematically, the following subsection presents global and local measures of spatial autocorrelation, with the aim of identifying the presence of spatial dependence and characterising territorial clusters associated with the composite smart city index.

4.5.3 Exploratory spatial analysis of smart city indicators

Table 4.8 presents the values of global Moran's I for the smart city dimensions and for the composite index, considering different spatial weights matrices. The results indicate positive and statistically significant spatial autocorrelation for all the indicators analysed. This means that municipalities with similar levels of performance in the dimensions of urban smartness tend to be located close to one another across the Brazilian territory, suggesting the existence of spatial clustering patterns.

Table 4.8 - Global Moran's I statistics for smart city indicators under alternative spatial weight matrices

Spatial weight matrix	Economy	Society	Environment	Governance	Technology	Smart City
Queen contiguity	0.623***	0.765***	0.631***	0.158***	0.478***	0.705***
Rook contiguity	0.623***	0.766***	0.543***	0.159***	0.480***	0.706***
Queen contiguity (2nd order)	0.571***	0.710***	0.588***	0.119***	0.430***	0.675***
Queen contiguity (3rd order)	0.530***	0.656***	0.563***	0.082***	0.382***	0.612***
4 nearest neighbors	0.626***	0.772***	0.613***	0.168***	0.490***	0.706***
8 nearest neighbors	0.607***	0.754***	0.597***	0.150***	0.471***	0.688***
12 nearest neighbors	0.597***	0.741***	0.587***	0.143***	0.454***	0.676***
Distance band (100 km)	0.561***	0.682***	0.582***	0.107***	0.415***	0.640***
Distance band (200 km)	0.501***	0.618***	0.549***	0.060***	0.356***	0.583***
Distance band (300 km)	0.484***	0.587***	0.534***	0.041***	0.325***	0.561***
Inverse distance	0.626***	0.772***	0.613***	0.168***	0.490***	0.706***

Source: Author's own elaboration.

Note: *** $p < 0.001$. Pseudo-significance based on 9,999 random permutations.

The values of Moran's I show a high degree of consistency across the different spatial weights matrices considered, including contiguity matrices, matrices based on the number of nearest neighbours and matrices defined by distance criteria. This stability indicates that the presence of spatial autocorrelation does not depend on a particular specification of the neighbourhood structure, reinforcing the consistency of the spatial pattern identified.

Among the dimensions analysed, the highest values of spatial autocorrelation are observed for Society and Economy. These results indicate a strong tendency for territorial clustering among municipalities with similar socioeconomic characteristics, suggesting that conditions associated with human capital, wellbeing, productive structure and economic dynamism display a clear spatial organisation across the national territory. The composite smart city index also presents high Moran's I values, indicating that the multidimensional synthesis of urban smartness preserves a strong spatial component.

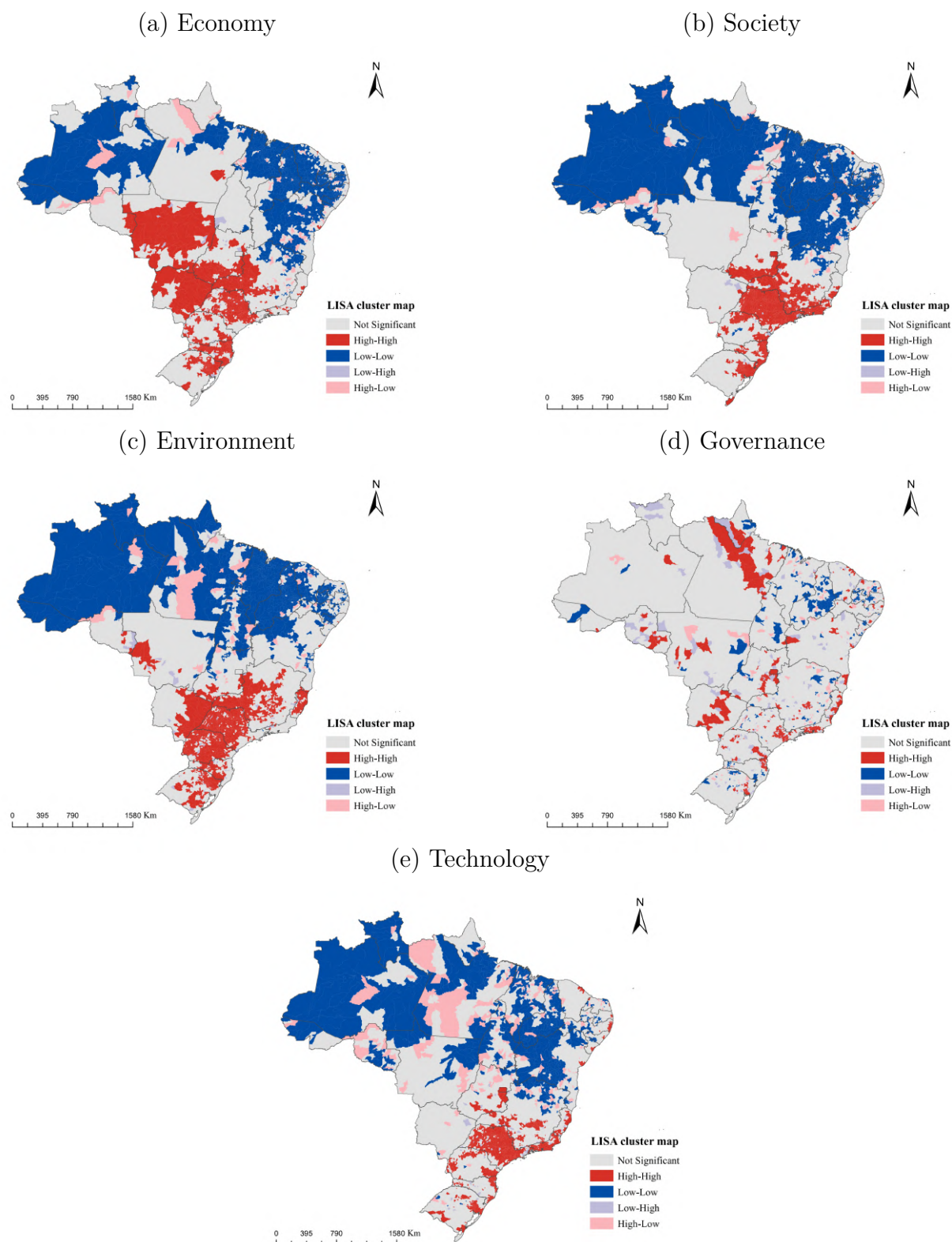
Environment and Technology show positive spatial autocorrelation of intermediate magnitude. This result suggests that environmental infrastructure, sanitation, mobility, connectivity and digital infrastructure also display spatial organisation, although with lower intensity than that observed for Society and Economy. Governance, in turn, presents the lowest Moran's I coefficients, indicating lower relative spatial dependence. This difference is consistent with the nature of this dimension, which is more closely associated with institutional instruments, interaction channels and administrative mechanisms that may vary more discontinuously across neighbouring municipalities.

The results also indicate a gradual decline in the coefficients as the distance thresholds used to define the spatial weights matrix are expanded, as in the case of matrices based on 100 km, 200 km and 300 km radii. This pattern suggests that spatial dependence among the smart city indicators tends to weaken as the geographical distance between municipalities increases, a result consistent with the principle of spatial interaction underlying Tobler's (1970) first law of geography.

The global analysis, however, does not make it possible to identify where spatial clusters occur. To this end, Figure 4.6 presents the LISA cluster maps for the five dimensions of urban smartness. These maps classify municipalities into four main types of local spatial association: high-high clusters, low-low clusters, and spatial outliers of the high-low and low-high types. High-high clusters indicate municipalities with high values surrounded by neighbours that also present high values, while low-low clusters correspond to municipalities with low values surrounded by neighbours that are likewise low. The high-low and low-high categories indicate municipalities that differ from their immediate surroundings.

Overall, the maps for each dimension reveal a territorial structure consistent with the results of global Moran's I. Economy, Society and Technology present high-high clusters concentrated mainly in the South and Southeast regions, especially in areas with greater economic, population and infrastructural density. Conversely, low-low clusters appear more frequently in the North and Northeast regions, indicating the presence of groups of municipalities with lower relative levels in these dimensions.

Figure 4.6 - LISA cluster maps of the Smart City dimension indices across Brazilian municipalities



Source: Author's own elaboration.

Note: The maps report local Moran's I cluster classifications. High-High indicates municipalities with high values surrounded by municipalities with high values; Low-Low indicates municipalities with low values surrounded by municipalities with low values; High-Low and Low-High indicate spatial outliers. Non-significant local associations are shown in grey. The maps were estimated using a queen-contiguity spatial weights matrix and produced using ArcGIS 10.5.

The Environment dimension presents a similar spatial pattern in part of the territory, but with a more heterogeneous distribution. High-high clusters appear in areas of the South, Southeast and Central-West regions, while low-low clusters are concentrated in parts of the North and Northeast. This result suggests that indicators associated with environmental infrastructure, mobility, energy and waste management are not distributed solely along the traditional economic axis, although they still display marked territorial differentiation.

Governance presents a more dispersed configuration, with less extensive clusters and a greater presence of non-significant areas. This pattern is consistent with the lower values of global Moran's I observed for this dimension. The presence of institutional instruments, service channels, government-citizen interaction mechanisms and municipal transparency appears to vary less continuously across space than the other dimensions, indicating greater heterogeneity among neighbouring municipalities.

Figure 4.7 presents the LISA cluster map for the composite smart city index. Since the aggregate indicator synthesises the five estimated dimensions, the map makes it possible to observe whether the spatial structure identified in the dimensions also appears in the general measure of urban smartness.

The spatial pattern of the composite index reveals the formation of extensive high-high clusters in the South and Southeast regions, as well as in specific areas of the Central-West. By contrast, low-low clusters appear more frequently in the North and in parts of the Northeast. This result suggests that urban smartness, when observed as a multidimensional phenomenon, is not randomly distributed across Brazilian municipalities. Rather, it displays a territorial configuration marked by regional clusters of similar performance.

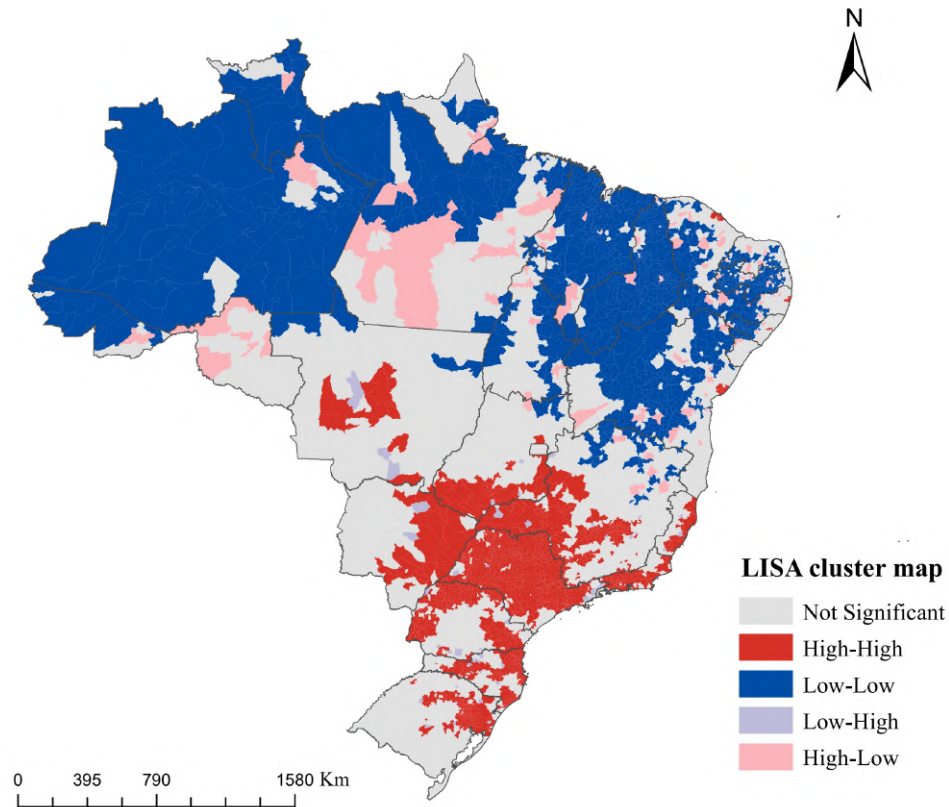
Taken together, Figures 4.6 and 4.7 reinforce the interpretation that the attributes associated with urban smartness are related to broader territorial structures. The high-high clusters identify areas in which neighbouring municipalities tend to display comparatively high values in the dimensions considered, while the low-low clusters identify areas characterised by spatial concentrations of lower relative scores. This result is consistent with interpretations in the regional development literature,¹³ according to which more dynamic territorial trajectories may generate cumulative processes, while less developed areas may remain associated with persistent patterns of lower relative performance.

The high-low and low-high categories appear to a lesser extent, but they also provide substantive information. They indicate municipalities that differ from their surroundings, potentially representing local centralities, points of regional transition, or localities with higher or lower performance than the pattern observed in neighbouring municipalities. This reading is particularly relevant for an urban-regional analysis, as it suggests that urban

¹³ See Perroux (1982).

smartness may be expressed both in continuous clusters and in isolated municipalities that differ from their immediate areas of influence.

Figure 4.7 - LISA cluster map of the Smart City Composite Index across Brazilian municipalities



Source: Author's own elaboration.

Note: The map reports local Moran's I cluster classifications. High-High indicates municipalities with high values surrounded by municipalities with high values; Low-Low indicates municipalities with low values surrounded by municipalities with low values; High-Low and Low-High indicate spatial outliers. Non-significant local associations are shown in grey. The map was estimated using a queen contiguity spatial weights matrix and produced by the author using ArcGIS 10.5.

The relationship between urban smartness and population dynamics also warrants descriptive examination. Hao, Chen and Min (2021) discuss its possible association with factor mobility, while Chen et al. (2023) examine residential retention in smart cities. In the present application, however, the available measure is total municipal population growth between 2022 and 2025, which does not distinguish natural increase from net migration.

The composite Smart City Index is positively correlated with this growth rate ($\rho = 0.13; p < 0.01$), although the association is weak. Table 4.9 complements this within-municipality comparison with the global bivariate Moran's I, relating municipal index values to population growth in neighbouring municipalities under alternative contiguity-based spatial weights.

Table 4.9 - Global bivariate Moran's I between the Smart City Index and municipal population growth

Spatial weight matrix	Bivariate Moran's I
Queen contiguity	-0.013**
Rook contiguity	-0.012**
Queen contiguity (2nd order)	-0.041***
Queen contiguity (3rd order)	-0.060***

Source: Author's own elaboration.

Note: The table reports the global bivariate Moran's I between the Smart City Index and the municipal population growth rate (2022–2025). *** $p < 0.01$, ** $p < 0.05$. Pseudo-significance based on 9,999 random permutations.

The bivariate Moran's I coefficients are negative and small in magnitude across the four spatial specifications. Their contrast with the positive within-municipality correlation indicates that the two measures capture different geographical relationships. These results describe how index scores and population growth are distributed across municipalities and their neighbourhoods; they do not establish that higher-scoring localities attract residents from surrounding areas.

4.6 Conclusion

This chapter aimed to measure and analyse the distribution of urban smartness across Brazilian municipalities, seeking to understand how different dimensions associated with the concept of smart cities are manifested across the national territory. To this end, a composite urban smartness index was constructed from multiple indicators that capture the economic, social, environmental, institutional and technological aspects of municipalities. Constructing this indicator for the full 5,570-unit municipal-level statistical universe used in the application makes it possible to broaden the scope of analysis in relation to existing initiatives for measuring urban smartness in the country, which generally focus on more restricted subsets of localities, often composed of medium- and large-sized cities. In the Brazilian context, where municipalities play an important role in the formulation and implementation of urban policies, analysing a broader set of cities may contribute to a more comprehensive understanding of these territorial patterns.

Building on this measurement exercise, the chapter sought to move beyond a descriptive analysis of levels of urban smartness by also exploring its spatial dimension. Part of the literature on smart cities has focused predominantly on the analysis of cities' internal characteristics, such as digital infrastructure, innovation or local governance, while aspects related to the territorial distribution of these phenomena have received less attention. However, cities are embedded in interdependent urban systems, in which economic, demographic and institutional flows connect different localities and contribute

to the formation of hierarchies and spatial patterns.

The exploratory spatial analysis carried out in this chapter therefore sought to investigate whether urban smartness displays territorial distribution patterns consistent with these interdependencies. The results indicate the presence of statistically significant spatial autocorrelation, suggesting that municipalities with similar levels of urban smartness tend to be located close to one another. This pattern points to the existence of territorial clusters of municipalities with relatively high or low levels of urban smartness, which may be associated with shared regional, institutional or economic factors.

These findings suggest that the study of smart cities can also be approached from a regional perspective. Urban smartness is not expressed solely through local initiatives for technological modernisation or improvements in urban management, but may be associated with broader processes of territorial organisation, the diffusion of institutional capacities and the spatial concentration of economic and technological resources. Accordingly, spatial analysis helps situate the debate on smart cities in dialogue with approaches from regional and urban economics.

At the same time, the limitations inherent in the analyses conducted in this chapter should be acknowledged. The results presented are exploratory in nature and do not allow causal relationships to be established between urban smartness and other territorial phenomena, such as population growth, economic dynamism or the position of municipalities within the urban hierarchy. In particular, it is not possible to determine whether higher levels of urban smartness contribute to attracting population and economic activities, or whether municipalities that already occupy more central positions in urban networks tend to exhibit higher levels of urban smartness as a result of pre-existing structural characteristics.

Two additional measurement features qualify the interpretation of the composite results. First, manifest-indicator availability is not perfectly balanced across the municipal sample. The benchmark specification retains all 5,570 model-based dimensional scores using the observed information available for each unit. Re-estimation on the 5,009 units with complete information on all 25 manifest indicators produces an almost identical overall ordering, suggesting limited practical sensitivity to this source of incomplete coverage.

Second, a small number of unusually high observations in the environmental indicators affect some exact positions near the upper tail of the ranking. Sensitivity exercises that reduce their influence leave the broad distribution of the Smart City Index highly correlated with the benchmark, while some individual rank positions change more substantially. For this reason, the empirical contribution of the index is better interpreted through dimensional profiles, distributional bands and spatial patterns than as a definitive league table of municipalities.

Beyond these measurement considerations, investigating the relationships between

urban smartness and the territorial phenomena discussed above would require empirical strategies aimed at identifying causal effects. In the Brazilian case, this type of analysis faces additional challenges related to the availability and nature of public policies associated with the smart city agenda. Unlike some international contexts, the country does not have a comprehensive and homogeneous national policy specifically aimed at the development of smart cities that would allow the effects of these initiatives on urban or regional development to be assessed systematically. Existing initiatives tend to occur in a relatively dispersed manner, often associated with specific programmes, such as some actions conducted under the Ministério das Cidades (Ministry of Cities), including the Programa de Desenvolvimento Urbano (Urban Development Programme, Pró-Cidades), or with projects developed by local governments and partnerships with the private sector.

In this context, many initiatives related to urban smartness in Brazil appear to emerge from processes conducted at the municipal level. This characteristic suggests that understanding the smart development trajectories of Brazilian cities also requires analysing the institutional and planning instruments available to local governments.

Among these instruments, the Municipal Master Plan stands out as one of the main mechanisms guiding urban development policies in the country. Provided for in the Federal Constitution and regulated by the Estatuto da Cidade (City Statute), the Master Plan establishes guidelines for spatial planning, urban expansion, infrastructure provision and the management of urban space. In practice, incorporating initiatives associated with smart cities often depends on how these planning instruments are structured and updated by municipalities.

Thus, while the results of this chapter reveal the existence of territorial patterns in the distribution of urban smartness in Brazil, they also point to the importance of understanding the institutional mechanisms through which these initiatives are formulated and implemented at the local level. Accordingly, the following chapter examines the role of the Municipal Master Plan as an urban planning instrument and discusses how this instrument may be related to the incorporation of strategies and initiatives associated with smart city development in the Brazilian context.

5 MASTER PLANS AND THE INCORPORATION OF THE SMART CITY AGENDA IN BRAZILIAN MUNICIPALITIES

5.1 Introduction

This chapter examines how the smart city agenda is structured and manifested within the Brazilian institutional context, with emphasis on the role of formal urban planning instruments. In Brazil, the incorporation of this agenda takes place in an environment marked by the absence of a comprehensive national policy and by the predominance of decentralised and heterogeneous initiatives, often conducted at the municipal level and associated with different institutional arrangements (Andrade, 2023; BRASIL, 2021a). In this setting, the systematic identification of policies and strategies related to smart cities poses relevant empirical challenges, since such initiatives are neither standardised nor directly observable.

Against this background, the chapter proceeds from the premise that the Master Plan, as the main normative instrument of urban planning in Brazil, constitutes a particularly suitable locus for observing these strategies. More than a technical document, the Master Plan organises guidelines, priorities and instruments that orient the actions of municipal public authorities, reflecting, albeit indirectly, the agendas and models of urban development adopted locally (Bodnar; Priess; Bianchi, 2019; Gouvea; Ramos Junior; Ramos, 2026). In this sense, the presence of content associated with smart cities in these documents may be interpreted as an indication of the degree to which this agenda has been incorporated into the field of urban policy.

Building on this premise, an empirical strategy is developed for the textual analysis of municipal Master Plans, with the aim of systematically and comparably identifying the presence of elements associated with the different dimensions of urban smartness. Through the construction of a citation indicator, the content of these documents is used to measure the breadth and composition of themes associated with urban smartness in formal municipal planning. The indicator therefore captures documented agenda content rather than the implementation or effectiveness of smart city policies and strategies.

To this end, the chapter is organised into three complementary stages. First, it presents an overview of smart city initiatives in Brazil, highlighting their fragmentation and the absence of national coordination. It then discusses the Master Plan as an institutional instrument of urban planning and as a space for incorporating contemporary agendas. Finally, it develops the empirical strategy based on the textual analysis of the documents, culminating in the construction and analysis of citation indices, which make it possible to examine the distribution, composition and spatial patterns of these agendas across the national territory.

By articulating the institutional analysis of urban planning with an empirical

approach based on normative documents, the chapter offers a pathway for the systematic investigation of smart city policies in contexts characterised by the absence of standardisation and central coordination, contributing to an understanding of how these agendas are formulated and incorporated at the local level.

5.2 Smart city initiatives in Brazil: fragmentation and the absence of national coordination

This section examines smart city initiatives in Brazil, with the aim of characterising their evolution, structure and forms of implementation across the national territory. To this end, the analysis is organised along two complementary lines. The first presents a historical overview of public policies associated with digitalisation and the incorporation of technologies into the urban context, highlighting their main milestones and limitations. The second discusses the decentralised and heterogeneous nature of these initiatives, drawing on empirical examples from different municipalities and highlighting the absence of national coordination and the diversity of strategies adopted at the local level.

5.2.1 Historical overview of public initiatives in Brazil

In the context of initiatives associated with the smart city agenda in Brazil, one of the first experiences aimed at building connectivity infrastructure was the Projeto Redes Metropolitanas de Alta Velocidade (High-Speed Metropolitan Networks Project), implemented in 1997 (RNP, s.d.). Funded by the Ministério da Ciência, Tecnologia e Inovação (Ministry of Science, Technology and Innovation), the project enabled the implementation of an internet backbone¹ linked to the Rede Nacional de Ensino e Pesquisa (National Education and Research Network), associated with the Conselho Nacional de Desenvolvimento Científico e Tecnológico (National Council for Scientific and Technological Development). Although it contributed to the consolidation of a national connectivity network among teaching and research institutions, its effects on the broader integration of cities remained limited, and it did not constitute a structured strategy for digital urban development (BRASIL, 2021a).

The initial experience revealed important limitations, especially regarding the territorial reach of urban connectivity and its articulation with broader social demands. As a result, subsequent initiatives began to emphasise the expansion of internet access and the response to digital exclusion, with particular focus on schools (BRASIL, 2021a). In this context, in 2008, the Federal Government determined, through Decree No. 6,424 (BRASIL, 2008a), that fixed-line telephony concessionaires should implement backhaul

¹ An internet backbone refers to the main high-capacity network responsible for transporting large volumes of data between different regions and smaller networks, forming the core infrastructure of the internet.

networks² with the aim of expanding internet access in 3,439 municipalities. In the same year, the Programa Banda Larga nas Escolas (Broadband in Schools Programme) was launched, establishing the requirement of free internet connection for all urban schools by 2010 (ANATEL, 2025).

This movement was deepened in 2010 with the launch of the Programa Nacional de Banda Larga (National Broadband Programme) through Decree No. 7,175, whose aim was to expand internet access in regions with low coverage, reduce costs for users and strengthen the country's telecommunications infrastructure (BRASIL, 2010a). In the same year, the Programa Um Computador por Aluno (One Computer per Student Programme) was established to promote digital inclusion in the public education system (BRASIL, 2010b). Although these initiatives expanded the available digital infrastructure, their orientation remained predominantly centred on the provision of connectivity, with weaker articulation with urban applications or with the effective use of these technologies in the everyday life of cities (BRASIL, 2021a). Taken together, these policies maintained a focus on infrastructure expansion, with limited integration into urban planning.

A partial shift in this trajectory can be observed with the launch of the Cidades Digitais programme (Digital Cities Programme) in 2012, under the Ministry of Communications. Unlike previous initiatives, the programme incorporated, albeit to a limited extent, the dimension of municipal public management by promoting administrative modernisation through the implementation of fibre-optic networks, e-government systems, training for civil servants and the provision of public internet access (BRASIL, 2021a). In this sense, it constituted one of the first federal initiatives with a more direct focus on incorporating digital technologies into urban management. Its territorial coverage, however, remained limited. In 2023, the programme covered 198 municipalities, unevenly distributed across regions, with greater concentration in the Northeast and Southeast (BRASIL, 2023).

From the mid-2010s onwards, there was a more explicit incorporation of elements associated with the international sustainable development agenda. In 2015, the adoption of the 2030 Agenda introduced a more integrated framework for public policy formulation, with particular emphasis on Sustainable Development Goal 11, which seeks to make cities and human settlements more inclusive, safe, resilient and sustainable (UNITED NATIONS, 2015).

This agenda influenced initiatives in Brazil, such as the formulation of the *Carta Brasileira para Cidades Inteligentes* (Brazilian Charter for Smart Cities) (BRASIL, 2021), and is connected to federal programmes directed towards urban infrastructure, such as Avançar Cidades, launched in 2017 (BRASIL, 2025a), and Pró-Cidades, established in 2018 (BRASIL, 2025b). However, these initiatives retained a predominantly sectoral and financial character, without establishing an integrated urban policy framework oriented

² Backhaul refers to the segments that connect access networks to the backbone.

towards urban smartness.

Also in 2018, the Sistema Nacional para a Transformação Digital (National System for Digital Transformation) and the Política Nacional de Telecomunicações (National Telecommunications Policy) were established, reinforcing the centrality of connectivity and digitalisation as vectors of development (BRASIL, 2018a, 2018b). In 2019, the Plano Nacional de Internet das Coisas (National Internet of Things Plan), established by Decree No. 9,854/2019, extended this movement by including urban applications among its strategic axes (BRASIL, 2019). Even so, these initiatives remained weakly articulated with urban planning instruments.

The chronological analysis of these policies therefore reveals a pattern characterised by sectoral segmentation, overlapping instruments and the absence of institutional coordination. Although the country has a consolidated legal framework in areas such as housing³, land regularisation⁴, environmental sanitation⁵, urban mobility⁶ and environmental risk management⁷, its articulation with the smart city agenda remains indirect and diffuse (Andrade, 2023).

Against this background, the absence of national coordination contributed to municipalities developing their own initiatives in a decentralised and heterogeneous manner (BRASIL, 2021a). Some of these cases are discussed, without any claim to exhaustiveness, in the following section.

5.2.2 The decentralised and heterogeneous nature of the initiatives

Smart city initiatives in Brazil are predominantly decentralised, being formulated by municipalities, research institutions and private actors (BRASIL, 2021a). This pattern reflects the absence of a coordinated national strategy, resulting in heterogeneous experiences in terms of scope and institutionalisation (Andrade, 2023).

Against this background, projects are found across cities of different population sizes, although the more structured experiences are generally concentrated in large urban centres. Among these, municipalities such as São Paulo and Curitiba stand out as relevant examples of this pattern.

São Paulo is one of the most consolidated examples of the smart city agenda in the country. In 2025, the municipality was recognised as the first Brazilian state capital to obtain the maximum score in the international certification as a Smart, Sustainable and Resilient City, granted by the Associação Brasileira de Normas Técnicas (Brazilian

³ Federal Law No. 11,124/2005.

⁴ Federal Law No. 13,465/2017.

⁵ Federal Law No. 12,305/2010.

⁶ Federal Law No. 12,587/2012.

⁷ Federal Law No. 12,608/2012.

Association of Technical Standards, ABNT), based on the ISO 37122 standard (SÃO PAULO, 2025).

The São Paulo experience involves an articulated set of initiatives distributed across different dimensions of urban smartness, including mobility, urban management, health and the environment. In the field of mobility and public safety, real-time monitoring and information systems stand out (e.g., Olho Vivo, Trânsito Agora and Smart Sampa), while, in the area of public services, there has been the digitalisation of processes and the expansion of access to health services through digital platforms (e.g., Agenda Fácil and Remédio na Hora). In addition, the municipality has developed initiatives aimed at fostering the creative economy, the knowledge economy and digital inclusion (e.g., Prêmio Mulheres Tech em Sampa, Fab Lab Livre SP, Telecentro Livre SP and Escola Metaverso SP), indicating a broad approach to the concept of the smart city.

At the institutional level, São Paulo has also made progress in incorporating guidelines associated with sustainable development and the climate agenda into its planning instruments. The approval of Law No. 16,817/2018, which internalises the 2030 Agenda as a guideline for municipal public policies, and the establishment of the Climate Action Plan (*PlanClima SP*) in 2021 illustrate this movement. In addition, the municipality's Strategic Master Plan, revised by Law No. 16,050/2014, was recognised by UN-Habitat (2016b) as an example of good practice in inclusive urban planning and participatory governance.

The city of Curitiba, named the world's smartest city in 2023 in an award granted by Fira Barcelona, Spain, at the World Smart City Awards (Marques, 2024), stands out for the articulation between technological innovation, urban planning and environmental sustainability. The Curitiba experience brings together actions distributed across multiple dimensions of urban smartness, including mobility, digital governance, economic development and sustainability (CURITIBA, s.d.). In the field of mobility, the municipality has incorporated solutions aimed at electromobility and the multimodal integration of transport. In the sphere of public management and urban services, the broad digitalisation of municipal services stands out, with platforms such as e-Cidadão and integrated applications that provide access to administrative services (e.g., Curitiba App), tax services (e.g., Nota Curitibana) and health services (e.g., Saúde Já), alongside the use of urban monitoring systems, such as Muralha Digital.

In addition, the municipality promotes policies aimed at developing the innovation ecosystem and digital inclusion, articulating training, entrepreneurship and the use of technologies, notably through Vale do Pinhão. In the environmental field, Curitiba incorporates solutions associated with the energy transition and urban sustainability, such as the Pirâmide Solar, as well as waste management and food security programmes (CURITIBA, s.d.). In 2022, the Curitiba Municipal Government established, through Decree No. 405, the Curitiba Destino Turístico Inteligente programme (Curitiba Smart

Tourist Destination), with the aim of turning the city into a global reference for smart tourist destinations by 2030 (CURITIBA, 2022).

Among smaller municipalities, initiatives in the cities of São Gonçalo do Abaeté, in Minas Gerais, and Pindamonhangaba, in the state of São Paulo, stand out. The municipality of São Gonçalo do Abaeté, with a population of 7,375 according to the latest IBGE Demographic Census (2023a), won the second edition of the Smart City Expo Curitiba Brazilian Awards in the Smart City category. The international award, which recognises initiatives that make urban spaces better places to live, was granted to the municipality for its São Gonçalo Mais Feliz programme. Launched in 2022, this is the first Brazilian programme to apply Felicidade Interna Bruta (Gross National Happiness, FIB) to municipal management, with the aim of linking the municipality's development to the well-being of its population (Ulhoa, 2025).

The São Gonçalo Mais Feliz programme comprises 13 projects related to the nine FIB dimensions: education, health, psychological well-being, culture, time use, environment, community vitality, standard of living and governance. In an interview with the portal of the Serviço Brasileiro de Apoio às Micro e Pequenas Empresas (Brazilian Micro and Small Business Support Service, Sebrae), the mayor stated that the award confirms that it is possible to innovate in public management even in small municipalities (Ulhoa, 2025).

Pindamonhangaba, which recorded 165,428 inhabitants in the latest Census, was the second Brazilian city – and the first medium-sized city – to obtain ISO 37120, 37122 and 37123 certification, qualifying as a Smart, Sustainable and Resilient City. In 2020, the municipal executive launched the Programa Cidade Inteligente (Smart City Programme), aimed at implementing technological solutions in areas such as connectivity, security, mobility and the digitalisation of public services (PINDAMONHANGABA, 2020).

The initiatives include the expansion of public Wi-Fi, video-monitoring systems with facial recognition and number-plate reading, smart traffic lights and digital service platforms. Also noteworthy are the development of a municipal data lake for data analysis, the deployment of sensors, the creation of the Pindamonhangaba App, which integrates citizen services, and the use of solutions such as the MyPetTrack platform and vehicles equipped with artificial intelligence for urban monitoring (Sydow, 2023). This programme reinforces the predominantly administrative, rather than normative, character of the initiative, indicating the limited formal institutionalisation of these strategies at the local level. In 2023, the Municipal Government even proposed a document for the implementation of a *Plano Diretor de Tecnologia da Informação para Cidades Inteligentes* (Information Technology Master Plan for Smart Cities) (PINDAMONHANGABA, 2023), but the project was not converted into a formal legal instrument.

In contrast to these experiences, some municipalities have advanced in the insti-

tutional formalisation of their strategies through legal instruments and structured plans. In this regard, the cases of Juazeiro do Norte, in Ceará, and Campinas, in the state of São Paulo, stand out. In 2018, Juazeiro do Norte approved, through Complementary Law No. 117, the *Plano Diretor de Tecnologias da Cidade Inteligente* (Master Plan for Smart City Technologies), covering initiatives related to digital entrepreneurship, smart public lighting, public Wi-Fi and video monitoring (BRASIL, 2021a).

The municipality of Campinas, in turn, developed its *Plano Estratégico de Cidades Inteligentes* (Strategic Smart Cities Plan, PECCI) 2019–2029 (CAMPINAS, 2019), whose objective is to transform the city into a smart, human and sustainable city. To this end, it proposes a set of strategic guidelines based on the integration of information and communication technologies, the strengthening of governance and the promotion of sustainable development. The plan starts from a detailed diagnosis of the existing technological infrastructure and services and establishes an integrated technology architecture aimed at system interoperability, data use and coordination across different sectors of public administration, indicating a higher degree of institutionalisation and strategic planning when compared with other local initiatives.

Beyond municipal initiatives, the smart city agenda in Brazil involves multiple institutional actors, such as oversight bodies, public universities and civil society organisations. Challenges persist in innovation procurement, related to low institutional integration, the absence of a results-oriented culture and the difficulty of defining public problems. At the same time, these actors contribute to the development and diffusion of methodologies, indicators and good practices, revealing that this agenda is structured in a distributed manner (BRASIL, 2021a).

Taken together, these elements reinforce that the diffusion of smart city initiatives in the country occurs in a decentralised and heterogeneous manner, with institutional arrangements still being consolidated. In this context, the diversity and lack of standardisation of municipal actions have motivated institutional efforts aimed at defining common guidelines and building shared reference frameworks for incorporating digital technologies into urban development, such as the formulation of the *Carta Brasileira para Cidades Inteligentes* (Brazilian Charter for Smart Cities) (BRASIL, 2021) and the bill for the *Política Nacional de Cidades Inteligentes* (National Smart Cities Policy) (BRASIL, 2021b), presented in Chapter 3.

Andrade (2023) observes that, although these initiatives do not have normative force, they indicate the insertion of the smart city discourse into the Brazilian institutional landscape. Against this background, the incorporation of these agendas tends to materialise, albeit indirectly, through formal urban planning instruments, especially the Master Plan, the main legal instrument for territorial ordering and urban development in Brazilian municipalities (Bodnar; Priess; Bianchi, 2019).

Tang et al. (2019) investigate how local governments in 60 cities around the world have formulated their smart city plans and use Master Plans as an analytical instrument to identify different profiles of adopted initiatives. The authors justify this choice on the grounds that these plans constitute the formal management instruments most directly related to the urban problems that smart city initiatives seek to address. They also recognise that, although plans must respond to local specificities and budgetary constraints and are therefore heterogeneous, a certain degree of convergence can be observed in the initiatives incorporated, owing to the influence of institutional actors and higher-level guidelines.

Accordingly, the following section examines the Master Plan in the Brazilian context, discussing its role as an institutional instrument of urban planning and as a basis for incorporating and analysing smart city initiatives at the municipal level.

5.3 The Master Plan as an institutional instrument of urban planning in Brazil

Understanding how the smart city agenda materialises in the Brazilian context requires an analysis of the institutional instruments that structure urban planning at the municipal level. Accordingly, this section examines the Master Plan as the main instrument of territorial ordering in Brazil, highlighting its role in organising urban policies and incorporating contemporary urban development agendas. The analysis is organised around three dimensions: the legal foundations of urban planning, the normative character of the Master Plan, and its role in incorporating contemporary urban agendas, including those associated with smart cities.

5.3.1 Legal foundations of urban planning

The Brazilian Federal Constitution of 1988 marked a departure from previous constitutions by explicitly incorporating urban policy into its text, granting it its own constitutional status (Andrade, 2023). This institutional change consolidated an agenda built over the preceding decades, especially within the urban reform movement, by linking the development of cities to the realisation of social rights⁸ and to the promotion of collective well-being (Saule; Uzzo, 2011).

Under Article 182, urban development policy, carried out by the municipal public authorities, aims to guide the full development of the social functions of the city and guarantee the well-being of its inhabitants (BRASIL, 1988). This provision simultaneously establishes the normative content of urban policy and the centrality of the municipality as the entity responsible for its implementation.

⁸ In Article 6, the Federal Constitution defines social rights as education, health, housing, food, work, transport, leisure, security, protection of motherhood and childhood, social security, and assistance to those in need (BRASIL, 1988).

Still at the constitutional level, Article 182 defines the Master Plan as the basic instrument of urban development and expansion policy. It must be approved by the Municipal Council and assumes a structuring role in the organisation of the territory (BRASIL, 1988). At the same time, the Constitution assigns to it the function of defining compliance with the social function of urban property, granting it a normative and regulatory character over land use and occupation (Levy; Nalini, 2018).

These provisions were regulated through the enactment of Federal Law No. 10,257/2001, the *Estatuto da Cidade* (City Statute), here cited as Brasil (2008b). The Statute establishes the general guidelines of urban policy and organises a set of instruments aimed at territorial ordering, the promotion of the social function of property and the guarantee of the right to the city. It constitutes a legal framework that gives concrete form to the constitutional provisions and structures urban planning as a public function.

Beyond its regulatory function, the Statute sets out principles that guide urban policy in the country. As highlighted by Andrade (2023), Article 2 of the City Statute establishes guidelines such as guaranteeing the right to sustainable cities, promoting democratic management through social participation, fostering cooperation between different spheres of government and social actors, and planning urban development so as to avoid distortions in growth and their socio-environmental impacts. These guidelines indicate that Brazilian urban planning is conceived in an integrated manner, incorporating social, economic, environmental and institutional dimensions.

Within this arrangement, the Master Plan occupies a central position. Defined as the basic instrument of urban policy, it guides the actions of public authorities and private actors, while also incorporating the requirement of social participation in its preparation and revision (Bodnar; Priess; Bianchi, 2019). Urban planning is thereby institutionalised as a normative and political process, articulating interests, scales and objectives within the municipal territory.

5.3.2 The Master Plan as a normative instrument of urban planning

Within the institutional arrangement established by the 1988 Federal Constitution and regulated by the City Statute, the Master Plan assumes a central role in steering urban policy and organising the municipal territory. Beyond its technical dimension, the Master Plan constitutes a normative device that articulates planning, land-use regulation and the coordination of public action, establishing guidelines for urban development (Bodnar; Priess; Bianchi, 2019).

The City Statute defines the Master Plan as the basic instrument of urban development and expansion policy, while also detailing its functions, scope, and mechanisms for preparation and implementation. As set out in Article 40:

Art. 40. The Master Plan, approved by municipal law, is the basic

instrument of urban development and expansion policy.

§ 1 The Master Plan is an integral part of the municipal planning process, and the multi-year plan, budgetary guidelines and annual budget must incorporate the guidelines and priorities contained therein.

§ 2 The Master Plan shall encompass the territory of the Municipality as a whole.

§ 3 The law establishing the Master Plan shall be revised at least every ten years.

§ 4 In the process of preparing the Master Plan and monitoring its implementation, the municipal Legislative and Executive branches shall guarantee:

I – the promotion of public hearings and debates with the participation of the population and of associations representing the various segments of the community;

II – public access to the documents and information produced;

III – access by any interested party to the documents and information produced (BRASIL, 2008b, p. 27, author's translation).

These provisions make clear that the Master Plan should be understood as part of a broader system of public planning, articulated with the budgetary cycle, covering the municipal territory as a whole and subject to periodic revision mechanisms. Moreover, the requirement of social participation and institutional transparency reinforces its political character, beyond its technical dimension.

The requirement to prepare a Master Plan is also defined in legal terms. In the 2008 edition consulted, Article 41 provides:

Art. 41. The Master Plan is mandatory for cities:

I – with more than twenty thousand inhabitants;

II – that are part of metropolitan regions and urban agglomerations;

III – where the municipal public authority intends to use the instruments provided for in § 4 of Art. 182 of the Federal Constitution;⁹

IV – that are part of areas of special tourist interest;

V – located within the area of influence of projects or activities with significant environmental impact at the regional or national level (BRASIL, 2008b, p. 27, author's translation).

Federal Law No. 12,608/2012 subsequently added item VI to Article 41, extending the requirement to municipalities included in the national register of municipalities with areas susceptible to major landslides, flash floods or related geological or hydrological processes (BRASIL, 2012, Article 25). The obligation thus encompasses population size, metropolitan integration, land-use instruments, tourism, environmental impacts and

⁹ Paragraph 4 of Article 182 of the 1988 Federal Constitution establishes that the municipal public authority may require the proper use of unbuilt, underused or unused urban land through instruments such as compulsory subdivision or building, time-progressive urban property and land tax, and expropriation with payment in public debt bonds (BRASIL, 1988).

disaster risk. Municipal population alone is therefore insufficient to determine whether preparation of a Master Plan is mandatory.

In addition, the City Statute establishes minimum content that must be included in the Master Plan, ensuring its capacity to operate as an instrument of territorial ordering. As set out in Article 42:

Art. 42. The Master Plan shall include, at a minimum:
I – the delimitation of the urban areas where compulsory subdivision, building or use may be applied, taking into account the existence of infrastructure and demand for use, pursuant to Article 5 of this Law (BRASIL, 2008b, p. 27, author's translation).

The definition of this minimum content does not, however, imply the existence of a standardised model of the Master Plan. The regulations governing the preparation of these instruments recognise the need for adaptation to local specificities. In this regard, Resolution No. 34/2005 of the Conselho das Cidades (Council of Cities), subsequently amended by Resolution No. 164/2014, establishes guidance on the content of Master Plans, while also allowing for the incorporation of additional themes considered relevant to each municipality (BRASIL, 2023). In Article 10, the resolution explicitly states that, beyond the required minimum content, the Master Plan may address other themes related to local characteristics, challenges and priorities.

Consequently, although there is a common set of guidelines orienting the preparation of these documents, the way in which different urban agendas are incorporated tends to vary across municipalities. This institutional flexibility contributes to the heterogeneous incorporation of themes associated with sustainability, governance, mobility, innovation or digital transformation into urban planning instruments, reflecting different interpretations and local development strategies.

Taken together, these provisions show that the Master Plan constitutes the main instrument for the institutionalisation of urban planning in Brazil, combining normative, operational and participatory dimensions. This legal-institutional structure is particularly relevant to the analysis developed in this study, insofar as it conditions both the formulation and the implementation of urban policies in municipalities, directly influencing the way in which different agendas, including those associated with the notion of smart cities, are incorporated into local planning.

5.3.3 The Master Plan as a space for incorporating contemporary urban agendas

The institutionalisation of the Master Plan as a central instrument of urban policy creates the conditions for it to function not only as a mechanism for territorial regulation, but also as a space for incorporating contemporary urban agendas. Among these agendas,

those related to sustainability, urban governance and the integration of technologies into the planning and management of cities stand out.

Recent literature has emphasised that urban planning, when structured strategically and participatively, makes it possible to articulate different dimensions of urban development, encompassing economic, social, environmental and institutional aspects. In this context, the Master Plan can operate as an instrument through which these dimensions converge, by defining guidelines that orient both spatial organisation and the implementation of public policies (Bodnar; Priess; Bianchi, 2019).

This capacity becomes particularly relevant in view of the growing complexity of contemporary cities, where problems associated with mobility, housing, the provision of urban services and environmental sustainability tend to manifest themselves interdependently, requiring responses that go beyond sectoral approaches. By structuring urban planning in an integrated manner, the Master Plan makes it possible to address these interdependencies more consistently.

In the specific case of smart cities, this function takes on additional contours. The incorporation of digital technologies into urban management is not limited to the introduction of technical solutions, but involves institutional choices, the definition of priorities and coordination among different actors (Andrade, 2023). In this sense, the Master Plan can function as the instrument through which these initiatives are aligned with the broader guidelines of urban development, ensuring the social functions of the city.

Recent studies indicate that the Master Plan can play a relevant role in articulating technological innovation and the realisation of urban rights, by guiding the implementation of policies related to mobility, housing and environmental quality on a more integrated basis (Gouvea; Ramos Junior; Ramos, 2026). By incorporating these dimensions into planning, the instrument helps ensure that the adoption of technologies is associated with broader objectives of urban development.

Thus, the Master Plan can be understood as an institutional space in which contemporary agendas are translated into guidelines, norms and concrete instruments. This characteristic reinforces its importance not only as a mechanism of territorial ordering, but also as an element for coordinating ongoing urban transformations, including those associated with the diffusion of smart city strategies.

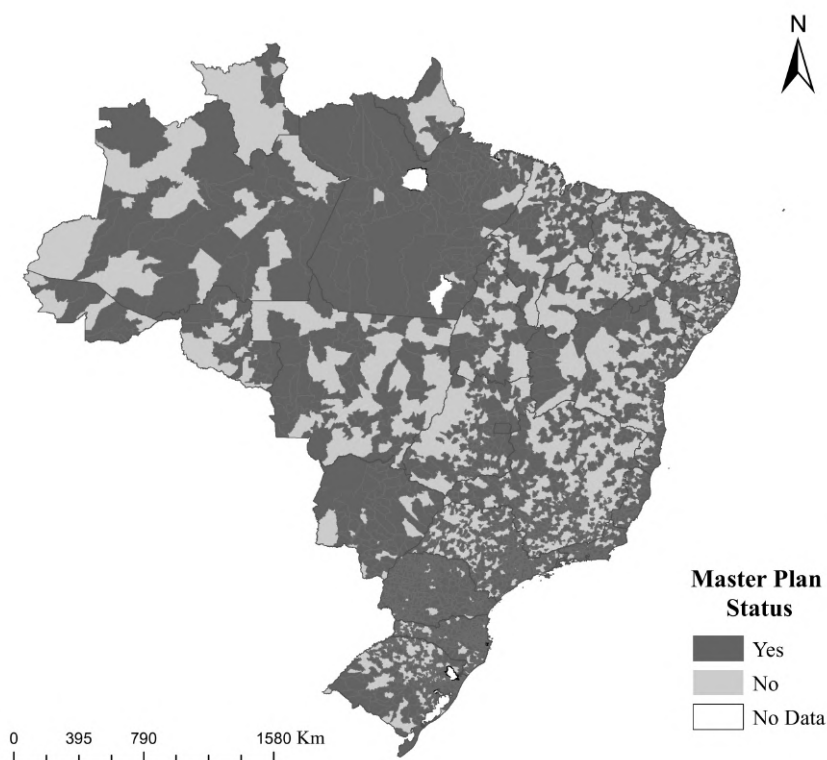
5.4 Master Plans in Brazil: distribution and characteristics of municipalities

This section examines the presence of Master Plans in Brazilian municipalities using information from the 2021 edition of the Pesquisa de Informações Básicas Municipais (Survey of Basic Municipal Information, MUNIC), conducted by IBGE (2022b), considering

the situation reported by municipal governments for the year 2020.¹⁰ In this context, 2,919 municipalities reported having a Master Plan, while 2,643 reported not having one and 8 provided no information. Thus, just over half of Brazilian municipalities indicated that they had this instrument at the end of the period analysed.

The spatial distribution of these municipalities is presented in Figure 5.1. The map shows that the presence of Master Plans is not distributed homogeneously across the national territory. A higher relative incidence can be observed in parts of the South and Southeast regions, as well as in specific areas of the Centre-West and along the coast, whereas extensive areas of the North and the interior of the Northeast concentrate a higher proportion of municipalities without this instrument. Although the spatial pattern is not uniform, the visualisation suggests that the diffusion of the Master Plan in Brazil follows, to some extent, patterns already observed in the organisation of the urban network and in local institutional capacities.

Figure 5.1 - Distribution of municipalities by Master Plan status in Brazil (2020)



Source: Author's own elaboration based on IBGE (2022b).

Note: The map was produced using ArcGIS 10.5. "No data" refers to municipalities with missing information in the MUNIC 2021 survey.

¹⁰ The Pesquisa de Informações Básicas Municipais (Survey of Basic Municipal Information, MUNIC) is a nationwide survey conducted by IBGE that collects information on the institutional structure, public management and planning instruments of municipal administrations. The data are obtained through questionnaires administered to municipal governments. Although the survey is conducted annually, its thematic modules vary across editions (IBGE, s.d.).

The temporal evolution of reported adoption and revision is presented in Table 5.1. Although the aggregate block between 1958 and 2009 includes 1,827 municipalities that reported having established a Master Plan, this period encompasses quite distinct dynamics. Records before the 2000s were relatively sparse, whereas the diffusion of the instrument intensified from the mid-2000s onwards, with particular emphasis on the peak observed in 2006. Between 2010 and 2020, annual adoptions remained sizeable, but did not repeat the intensity of that earlier moment. By contrast, revisions gained increasing weight over the decade, surpassing the number of new plans from 2017 onwards. This movement suggests that, in the more recent period, the pattern of Master Plans became marked less by the initial expansion of the instrument and more by the revision of already existing plans.

Table 5.1 - Annual number of municipalities adopting and revising Master Plans in Brazil

Year	Plans Adopted	Plans Revised
1958–2009	1827	9
2010	135	14
2011	134	21
2012	131	26
2013	86	32
2014	87	31
2015	63	55
2016	110	78
2017	80	84
2018	99	114
2019	86	153
2020	81	148

Source: Author's own elaboration based on IBGE (2022b).

The association between the Master Plan and population size can be observed in Table 5.2. Among municipalities with up to 20,000 inhabitants, just over one third report having a Master Plan, with percentages ranging between approximately 34% and 37% across the three population groups considered. The most pronounced change occurs in the 20,001 to 50,000 inhabitants group, in which 82.95% of municipalities report having the instrument. In the higher classes, its presence becomes almost generalised, reaching 97.46% among municipalities with 50,001 to 100,000 inhabitants, 98.19% among those with 100,001 to 500,000 inhabitants, and 100% among municipalities with more than 500,000 inhabitants. These results indicate that the diffusion of the Master Plan in Brazil is strongly associated with population scale, with a clear discontinuity between municipalities below and above the threshold of 20,000 inhabitants.

Table 5.2 - Reported Master Plan status by municipal population size

Population Size (inhabitants)	Reported having a Master Plan		No affirmative report		Total
	Number	%	Number	%	Number
Up to 5,000	421	33.68	829	66.32	1250
5,001 to 10,000	416	34.64	785	65.36	1201
10,001 to 20,000	487	36.92	832	63.08	1319
20,001 to 50,000	929	82.95	191	17.05	1120
50,001 to 100,000	345	97.46	9	2.54	354
100,001 to 500,000	272	98.19	5	1.81	277
More than 500,000	49	100.00	0	0.00	49
Total	2919		2651		5570

Source: Author's own elaboration based on data from IBGE (2022b).

Note: "No affirmative report" includes municipalities reporting that they did not have a Master Plan and the eight municipalities for which no information was reported in MUNIC 2021.

Table 5.3 complements this overview by comparing the average characteristics of municipalities with and without a Master Plan. On average, municipalities that have this instrument display higher GDP per capita, around BRL 32,700, compared with BRL 21,700 among those without one. The difference is also reflected in population size: municipalities with a Master Plan have, on average, approximately 63,800 inhabitants, whereas the others have just over 10,000. The medians reinforce this contrast. Taken together, these results suggest that the presence of a Master Plan is associated with relatively more populous municipalities and greater economic dynamism.

Table 5.3 - Descriptive statistics by Master Plan status in Brazilian municipalities

	Statistic	GDP per capita (BRL)	Population
With Master Plan	Mean	32682.66	63779
	Median	25771.12	22643
	Min	4920.64	1171
	Max	590594.90	12400000
Without Master Plan	Mean	21735.70	10067
	Median	14301.73	7653
	Min	5379.08	771
	Max	288666.20	469173

Source: Author's own elaboration based on IBGE (2022b) and IBGE (2021).

Note: GDP per capita is measured in current Brazilian reais (BRL). Values are reported at the municipal level.

Table 5.4 focuses on municipalities with fewer than 20,000 inhabitants that reported having a Master Plan and disaggregates this group according to whether they belong to

metropolitan areas, urban agglomerations, or neither of these territorial classifications. Thus, in each panel, the “Yes” and “No” columns refer to belonging to the corresponding territorial category, not to the existence of the Master Plan itself. Among small municipalities with a Master Plan, the share located in metropolitan areas ranges between 33% and 37% across the three population groups considered. The share located in urban agglomerations, by contrast, is residual, ranging from 0.72% to 2.14%. Conversely, most small municipalities with a Master Plan belong neither to metropolitan areas nor to urban agglomerations, with percentages above 60% in all three population groups considered.

Table 5.4 - Territorial classification of small municipalities with Master Plans in Brazil

Panel A. Metropolitan Area

Population Size	Yes (Number)	Yes (%)	No (Number)	No (%)	Total
Up to 5,000	140	33.25	281	66.75	421
5,001–10,000	155	37.26	261	62.74	416
10,001–20,000	163	33.47	324	66.53	487
Total	458		866		1324

Panel B. Urban Agglomeration

Population Size	Yes (Number)	Yes (%)	No (Number)	No (%)	Total
Up to 5,000	9	2.14	412	97.86	421
5,001–10,000	3	0.72	413	99.28	416
10,001–20,000	8	1.64	479	98.36	487
Total	20		1304		1324

Panel C. Neither Metropolitan Area nor Urban Agglomeration

Population Size	Yes (Number)	Yes (%)	No (Number)	No (%)	Total
Up to 5,000	272	64.61	149	35.39	421
5,001–10,000	258	62.02	158	37.98	416
10,001–20,000	316	64.89	171	35.11	487
Total	846		478		1324

Source: Author’s own elaboration based on data from IBGE (2022b).

Note: The table includes only municipalities with fewer than 20,000 inhabitants that reported having a Master Plan. In each panel, “Yes” and “No” indicate whether municipalities belong to the corresponding territorial category. Percentages refer to the share of municipalities within each population group. Territorial classifications follow IBGE criteria. Information on municipalities classified as areas of special tourist interest is not available in the data.

This pattern indicates that, among small municipalities that have adopted a Master Plan, the instrument is not concentrated only in municipalities inserted into denser urban spaces. Its presence in municipalities outside metropolitan areas and urban agglomerations suggests that adoption may also reflect specific local institutional trajectories and

planning decisions. Some of these cases may also reflect adoption trajectories prior to the consolidation of the legal framework inaugurated by the City Statute, possibly associated with specific local initiatives.¹¹ Table A.5.2 in the Appendix presents examples of these municipalities.

Taken together, the results indicate that the presence of Master Plans in Brazilian municipalities is associated with well-defined demographic, economic and territorial patterns, as well as distinct dynamics over time. These patterns, however, do not translate into strict regularities, since the adoption of the instrument also reflects specific institutional trajectories and decisions taken at the local level. In this sense, although average trends can be identified, the presence of a Master Plan cannot be understood solely on the basis of the structural characteristics of municipalities.

Even so, the mere existence of the legal instrument does not make it possible to infer the content of the planning strategies adopted, nor the degree to which elements associated with urban smartness have been incorporated. Accordingly, analysing Master Plans on the basis of their content becomes a necessary step for understanding how these agendas materialise at the local level. The following section moves in this direction, exploring planning documents with the aim of systematically identifying the presence of elements related to the concept of smart cities.

5.5 Empirical strategy: identifying smart city elements through the analysis of Master Plans

Building on the recognition of the Master Plan as the main institutional instrument of urban planning in Brazil, this section presents the empirical strategy adopted to identify elements associated with the smart city agenda in these documents. The approach is based on the textual analysis of municipal Master Plans, encompassing the definition of the sample, the construction of the documentary corpus, the processing of the files and the development of a dictionary of terms. Finally, it describes the procedure used to construct the citation indicator, which is employed to measure the presence of these dimensions in urban planning instruments.

5.5.1 Methodological rationale: limitations of traditional approaches

The growing availability of textual data from institutional documents, planning instruments and administrative records has expanded the analytical possibilities of urban

¹¹ Before the enactment of the City Statute (Law No. 10,257/2001), the mandatory requirement for a Master Plan was mainly associated with the population criterion (municipalities with more than 20,000 inhabitants). Other situations in which the instrument became mandatory – items II to V of Article 41 – were subsequently incorporated by the Statute. In this context, small municipalities that implemented the instrument during this period did so, to a large extent, voluntarily.

planning research. In this context, text mining has become established as a set of techniques capable of extracting relevant patterns and information from unstructured data, making it possible to advance the understanding of complex urban phenomena (Ahmadian; Tousi, 2025; Feldman; Sanger, 2006).

In the field of urban planning, such techniques have been employed across different empirical fronts. Recent studies use textual data to analyse mobility patterns (e.g., Fontes et al., 2023), investigate mechanisms of social participation (e.g., Fu et al., 2024) and assess the formulation and implementation of public policies (e.g., Qin et al., 2022). Despite this diversity of applications, the operationalisation of textual analysis in this field has relied predominantly on three approaches: content analysis, term-frequency-based methods and automated text-modelling techniques.

Content analysis is one of the most widely used strategies in the urban planning literature. Traditionally, this approach was conceived as a systematic procedure for classifying and quantifying textual units, based on the premise that the frequency with which words or themes occur reflects their importance within the document (Berelson, 1952; Krippendorff, 2019). In its quantitative strand, content analysis seeks to reduce complex texts to predefined categories, allowing measurable indicators to be constructed from the counting of terms or concepts (Esmaeili; Sheydayi; Jamalabadi, 2025).

However, word counts do not have a context-independent substantive interpretation. Loughran and McDonald (2011) show that dictionaries developed outside the domain under study can misclassify terms in financial documents. Applied to municipal plans, this concern means that recurring expressions and differences in drafting should not automatically be read as differences in planning priorities.

In response to these limitations, qualitative content analysis has gained greater prominence in urban research, especially through the incorporation of interpretative approaches. From this perspective, the focus shifts from the counting of terms to the identification of latent meanings, discursive patterns and thematic structures (Hsieh; Shannon, 2005). As highlighted by Esmaeili, Sheydayi and Jamalabadi (2025), qualitative analysis allows textual content to be interpreted in greater depth, capturing dimensions that are not observable through purely quantitative metrics.

Despite its analytical advantages, the qualitative approach presents relevant limitations in terms of scalability and replicability, especially in studies involving large volumes of documents. Its reliance on manual coding and greater sensitivity to researcher judgement make it difficult to apply this strategy to extensive datasets, such as those composed of hundreds or thousands of planning documents (Esmaeili; Sheydayi; Jamalabadi, 2025).

Thus, the choice of textual analysis strategy involves a trade-off between interpretative capacity, scalability and semantic precision. Qualitative approaches tend to offer greater analytical depth, whereas quantitative methods favour the comparability

and replicability of results. Automated techniques, in turn, expand large-scale processing capacity, although they often face limitations in the contextual interpretation of terms. In this setting, dictionary-based approaches emerge as an intermediate alternative, as they make it possible to construct structured analytical categories that remain anchored in the specific vocabulary of the empirical domain (Ma; Ho, 2025).

In light of these considerations, the literature indicates that the definition of an appropriate methodological strategy should take into account not only the characteristics of the available methods, but also the specific features of the documents analysed and of the concepts to be measured. This is the context in which the strategy adopted in this research is situated: it seeks to combine elements of these approaches in order to capture, systematically and consistently, the presence of dimensions associated with the concept of smart cities in urban planning documents.

5.5.2 Master Plans as a documentary source for the formal incorporation of the smart city agenda

The participatory Master Plan occupies a central position in the institutional arrangement of Brazilian urban planning. In addition to constituting the main legal instrument of territorial ordering at the municipal level, it organises guidelines, priorities and rules that guide the actions of public authorities and regulate the occupation of urban land (Bodnar; Priess; Bianchi, 2019). In this capacity, it functions as a normative and political instrument through which collective choices concerning the development of the city are translated (Gouvea; Ramos Junior; Ramos, 2026).

This characteristic is particularly relevant to the analysis of the smart city agenda. As discussed in the previous chapters, more recent literature has moved away from strictly technocentric definitions and has come to understand urban smartness in multidimensional terms, incorporating themes such as governance, sustainability, mobility, quality of life, inclusion and participation. In a broad survey of international scholarship on smart cities, Lim, Cho and Kim (2021) identify a Smart City Policies dimension, in which citizen governance and planning and development appear as distinct topics, indicating that the debate on smart cities involves not only technological infrastructure and digital services, but also institutional arrangements and urban planning strategies.

From this perspective, the incorporation of the smart city agenda at the municipal level tends to occur, albeit unevenly, through formal planning instruments. This heterogeneity is consistent with the regulatory framework governing Master Plans, which establishes mandatory minimum content but allows additional themes to be incorporated according to the specificities and priorities of each municipality.

This is even more plausible in the Brazilian case, where the Master Plan articulates urban development, social participation, land-use regulation and the definition of sectoral

policies. Along these lines, Bodnar, Priess and Bianchi (2019) associate the Master Plan with the construction of smart and sustainable urban environments, while Gouvea, Ramos Junior and Ramos (2026) argue that the instrument can play a central role in implementing initiatives that harmonise economic development, social equity, environmental preservation and technological integration. Although these studies do not propose a textual measurement strategy such as the one adopted in this study, they reinforce the substantive plausibility of treating the Master Plan as the institutional locus in which contemporary urban agendas are inscribed.

From an empirical standpoint, this choice is also supported by the literature on textual analysis applied to planning. A review by Ahmadian and Tousi (2025) shows that data mining and text mining techniques have been used in urban studies based on different textual sources, explicitly including planning documents, with the aim of producing evidence on policies, interventions and urban problems. In broader methodological terms, Macanovic (2022) observes that dictionary-based approaches are especially useful when the objective is to identify and quantify the presence of concepts of interest in large documentary corpora.

Thus, although the literature remains scarce in its use of Brazilian Master Plans to measure the incorporation of the smart city agenda, the procedure adopted here is situated within two already established movements: the use of institutional documents as a source for textual analysis, and the recognition that urban smartness is also expressed through policies, planning and governance.

Within this framework, the Master Plan is used to observe the formal incorporation of themes associated with the multidimensional smart city agenda. The citation index measures the breadth of this documentary presence, rather than the amount of expenditure, the quality of implementation or the intensity of services delivered. This is a narrower object than an implemented smart city strategy. Its value lies in making the content of a comparable municipal planning instrument observable across a large documentary corpus, without assuming that textual inclusion necessarily changes economic behaviour.

The use of text as data is compatible with economic research, but the economic meaning of the resulting measure must be defined separately from the procedure used to extract it (Gentzkow; Kelly; Taddy, 2019). Here, a detected expression provides evidence of thematic presence in a legal document. Whether it constitutes an operational commitment, receives funding or affects firms and households remains a separate empirical question. The index should consequently be read as a measure of documented agenda content, not as a direct measure of the policy mechanisms discussed in Chapter 2.

On this premise rests the empirical strategy developed in the following sections, which focus on defining the sample, constructing the documentary corpus and establishing the dictionary of terms used to capture, in the texts of the Master Plans, the presence of

content associated with the smart city agenda.

5.5.3 Temporal delimitation, sample selection and composition of the Master Plan database

Once the Master Plan has been established as a documentary source for observing the formal incorporation of themes associated with the smart city agenda, the next step consists of delimiting the empirical basis of the research, involving the definition of the time frame, the criteria for selecting municipalities and the composition of the documentary corpus of Master Plans.

The time frame adopted covers the period from 2010 to 2020. The choice of this window is associated, first, with § 3 of Article 40 of the City Statute (BRASIL, 2008b), according to which the law establishing the Master Plan must be revised at least every ten years. The adoption of a ten-year interval makes it possible to observe a set of relatively recent and legally comparable documents, produced under the same normative horizon for revision. In addition, this time frame favours the analysis of plans that, in principle, express guidelines that are either in force or have been recently reformulated within the Brazilian institutional context.

The year 2020 was defined as the upper limit of the analysis window because it represents the last full year prior to the 2021 edition of the Pesquisa de Informações Básicas Municipais (Survey of Basic Municipal Information, MUNIC), used as the reference source for the initial selection of municipalities. This choice makes it possible to work with a closed and comparable documentary window, avoiding the incorporation of cases in which the reported revision might not yet have been fully reflected in the public availability of the documents in institutional repositories at the time of the survey. In this way, the adopted time frame reduces problems of lag between the declaratory record in the IBGE survey and the effective availability of Master Plans for collection and processing.

The initial selection of municipalities was based on the 2021 edition of MUNIC, conducted by IBGE (2022b). As a first filter, municipalities that reported having established and/or revised their Master Plans between 2010 and 2020 were considered. This procedure resulted in an initial universe of 1,591 municipalities.

From this initial universe, an individual search for the documents was carried out in the institutional repositories of municipal governments and Municipal Councils, with the aim of locating files in Portable Document Format (PDF) corresponding to the Master Plans in force or revised during the period considered. This stage required a manual survey, municipality by municipality, given the absence of a centralised and standardised national database of documents of this nature.

The procedure revealed some important discrepancies between the information reported in MUNIC and the documentary evidence actually found. Examples of these

inconsistencies, as well as their typology, are presented in Section A.5.1 of the Appendix. During the verification process, 1,235 municipalities from the initial sample were identified as having Master Plans established and/or revised between 2010 and 2020 and effectively located in digital format. By contrast, 356 initially selected municipalities could not be confirmed within the period considered, either because the documents found indicated a revision outside the established interval or because it was not possible to locate documentary evidence compatible with the information reported. In some cases, no indication of the existence of a Master Plan was found in the repositories consulted, even though § 4 of Article 40 of the City Statute provides for the public disclosure of, and access to, the documents produced (BRASIL, 2008b).

Despite these inconsistencies, MUNIC was used as the initial filtering stage for the sample, given the high operational cost associated with exhaustive documentary verification for all 5,570 Brazilian municipalities. In aggregate terms, the declaratory database is assumed to constitute a reasonable approximation of the universe of municipalities with Master Plans in the period considered, although it is subject to specific inaccuracies, especially regarding the date of revision of the instruments. Given the institutional framework established by the City Statute, it is plausible to assume that municipalities subject to the legal requirement have incentives to report the existence and revision of the Master Plan, so that possible inconsistencies tend to be concentrated more in the date or nature of the instrument reported than in its complete absence.

Table 5.5 presents the distribution of municipalities included in the final sample and those excluded during the documentary verification process, considering breakdowns by population class and by the country's major regions. The excluded municipalities are relatively more concentrated in smaller population groups, especially those with up to 20,000 inhabitants, which account for more than 60% of excluded cases. In regional terms, there is a higher relative incidence of exclusions in the North and Northeast regions, while the final sample has a larger share of municipalities located in the South and Southeast. These patterns may partly reflect differences in institutional capacity to produce, update and make urban planning documents available, as well as in the degree of digitisation of municipal public archives.

Table A.5.3 in the Appendix presents, in detail, the 17 municipalities with populations above 100,000 inhabitants that were excluded from the sample, together with the characterisation of the inconsistencies identified between the information reported in the 2021 MUNIC survey and the documentary evidence available in institutional repositories. Presenting these cases makes it possible to clarify the exclusion criteria adopted and reinforces the transparency of the verification process, showing that the inconsistencies observed are not restricted to small municipalities, but occur across different types of municipalities, albeit under potentially distinct institutional contexts.

Table 5.5 - Distribution of municipalities included and excluded from the sample, by population size and region

Population size	Excluded municipalities		Sample municipalities	
	Number	%	Number	%
Up to 20,000 inhabitants	224	62.92	606	49.03
20,000 to 100,000	115	32.30	448	36.25
100,000 to 500,000	14	3.93	151	12.22
More than 500,000	3	0.84	31	2.51
Total	356	100	1236	100
Region	Excluded municipalities		Sample municipalities	
	Number	%	Number	%
North	55	15.45	88	7.12
Northeast	128	35.96	154	12.46
Centre-West	37	10.39	110	8.90
Southeast	55	15.45	356	28.80
South	81	22.75	528	42.72
Total	356	100	1236	100

Source: Author's own elaboration based on IBGE (2022b) and institutional repositories.

Note: Percentages are calculated within each group (excluded and sample municipalities). Population classes follow IBGE (2022b) classification criteria.

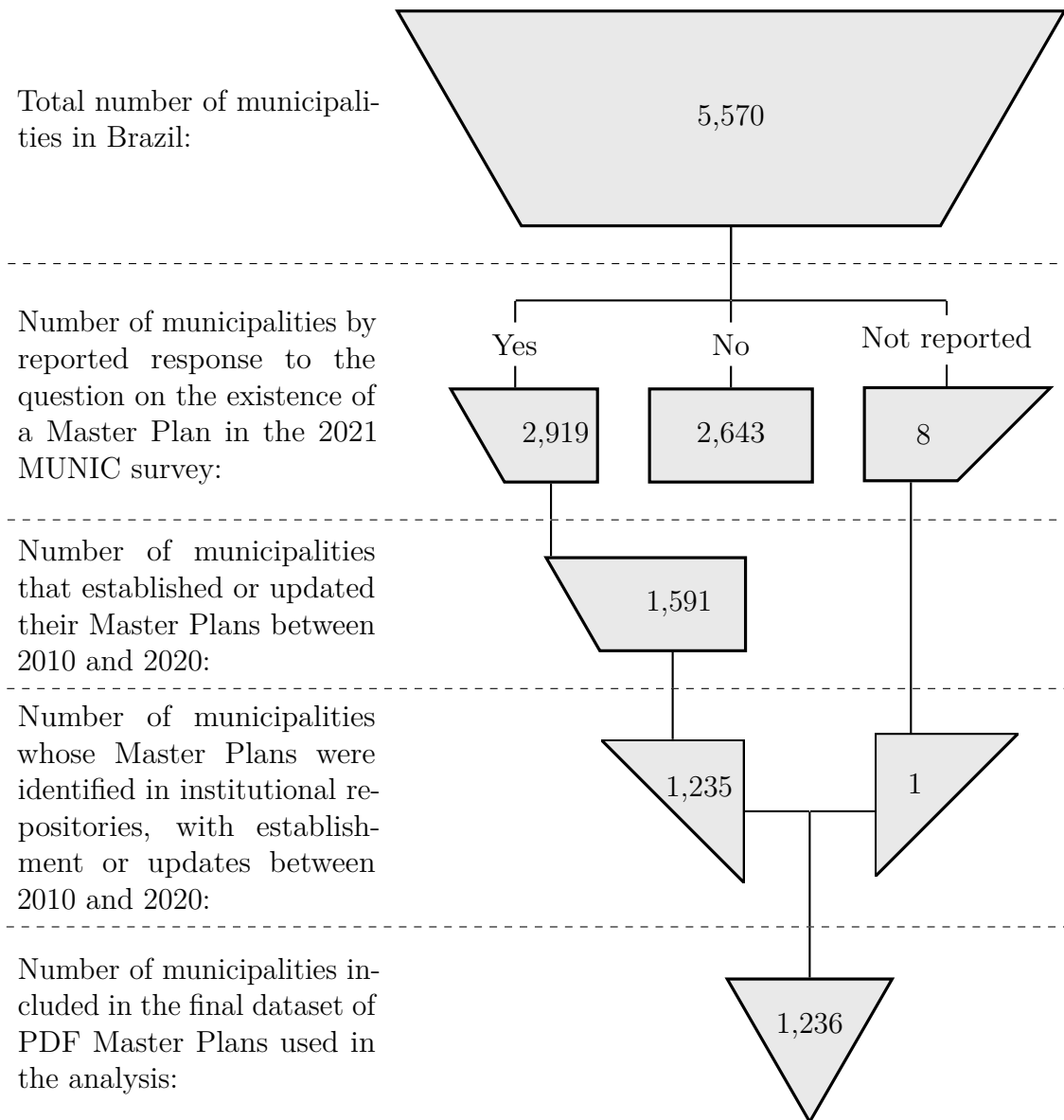
In addition, a check was carried out for the eight municipalities that had not reported the existence of a Master Plan in the 2021 MUNIC survey,¹² identifying that the municipality of São Francisco de Paula, in Rio Grande do Sul, had a Master Plan revised in 2019. As a result, the final documentary corpus comprised 1,236 Master Plans in PDF format.

Unlike the nationwide coverage of Chapter 4, the documentary corpus includes only Master Plans identified and retrieved under the selection procedures described above and therefore does not constitute a census of municipal planning activity. Municipalities without a compatible document are not assigned a zero citation score, since missing documentary evidence cannot be interpreted as absence of the agenda; the uneven pattern of exclusions across population groups and regions also limits generalisation beyond the observed corpus. Chapter 6 applies additional temporal and eligibility criteria, further narrowing the set of institutional events analysed.

The complete procedure for sample selection, document identification and composition of the final database is summarised in Figure 5.2.

¹² These are: Cumaru do Norte (PA), Porto de Moz (PA), Vigia (PA), Catende (PE), Maraial (PE), São José (SC), Guaíba (RS) and São Francisco de Paula (RS).

Figure 5.2 – Sample selection and construction of the Master Plan database

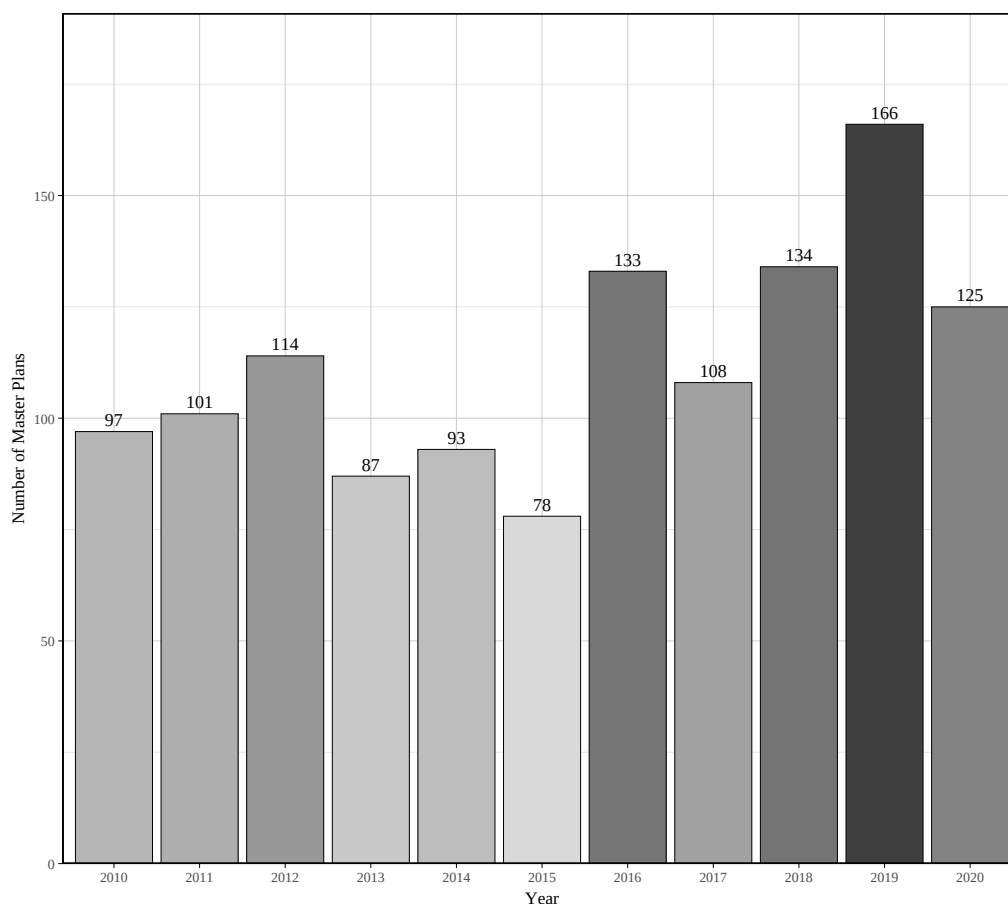


Source: Author's own elaboration.

Notes: The figure illustrates the sequential process of sample selection, document retrieval and validation based on MUNIC-2021 (IBGE, 2022b) and institutional repositories of Brazilian municipalities.

From the final documentary corpus, it is possible to examine the temporal distribution of the Master Plans considered in the analysis, taking as reference the year of the most recent law that establishes or revises the instrument. Figure 5.3 presents this distribution for the period from 2010 to 2020, showing the number of Master Plans by year of most recent revision in the sample. Records are observed for all years in the window considered, ensuring temporal coverage throughout the period analysed and reducing the risk of excessive concentration of the sample in specific years.

Figure 5.3 - Distribution of master plans by year of the most recent law (2010–2020)



Source: Author's own elaboration based on institutional repositories of Brazilian municipalities.

Note: The figure reports the number of master plans in the final sample ($N = 1,236$) by the year of the most recent law adopting or revising the instrument. The temporal distribution reflects the availability of documents collected from municipal institutional repositories and may differ from declaratory information reported in MUNIC-2021 (IBGE, 2022b).

Once the empirical basis had been delimited, the next stage consisted of obtaining, organising and technically processing the documents, a process that required additional procedures for standardisation and text extraction due to the considerable heterogeneity of the files collected.

5.5.4 Obtaining, processing and standardising the documents

The stage of obtaining and processing the documents constituted one of the most challenging phases in the construction of the empirical database, owing to the lack of standardisation in the Master Plans made available by Brazilian municipalities. Unlike structured and centralised databases, the documents were obtained from multiple institutional sources, including municipal government websites, Municipal Council websites and legal repositories, resulting in considerable heterogeneity in the format, quality and structure of the files.

Although aggregating platforms, such as the Leis Municipais portal (2026), contributed to obtaining a relevant share of the documents, especially for larger municipalities with greater availability of digital documentation, a significant proportion of the Master Plans was collected directly from local institutional repositories. In these cases, the files often presented important limitations, such as low digitisation quality, the absence of a recognisable textual structure and non-standardised formatting.

This heterogeneity is reflected both in the visual presentation of the documents and in the way their contents are organised. In some cases, Master Plans are made available as structured texts, with good legibility and clear segmentation into chapters and sections. In others, the files correspond to scans of physical documents, often with low resolution, visual noise and no textual metadata. Illustrative examples of this variation are presented in Figure A.5.1 of the Appendix, which brings together the opening pages of selected Master Plans, showing differences in formatting, digitisation quality and textual structure across documents.

From an operational standpoint, this diversity imposes relevant challenges for the automated extraction of textual content. Conventional methods for reading PDF files, based on libraries such as PyMuPDF and pypdf, proved effective only for documents with a native digital structure. For a portion of the files, however, these methods were unable to retrieve the textual content, requiring the adoption of optical character recognition (OCR) techniques.

Different text extraction strategies were tested, including standard OCR routines and more intensive configurations aimed at recovering text from low-quality documents. Even so, in some specific cases, none of these approaches was able to produce satisfactory results. In these cases, it was necessary to adopt a complementary manual conversion procedure, in which the documents were processed using OCR tools on mobile devices and then reconstructed as editable digital text. After this stage, the files were reincorporated into the automated processing workflow.

This set of procedures shows that the construction of the documentary corpus was not limited to collecting the files, but involved a systematic process of document processing, standardisation and validation, with the aim of ensuring the greatest possible recovery of textual content. This care was essential to ensure the consistency of the subsequent stage of term identification and the construction of keyword-based indicators. The technical procedures associated with this stage are detailed in Section A.5.2 of the Appendix.

5.5.5 Definition of the dictionary of terms and structure of the indicator

Once the documentary corpus had been established and the challenges associated with text extraction and standardisation had been addressed, the next stage consisted of defining a set of keywords aimed at identifying elements associated with the concept

of smart cities in municipal Master Plans. This stage plays an important role in the empirical strategy adopted, insofar as it guides the construction of the citation indicator and conditions the interpretation of the results obtained.

The definition of the set of keywords was based, first, on the conceptual structure developed in Chapter 4, especially Table 4.3, which organises the dimensions of the smart city concept on the basis of the specialised literature. This structure, drawing on contributions such as Fachinelli et al. (2022) and Yigitcanlar et al. (2020), was used as a reference for delimiting the analytical categories, making it possible to establish a correspondence between the theoretical elements of the concept and their potential manifestation in urban planning documents.

The delimitation of these categories is also supported by recent syntheses of the smart cities literature. As highlighted by Tura and Ojanen (2022), the recurring components associated with the concept encompass technological, economic, human, institutional and environmental dimensions, as well as their interface with the provision of urban services and physical infrastructure. This perspective reinforces the multidimensional nature of the phenomenon and suggests that the empirical identification of elements of urban smartness in planning documents requires the simultaneous consideration of these different domains.

Based on this approach, the organisation of the keywords adopted in this study seeks to reflect these broad dimensions by grouping terms into categories that correspond to thematic axes consolidated in the literature, rather than treating each expression in isolation. This procedure makes it possible to maintain theoretical coherence in the construction of the indicator, while preserving the flexibility needed to capture the diversity of terminologies used in the Master Plans.

On this basis, a dictionary of terms was constructed to identify, in the texts of the Master Plans, the presence of content associated with the different dimensions of urban smartness. The development of this dictionary combined two complementary procedures, in order to reduce arbitrariness in the selection of terms and ensure greater transparency and methodological consistency.

First, the literature underpinning each dimension of the indicator was considered in order to identify recurrent terms associated with themes such as economic development (Caragliu; Del Bo, 2020; Ulya et al., 2024; Vanli; Akan, 2023; Zygiaris, 2013), social inclusion (Caragliu; Del Bo; Nijkamp, 2011; Makkonen; Inkinen, 2024; Qian et al., 2024; UN-HABITAT, 2022), environmental sustainability (De Jong et al., 2015; Toli; Murtagh, 2020; Yigitcanlar et al., 2019), governance (Gil-Garcia; Pardo; Nam, 2015; Kaiser, 2024; Paskaleva, 2009; Rodríguez-Bolívar, 2015) and technology (Konhäuser, 2021; Lazaroiu; Roscia, 2012; Singh, 2023; Xie et al., 2019).

This stage contributed to the identification of expressions frequently associated with the smart city agenda, such as the Portuguese terms “*economia sustentável*” (sustainable

economy), “economia verde” (green economy), “economia criativa” (creative economy), “inclusão social” (social inclusion), “área verde” (green area), “mobilidade urbana” (urban mobility), “participação popular” (popular participation), “big data”, “conectividade” (connectivity), “inclusão digital” (digital inclusion) and “inovação” (innovation), among others.

Second, an exploratory reading was conducted of a randomly selected sample of Master Plans, with the aim of identifying linguistic patterns, terminological variations and specific forms of expression used in the documents. A random subset of 90 Master Plans was selected using Cochran’s (1991) formula with finite population correction, taking a 95% confidence level and a 10% margin of error as operational parameters for defining the size of the exploratory sample. These parameters concern the sampling procedure and should not be interpreted as evidence that the sample exhausts the semantic diversity of the documentary corpus or validates the accuracy of the dictionary. Table A.5.4 in the Appendix presents the selected municipalities and their respective legislation.

In addition to the random sample, the Master Plans available for the period from 2010 to 2020 for the 20 municipalities best ranked in the smart city ranking presented in Chapter 4 were also examined, together with the Plano Diretor de Tecnologias da Cidade Inteligente (Master Plan for Smart City Technologies) of Juazeiro do Norte (CE) and the Plano Estratégico Campinas Cidade Inteligente (Campinas Smart City Strategic Plan) of Campinas (SP).¹³ These additional documents were selected purposively to expose the dictionary-building process to plans more likely to contain explicit or specialised smart city vocabulary. They were therefore used to refine the dictionary and should not be interpreted as an independent validation sample. The selected municipalities are listed in Table A.5.5 of the Appendix.

The reading of these documents focused mainly on the opening sections, where the principles, guidelines and objectives of municipal planning are presented, since these parts tend to condense central elements of the urban strategies adopted. Given the lack of standardisation in the drafting of Brazilian Master Plans, this stage helped identify linguistic patterns, terminological variations and different forms of expression of concepts associated with the smart cities literature. For example, terms such as “economia sustentável” (sustainable economy) and “economia verde” (green economy), which are recurrent in the literature, are often expressed in the documents through variations such as “crescimento sustentável” (sustainable growth), “desenvolvimento sustentável” (sustainable development) and “produção sustentável” (sustainable production), among others.

¹³ Alongside Vitória’s Plano Diretor de Tecnologia de Cidades Inteligentes (Smart Cities Technology Master Plan), the initiatives of Juazeiro do Norte (CE) and Campinas (SP) constitute some of the few examples of urban planning instruments explicitly focused on the smart city agenda in Brazil. The Vitória document is not available in institutional repositories. Despite a formal request to the public administration, access to the file was not obtained.

This exploratory procedure justifies the decision to work with compound terms rather than isolated words. The use of isolated words could introduce relevant ambiguities into the classification of content. Terms such as “mobilidade” (mobility) and “desenvolvimento” (development), for example, have multiple meanings in the context of the documents, and may refer both to aspects of urban mobility and to issues related to technological infrastructure or data mobility. In this sense, the adoption of compound expressions, such as “mobilidade urbana” (urban mobility), “desenvolvimento econômico” (economic development) and “tecnologia da informação” (information technology), contributes to greater semantic precision in the identification of the content of interest.

The exploratory reading supported the construction of the dictionary and the identification of expressions used in municipal planning. It should not be interpreted as an independent validation of classification accuracy. Compound expressions reduce some ambiguities but do not eliminate differences in context, negation, aspiration or legal force. These limitations matter because a broad documentary vocabulary may overlap with conventional planning language even where no explicit smart city programme is present.

Based on these criteria, the keywords were organised into groups and subgroups, following the logic of the dimensions of the composite smart city indicator presented in Chapter 4. Each dimension was subdivided into thematic categories, bringing together semantically related terms or variations of the same concept, including singular and plural forms. This structure seeks to balance thematic breadth and semantic precision in the classification of content.

In addition, an implicit weighting strategy based on the presence of terms in the documents was adopted. For each subgroup, a binary variable was assigned, taking the value of one if the Master Plan contained at least one of the terms associated with that category, and zero otherwise. This procedure avoids overweighting documents that repeat certain terms excessively, keeping the focus on identifying thematic presence rather than the intensity of repetition. Binary subgroup coding limits the influence of repeated expressions, but it does not make detection independent of document length. Longer documents may offer more opportunities for at least one expression from a subgroup to appear, even when repetition itself does not increase the score.

Finally, based on Crippa et al. (2023), an additional category named Urban Brands was incorporated into the dictionary, designed to capture explicit references to labels or urban positioning strategies associated with the smart city agenda, such as “cidade inteligente” (smart city), “cidade sustentável” (sustainable city) and “cidade criativa” (creative city) (see De Jong et al., 2015; Janik; Ryszko, 2018; Yigitcanlar et al., 2018; Vanli; Akan, 2023). This inclusion makes it possible to identify not only substantive planning content, but also the discursive adoption of elements associated with the theme under analysis.

The final sets of keywords, organised by dimensions, categories and subgroups, are presented in Tables 5.6 to 5.11. In these tables, the use of the asterisk (“*”) indicates the inclusion of morphological variations of the terms, including singular and plural forms. Complementarily, the element “(a)” indicates the consideration of gender variations. Thus, for example, the expression “empreendedor(a)*” covers the forms “empreendedor”, “empreendedores”, “empreenedora” and “empreenedoras”.

The keywords are kept in Portuguese because the search was performed on the original municipal Master Plans, which are written in Portuguese. To facilitate interpretation by non-Portuguese-speaking readers, English translations of the search expressions are provided in Table A.5.6 of the Appendix.

Table 5.6 - Keyword groups and subgroups for the “Sustainable Economy, Productivity, and Entrepreneurship” dimension

Group	Keywords by Group (Portuguese)	Subgroup
Sustainable Economy	crescimento sustentável	SE1
	desenvolvimento sustentável	
	economia sustentável	
	economia verde	
	ecopolo*	
	economicamente sustentável	
	produção sustentável	
	sustentabilidade econômica	
	sustentabilidade urbana	
	indústria* não poluente*	SE2
	indústria* sustentável*	
	sustentabilidade da* atividade*	SE3
	turismo sustentável	
	inteligência da economia	SE4
Productivity	arranjo* produtivo* local*	P1
	associativismo	
	economia solidária	
	economia colaborativa	
	cooperativa* de produção	
	parque* tecnológico*	P2
	polo* tecnológico*	
	cidade industrial	
	condomínio* industrial*	

Table 5.6 - Continued

Group	Keywords by Group (Portuguese)	Subgroup
Productivity	distrito* industrial*	P4
	parque* industrial*	
	polo* de atividade*	
	polo* de crescimento*	
	polo* de desenvolvimento*	
	polo* de emprego*	
	polo* de indústria*	
	polo* estratégico* de desenvolvimento	
	zona* industrial*	
	diversificação da* atividade* industrial*	
	diversificação da base produtiva	P5
	diversificação da economia	
	diversificação da matriz econômica	
	diversificação da produção	
	diversificação econômica	
	modernização da estrutura produtiva	P6
	atividade* produtiva*	
	atividade* competitiva*	
	cadeia* produtiva*	
	setor* produtivo*	P7
	economia* criativa*	
	capacitação técnica	
	geração de emprego*	
	oportunidade* de trabalho	
	qualificação da mão-de-obra	
	trabalho e renda	
Entrepreneurship	instalação de empresa*	E1
	atração de empresa*	
	incubadora* de empresa*	
	nova* empresa*	
	novo* negócio*	
	startup*	
	empreendedor(a)*	E2
	empreendedorismo*	

Table 5.6 - Continued

Group	Keywords by Group (Portuguese)	Subgroup
	empreendimento*	E3
	microempreendedor*	
	atração de investimento* privado*	
	oportunidade* de negócio*	
	fortalecimento da* empresa*	
	parceria* público-privada*	

Source: Author's own elaboration.

Note: The asterisk (*) indicates that the keyword was considered in both singular and plural forms. In expressions containing more than one marked term, all applicable morphological combinations were considered.

Table 5.7 - Keyword groups and subgroups for the “Well-Being and Liveability” dimension

Group	Keywords by Group (Portuguese)	Subgroup
Well-Being	cidade mais justa	WB1
	direito à igualdade	
	direito* social*	
	equidade econômica	
	equidade social	
	igualdade de gênero	
	igualdade racial	
	justiça social	
	responsabilidade* social*	
	responsabilidade solidária	
	socialmente justa*	
	reduzir a* desigualdade*	WB2
	bem-estar	WB3
	qualidade de vida	
	convívio	WB4
	convivência comunitária	
	cultura de paz	WB5
	prevenção da violência	
	proteção social	
	cidade saudável	
	saúde	

Table 5.7 - Continued

Group	Keywords by Group (Portuguese)	Subgroup
	segurança	WB6
	segurança alimentar	
	ação* educacional*	
	cidade educadora	
	educação de excelência	
	educação profissional	
	ensino de tempo integral	
	formação educacional	
	qualidade da educação	
	qualidade de ensino	
	inclusão social	WB7
	inclusão sócio-territorial	
	inclusiva*	
Well-Being	integração* social*	WB7
	direito à moradia	WB8
	programa* habitacional*	
	redução do* déficit* habitacional*	
	reduzir o* déficit* habitacional*	
Well-Being	direito à cidade	WB9
	direito universal à cidade	
Liveability	arborização urbana	L1
	arborização viária	L2
	ecoparque*	
	ecoponto*	
	espaço* verde*	L3
	área* de lazer	
	estabelecimento de praça*	
	parque* linear*	
	parque* municipal*	
	parque* urbano*	
	recreação	
	habitabilidade	
	habitação de interesse social	
	habitação digna	

L4

Table 5.7 - Continued

Group	Keywords by Group (Portuguese)	Subgroup
	habitação social	
	habitação popular	
	moradia* adequada*	
	moradia* digna*	
	investir em infraestrutura	L5
	investimento* em infraestrutura	
	enterramento da* fiação*	L6
	iluminação pública	
	lixeira* inteligente*	L7
	iluminação inteligente	
	bueiro* inteligente*	
	hidrômetro* inteligente*	
	banheiro* público*	L8
Liveability	equipamento* comunitário*	L8
	equipamento* público*	
	equipamento* social*	
	equipamento* para terceira idade	
	requalificação de bairro*	L9
	requalificação urbana	
	requalificação de praça*	
	edifício* inteligente*	L10
	edifício* verde*	
	telhado* verde*	
	feira* de artesanato	L11
	horta* comunitária*	

Source: Author's own elaboration.

Note: The asterisk (*) indicates that the keyword was considered in both singular and plural forms. In expressions containing more than one marked term, all applicable morphological combinations were considered.

Table 5.8 - Keyword groups and subgroups for the “Environmental Sustainability, Urban Mobility, and Accessibility” dimension

Group	Keywords by Group (Portuguese)	Subgroup
	melhoria do meio ambiente	ES1

Table 5.8 - Continued

Group	Keywords by Group (Portuguese)	Subgroup
	qualificação ambiental	ES2
	preservação ambiental	
	preservação do meio ambiente	
	preservação dos mananciais	
	preservação dos recursos naturais	
	proteção ambiental	
	proteção dos recursos naturais	
	conservação ambiental	ES3
	educação ambiental	
	recuperação ambiental	ES4
	recuperação de áreas degradadas	
	resiliência	
	reflorestamento	
Environmental Sustainability	tratamento de efluentes	ES4
	reciclagem	ES5
	reciclável*	
	renovável*	
	reutilizável*	
	separação do lixo	
	separação absoluta dos resíduos	
	separação dos resíduos	
	coleta seletiva	ES6
	reuso da(e) água	
	drenagem urbana	ES7
	desenho urbano sustentável	ES8
	área* protegida*	
	biodiversidade	
	corredor* de integração ecológica	
	corredor* ecológico*	
	corredor* verde*	ES9
	ecologicamente equilibrado	
	ecossistema*	
	equilíbrio ecológico	
	área* verde*	ES10
	parede* verde*	

Table 5.8 - Continued

Group	Keywords by Group (Portuguese)	Subgroup
	eficiência energética	ES11
	energia* alternativa*	ES12
	energia* limpa*	
	energia* renovável*	
	fonte* limpa*	
	fonte* renovável*	
	eólica*	ES13
	solar*	
	ambientalmente sustentável*	ES14
	sustentabilidade ambiental	
	sustentabilidade urbano-ambiental	
	sustentável* ambientalmente	
Environmental Sustainability	sustentabilidade da cidade	ES15
	sustentabilidade urbana	
	construção* sustentável*	
	conforto climático	ES16
	redução de(as) emissão*	
	redução* de poluentes	
	reduzir* as emissões	
Urban Mobility	transporte* sustentável*	UM1
	transporte* coletivo*	UM2
	transporte* público*	
	transporte* integrado*	UM3
	ferroviário*	
	monotrilhos	
	metrô*	
	BRT*	
	trem*	
	VLP*	
	VLT*	
	mobilidade da população	UM4
	mobilidade e transporte	
	mobilidade urbana	
	plano de mobilidade	UM5
	política* de mobilidade	

Table 5.8 - Continued

Group	Keywords by Group (Portuguese)	Subgroup
	movilidade inclusiva	UM6
	transporte* solidário*	
	sistema* integrado* de mobilidade	UM7
	corredor* de ônibus	
	sistema* subterrâneo*	
	sistema* de mobilidade	
	terminal* de integração	UM8
	bicicletário*	
	ciclofaixa*	
	ciclomobilidade	
Urban Mobility	ciclopista*	UM8
	ciclorrota*	
	ciclovário(a)*	
	ciclovía*	UM9
	controle de semáforo*	
	controle de tráfego	
	semafórico(a)*	
	sinalização visual	
	controle* inteligente*	
	parada* de ônibus inteligente*	UM10
	semáforo* inteligente*	
Accessibility	acessibilidade de(para) pedestres	A1
	acessibilidade de(para) pessoas	
	acessibilidade universal	
	acessibilidade urbana	
	aterro* sanitário*	A2
	projeto* de esgotamento	
	saneamento ambiental	
	saneamento básico	

Source: Author's own elaboration.

Note: The asterisk (*) indicates that the keyword was considered in both singular and plural forms. The element "(a)" indicates that gender variations were considered. In expressions containing more than one marked term, all applicable morphological combinations were considered.

Table 5.9 - Keyword groups and subgroups for the “Governance and Planning” dimension

Group	Keywords by Group (Portuguese)	Subgroup
Governance	audiência* pública*	G1
	consulta* pública*	
	controle social	
	debate*	
	plebiscito*	
	referendo*	
	conselho da cidade	G2
	conselho* municipal*	
	conselho* regional*	
Governance	iniciativa popular	G3
	mobilização* comunitária*	
	participação da população	
	participação da sociedade	
	participação direta dos cidadãos	
	participação efetiva da sociedade	
	participativa	
	participação popular	
	participação social	
	engajados(as)	
	democracia comunitária	G4
	democracia participativa	
	descentralizada*	
	gestão democrática	
	sistema democrático e participativo	
	acesso à informação	G5
	sistema* municipal* de informações	
	transparência	
	governança	G6
Planning	gestão de processos	PL1
	gestão pública de qualidade	
	gestão inovadora	
	gestão plena compartilhada	
	planejamento e gestão	PL2
	planejamento integrado	

Table 5.9 - Continued

Group	Keywords by Group (Portuguese)	Subgroup
	planejamento municipal	PL3
	planejamento urbano	
	plano plurianual	
	plano* setorial*	
	plano* especial* de urbanização	

Source: Author's own elaboration.

Note: The asterisk (*) indicates that the keyword was considered in both singular and plural forms. The element “(as)” indicates that gender variations were considered. In expressions containing more than one marked term, all applicable morphological combinations were considered.

Table 5.10 - Keyword groups and subgroups for the “Technology, R&D, Connectivity, and Innovation” dimension

Group	Keywords by Group (Portuguese)	Subgroup
Technology	científico-tecnológico	T1
	técnico-científico(a)	
	tecnologia*	
	tecnológico(a)*	
	aplicativo*	T2
	informatização	
	processamento* digital*	
	processo* tecnológico*	
	digitalizar	
	digitalização*	
	sistema de registros online	
	informatizado(a)*	
	telemática	T3
	hardware	
	software*	
	robótica	
	inteligência artificial	
	realidade aumentada	
	telemedicina	
	bicicleta* elétrica*	T4
	carro* conectado*	

Table 5.10 - Continued

Group	Keywords by Group (Portuguese)	Subgroup
	carro* elétrico*	T5
	drone*	
	bilhetagem eletrônica	
	sensoriamento eletrônico	
	sistema* inteligente*	
R&D	centro* de pesquisa	RD1
	ciência e tecnologia	
	científico(a)*	
	banco* de dados	RD2
	big data	
	sistema* de informação*	
Connectivity	sistema integrado de informação*	C1
	conectividade	
	internet	
	inclusão digital	
Innovation	wi-fi	I1
	inovação*	
	inovador(a)*	
	inovativo(a)*	

Source: Author's own elaboration.

Note: The asterisk (*) indicates that the keyword was considered in both singular and plural forms. The element “(a)” indicates that gender variations were considered. In expressions containing more than one marked term, all applicable morphological combinations were considered.

Table 5.11 - Portuguese keywords and subgroups for “Urban Brands”

Keywords by Group (Portuguese)	Subgroup
cidade* sustentável*	UB1
município* sustentável*	
cidade* inteligente*	UB2
zona* urbana* inteligente*	
smart city*	
cidade* resiliente*	UB3
cidade* conectada*	UB4
cidade* criativa*	UB5

Table 5.11 - Continued

Keywords by Group (Portuguese)	Subgroup
cidade da ciência	UB6
cidade* tecnológica*	UB7
cidade* digital*	UB8
cidade* verde*	UB9
cidade* do futuro	UB10
metrópole* inovadora*	UB11

Source: Author's own elaboration.

Note: The asterisk (*) indicates that the keyword was considered in both singular and plural forms. In expressions containing more than one marked term, all applicable morphological combinations were considered.

5.5.6 Construction of the citation index related to the smart city agenda

Based on the definition of the dictionary of terms and the organisation of keywords into groups and subgroups, the next stage consisted of constructing an indicator capable of systematically synthesising the presence of elements associated with the smart city agenda in municipal Master Plans.

The logic for constructing the index follows a hierarchical structure, composed of three levels of aggregation: subgroups, groups and dimensions. Initially, for each Master Plan d , a binary variable is defined for each subgroup s , such that:

$$S_{d,s} = \begin{cases} 1, & \text{if at least one term from subgroup } s \text{ is present in document } d, \\ 0, & \text{otherwise.} \end{cases}$$

This stage makes it possible to identify the thematic presence of each subgroup in the document, independently of the frequency with which the terms occur.

Next, the subgroups are aggregated at the thematic group level. For each group g , the index is calculated as the simple average of the subgroups that compose it:

$$G_{d,g} = \frac{1}{N_g} \sum_{s \in g} S_{d,s} \quad (5.1)$$

where N_g represents the total number of subgroups belonging to group g .

The groups are then aggregated to compose the indices of the dimensions k , also using a simple average:

$$D_{d,k} = \frac{1}{N_k} \sum_{g \in k} G_{d,g} \quad (5.2)$$

where N_k corresponds to the number of groups that compose dimension k .

Finally, the overall citation index related to the smart city agenda for each municipality d is obtained from the simple average of the dimensions considered:

$$SC_d = \frac{1}{K} \sum_{k=1}^K D_{d,k} \quad (5.3)$$

where K represents the total number of dimensions included in the indicator, namely: Economy, Society, Environment, Governance, Technology and Urban Brands. For the descriptive and spatial analyses, the resulting indices were subsequently rescaled to the interval $[0, 1]$ using min–max normalisation, so that higher values indicate a greater relative incidence of references associated with the smart city agenda.

The use of a simple average at each aggregation stage reflects the absence of a clearly established theoretical hierarchy among the different components of the smart city concept in the literature. Accordingly, a uniform weighting structure was adopted, in which each subgroup contributes equally to the composition of the groups, and each group contributes equally to the formation of the dimensions. This choice prioritises methodological transparency and facilitates the interpretation of the results, avoiding the introduction of arbitrary weights, as discussed in the literature on the construction of composite indicators (OECD, 2008).

Despite this formal uniformity, the structure of the indicator incorporates a form of implicit weighting arising from the organisation of the dictionary of terms itself. In particular, subgroups composed of a single term or expression make the indicator more sensitive to their presence in the documents. This is the case, for example, of subgroup *SE4* (Table 5.6), associated with the term “*inteligência da economia*” (smart economy), as well as subgroup *G6* (Table 5.9), which directly includes the term “*governança*” (governance). Similarly, the Urban Brands dimension (Table 5.11) is composed mainly of subgroups with specific terms, such as “*cidade inteligente*” (smart city), “*cidade sustentável*” (sustainable city) and “*cidade criativa*” (creative city).

In these cases, the presence of a single term is sufficient to activate the corresponding subgroup, which tends to increase the relative influence of these elements in the composition of the aggregate indices. This characteristic does not stem from the exogenous assignment of weights, but from the structure of the dictionary itself, which seeks to highlight expressions more directly associated with the smart city agenda.

In addition, the use of binary variables at the subgroup level makes it possible to mitigate potential distortions associated with the excessive repetition of terms in certain documents. By considering only the presence or absence of the terms, the indicator avoids assigning greater weight to Master Plans that repeatedly use the same expression, focusing instead on identifying the thematic diversity of the content addressed.

Taken together, this procedure results in an indicator that combines operational simplicity, coherence with the conceptual structure adopted and the capacity to capture, in a comparable way across municipalities, the incorporation of elements associated with the smart city agenda into formal urban planning instruments.

5.6 Spatial distribution and characterisation of municipalities according to the citation indices

Based on the construction of the citation index related to the smart city agenda, this section examines its distribution and main characteristics across the municipalities analysed. The aim is to identify general patterns of occurrence, variations in the composition of the dimensions and possible spatial regularities associated with the incorporation of these elements into Master Plans. To this end, the analysis combines descriptive evidence, a spatial reading of the indicators and an exploratory examination of the relationship between the citation indices and the smart city indicators presented in Chapter 4.

5.6.1 Distribution of the indices and descriptive evidence

The initial analysis of the distribution of the citation indices begins with the statistical characterisation of the dimensions and the aggregate index, with the aim of identifying general patterns in the occurrence of references associated with the concept of smart cities in municipal Master Plans. Table 5.12 presents the descriptive statistics of the indices, considering the set of municipalities analysed.

Table 5.12 - Descriptive statistics of the Smart City Citation indices and dimensions

Citation Index	Obs.	Mean	SD	Min	Max
<i>Dimensions:</i>					
Economy	1,236	0.47	0.19	0	1
Society	1,236	0.57	0.17	0	1
Environment	1,236	0.58	0.19	0	1
Governance	1,236	0.68	0.15	0	1
Technology	1,236	0.43	0.25	0	1
Urban Brands	1,236	0.10	0.14	0	1
<i>Composite index:</i>					
Smart City	1,236	0.57	0.17	0	1

Source: Author's own elaboration.

Note: Obs. = number of observations; SD = standard deviation. All indices were normalised using min-max scaling and range from 0 (lowest value) to 1 (highest value). Because min-max normalisation was applied separately to each dimension, mean values should not be interpreted as directly comparable levels of thematic incidence across dimensions.

Table 5.12 summarises the distribution of the citation indices after dimension-specific min-max normalisation. The reported means therefore locate the municipalities within the observed range of each thematic dimension and should not be interpreted

as directly comparable measures of thematic incidence across dimensions. The indices nevertheless reveal different distributional patterns within each domain. Technology, for example, displays greater numerical dispersion on its transformed scale, indicating stronger differentiation among municipalities within this dimension. Comparisons of the substantive prevalence of themes are more appropriately based on the underlying subgroup occurrences and on their distribution across documents.

In addition, the dispersion of the indices varies across dimensions, with greater heterogeneity observed in Technology ($SD = 0.25$), suggesting wider variation in the incorporation of these elements across municipalities.

From this initial characterisation, the analysis moves to the temporal dimension of the indices, seeking to identify patterns associated with the timing of the preparation or revision of the Master Plans. To this end, the evolution of mean values over time is considered, taking as reference the year of the most recent legislation for each Master Plan. Figure 5.4 presents the trajectory of the annual means of the citation indices between 2010 and 2020, disaggregated by dimension and for the aggregate index.

In general, an upward trend is observed over the period, although with specific variations across years. This pattern is relatively consistent across the different dimensions, suggesting that more recent Master Plans tend to incorporate elements associated with contemporary urban planning agendas more frequently. In the case of the aggregate index, the trajectory closely follows the average behaviour of the dimensions, indicating that the incorporation of these elements occurs in a relatively broad manner, albeit with different levels of intensity.

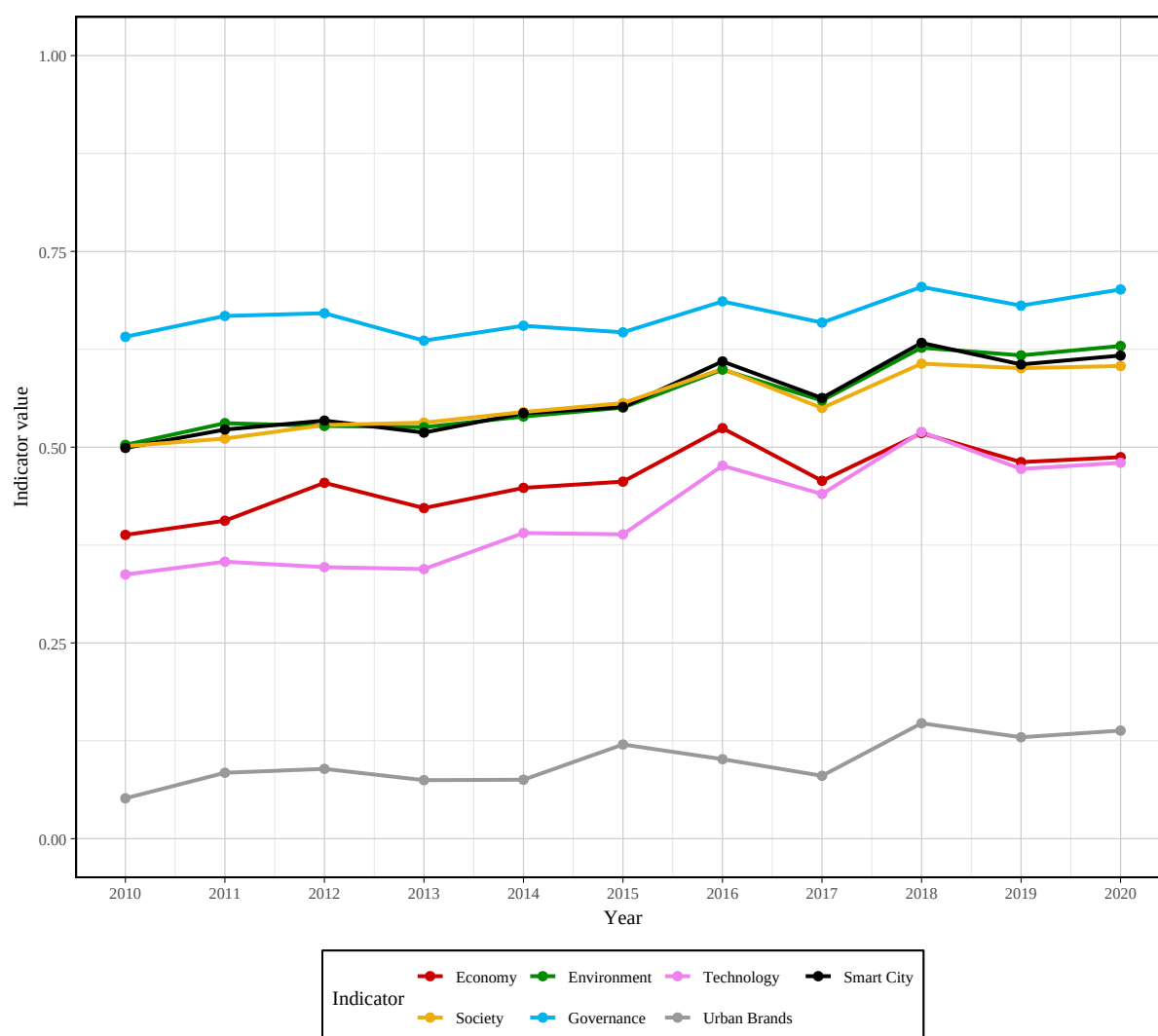
Although the evolution is not strictly monotonic, from the mid-2010s onwards a clearer increase in the indicators can be observed, particularly in the Governance, Technology and Society dimensions. This pattern may be associated with the broader diffusion of guidelines related to digital transformation, the expansion of participation mechanisms and the incorporation of themes linked to urban quality of life into planning instruments.

In addition, an average increase in the indices is observed among plans prepared or updated in 2015 and 2016, which may be related to the diffusion, in the national context, of international guidelines for sustainable urban development, especially the 2030 Agenda (UNITED NATIONS, 2015) and the New Urban Agenda (UN-HABITAT, 2016a). These frameworks contributed to the consolidation of a shared language of urban planning, based on principles of sustainability, inclusion and governance, which were progressively incorporated into local planning instruments.

By contrast, the Urban Brands dimension presents systematically lower values throughout the period, indicating a lower incidence of discursive strategies aimed at constructing urban identities and symbolically promoting cities within contemporary

urban planning agendas (Ashton; Emmendoerfer; Emmendoerfer, 2018). This result suggests that, although normative and operational elements associated with smart cities have been gradually incorporated, aspects related to symbolic construction and the strategic positioning of cities remain less widespread in the documents analysed.

Figure 5.4 - Average Smart City Citation Indices by year of the most recent Master Plan (2010–2020)



Source: Author's own elaboration based on IBGE (2022b, 2023a), MUNIC (2021), and municipal Master Plan legislation.

Note: The figure reports annual averages of the Smart City Citation Index and its six dimensions, computed according to the year of the most recent Master Plan law in each municipality. The index corresponds to the average of six dimensions: (i) Economy; (ii) Society; (iii) Environment; (iv) Governance; (v) Technology; and (vi) Urban Brands. The lines should be interpreted as within-dimension temporal trajectories; vertical differences between dimensions do not represent directly comparable levels of thematic incidence.

More disaggregated evidence on this dimension is presented in Table A.5.7 of the Appendix, which reports, for each year of initial adoption or revision of the Master Plans, the number of municipalities mentioning terms associated with the different subgroups

(UB1 to UB11), as well as the proportion of these municipalities relative to the total number of plans observed in each year. In general, terms associated with the notion of the smart city begin to appear more frequently from the mid-2010s onwards, while references to urban resilience become more visible from 2016. Even so, these occurrences remain relatively limited when compared with the other dimensions analysed.

Beyond the temporal dimension, Table 5.13 makes it possible to examine heterogeneity across municipalities in terms of the levels of the aggregate citation index, by presenting the ranking of the 20 municipalities with the highest values. The results show that the highest levels of the index are not restricted to a single type of municipality, with the simultaneous presence of metropolises, regional capitals and smaller population centres.

Table 5.13 - Top 20 Brazilian municipalities by Smart City Citation Index

Rank	State	Urban Hierarchy	Municipality	Population	Year	Smart City Citation Index
1	Rio de Janeiro	Metropolis	Niterói	481,749	2019	1.0000
2	Rio de Janeiro	Regional Capital	Campos dos Goytacazes	483,540	2020	0.9835
3	São Paulo	Metropolis	Campinas	1,139,047	2018	0.9676
4	Minas Gerais	Local Centre	Santa Bárbara	30,466	2020	0.9604
5	Paraná	Sub-Regional Centre	Toledo	150,470	2016	0.9564
6	São Paulo	Regional Capital	Ribeirão Preto	698,642	2018	0.9539
7	São Paulo	Regional Capital	Araraquara	242,228	2014	0.9521
8	Bahia	Regional Capital	Feira de Santana	616,272	2018	0.9506
9	São Paulo	Metropolis	São Paulo	11,451,999	2014	0.9494
10	Rio de Janeiro	Regional Capital	Macaé	246,391	2018	0.9489
11	Bahia	Metropolis	Salvador	2,417,678	2016	0.9476
12	São Paulo	Regional Capital	São Vicente	329,911	2018	0.9453
13	Pará	Regional Capital	Castanhal	192,256	2019	0.9409
14	Mato Grosso do Sul	Regional Capital	Campo Grande	898,100	2018	0.9387
15	Paraná	Metropolis	Araucária	151,666	2019	0.9355
16	São Paulo	Sub-Regional Centre	Botucatu	145,155	2017	0.9353
17	São Paulo	Regional Capital	Santos	418,608	2018	0.9329
18	Tocantins	Regional Capital	Palmas	302,692	2018	0.9321
19	São Paulo	Regional Capital	Jundiaí	443,221	2019	0.9319
20	São Paulo	Sub-Regional Centre	Bragança Paulista	176,811	2020	0.9254

Source: Author's own elaboration based on IBGE (2019b), IBGE (2023a) and municipal Master Plan legislation.

Note: The Smart City Citation Index corresponds to the average of six dimensions: (i) Economy; (ii) Society; (iii) Environment; (iv) Governance; (v) Technology; and (vi) Urban Brands. Population figures refer to the 2022 Population Census (IBGE, 2023a). Urban hierarchy follows the REGIC classification (IBGE, 2019b). The "Year" column indicates the year of the most recent Master Plan law.

This pattern suggests that the incorporation of elements associated with smart cities into Master Plans does not depend exclusively on population size or position in the urban hierarchy, but may reflect differentiated strategies for preparing and revising these instruments.

Figure 5.5 presents the dimensional profiles that make up the aggregate index for the nine highest-ranked municipalities, excluding state capitals. Although these municipalities display high values for the aggregate index, there are relevant variations in the relative contribution of each dimension. In particular, comparisons such as that between Niterói and Campos dos Goytacazes illustrate this heterogeneity. Despite presenting similar levels of the aggregate index and comparable structural characteristics, the two municipalities differ in the composition of their indicators, especially in the Economy and Urban Brands dimensions. This result indicates that high index levels may be reached through different combinations of dimensions, reflecting distinct choices in the process of formulating Master Plans.

This aspect becomes even clearer when relatively smaller municipalities are considered, such as Santa Bárbara (MG), which appears among the highest-ranked cases. In this case, the high incidence in the Technology and Governance dimensions suggests the incorporation of contemporary urban planning guidelines that cannot be explained solely by the local economic structure, but also by the adoption of more recent planning agendas and models.

Taken together, these results indicate that the diffusion of elements associated with smart cities in Master Plans occurs heterogeneously, both in terms of intensity and composition. The levels of the index therefore cannot be directly associated with simple structural characteristics, such as population size or position in the urban hierarchy.

The heterogeneity observed in the composition of the indices (Figure 5.5) suggests that high levels of the aggregate indicator may result from different combinations of the dimensions considered. No single pattern is identified among the highest-ranked municipalities, and distinct profiles can be distinguished, in which certain dimensions play a more prominent role. In some cases, there is greater concentration in the Technology and Governance dimensions, whereas in others the distribution across dimensions is more balanced.

This diversity of profiles becomes even more evident when the analysis is extended to a distinct set of municipalities, specifically the state capitals. Figure 5.6 presents radar charts for the highest-ranked capitals in the citation index, allowing comparison of the internal composition of the indicators in urban contexts marked by greater institutional and economic complexity.

In general, the capitals also display relevant variations in the composition of their indices, although, on average, they show relatively high levels in the Society, Environment and Governance dimensions. This result suggests that, even among municipalities with greater administrative capacity and higher economic density, the incorporation of elements associated with smart cities occurs in differentiated ways.

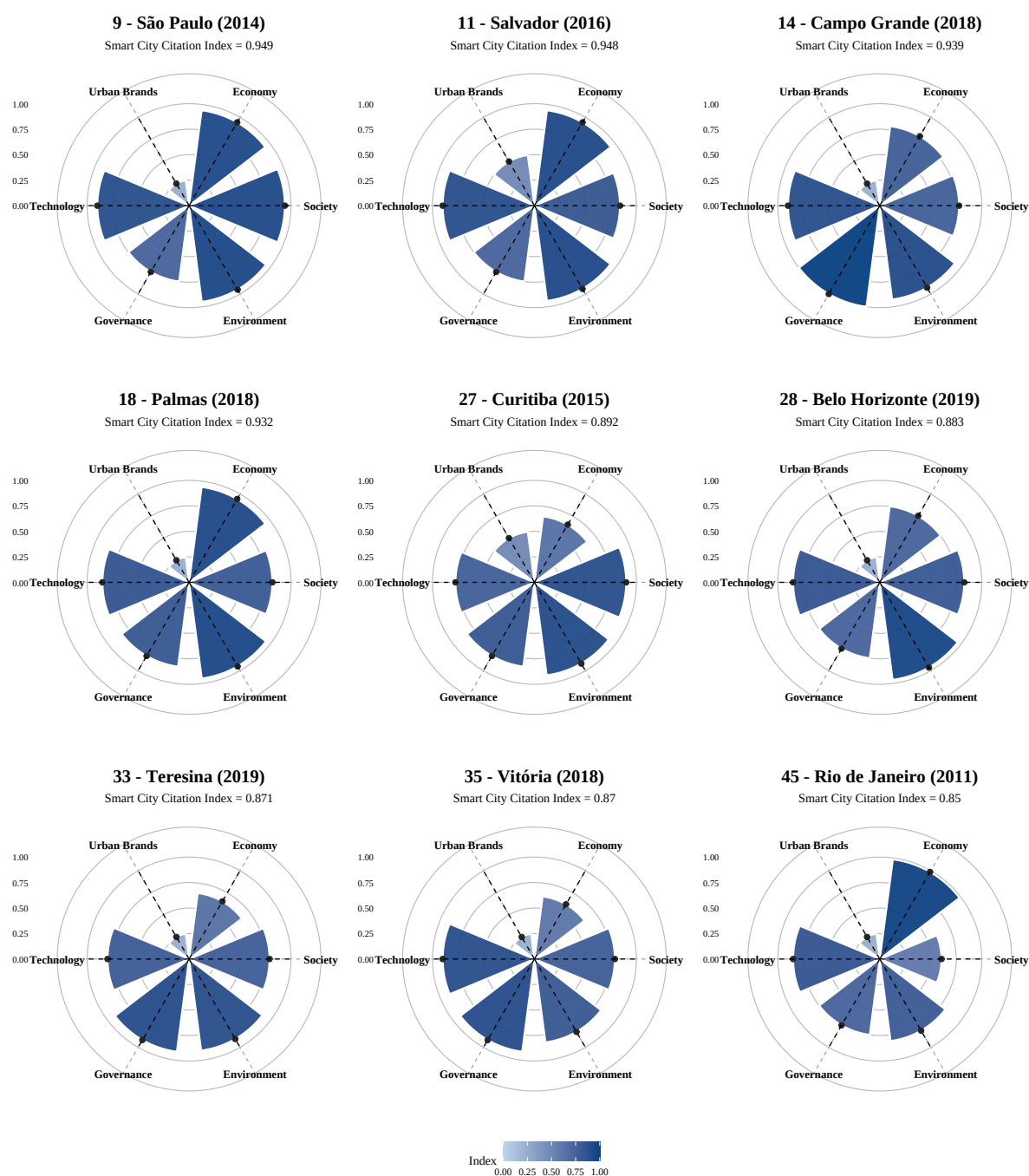
Figure 5.5 - Dimensional composition of the Smart City Citation Index for the top-ranked non-capital municipalities



Source: Author's own elaboration.

Note: The figure presents radar charts for the nine highest-ranked municipalities in the Smart City Citation Index, excluding state capitals. Each chart displays the values of the six dimensions that compose the index: (i) Economy; (ii) Society; (iii) Environment; (iv) Governance; (v) Technology; and (vi) Urban Brands. Values range from 0 to 1 and were obtained through min-max normalisation. The number preceding each municipality name indicates its position in the ranking reported in Table 5.13, while the year in parentheses corresponds to the most recent Master Plan law. The overall Smart City Citation Index value for each municipality is reported below its name.

Figure 5.6 - Dimensional composition of the Smart City Citation Index for the top-ranked state capitals



Source: Author's own elaboration.

Note: The figure presents radar charts for the highest-ranked Brazilian state capitals in the Smart City Citation Index. Each chart displays the values of the six dimensions that compose the index: (i) Economy; (ii) Society; (iii) Environment; (iv) Governance; (v) Technology; and (vi) Urban Brands. Values range from 0 to 1 and were obtained through min-max normalisation. The number preceding each municipality name indicates its position in the overall ranking reported in Table 5.13, while the year in parentheses corresponds to the most recent Master Plan law. The overall Smart City Citation Index value for each municipality is reported below its name.

In addition, the Urban Brands dimension remains relatively underrepresented even

among the capitals, reinforcing the pattern identified above. This behaviour indicates that, regardless of size or position in the urban hierarchy, elements related to the symbolic construction and strategic positioning of cities remain less explored in Master Plans when compared with more operational and normative dimensions.

Another relevant aspect concerns the greater relative presence of the Technology dimension in some capitals, which may reflect the wider diffusion of policies and initiatives aimed at digital transformation in more complex urban contexts. Even so, this presence is not uniform, reinforcing the interpretation that the adoption of these agendas depends not only on structural capacities, but also on specific decisions made in the process of formulating planning instruments.

Taken together, the comparison between non-capital municipalities and state capitals suggests that the heterogeneity observed in the composition of the indices is a recurrent feature of the process through which elements associated with smart cities are incorporated into Master Plans. This pattern indicates the coexistence of different trajectories of adoption of these agendas, reflecting variations in the strategies and priorities that guide the preparation of these instruments at the municipal level.

5.6.2 Spatial patterns and relationships between indicators

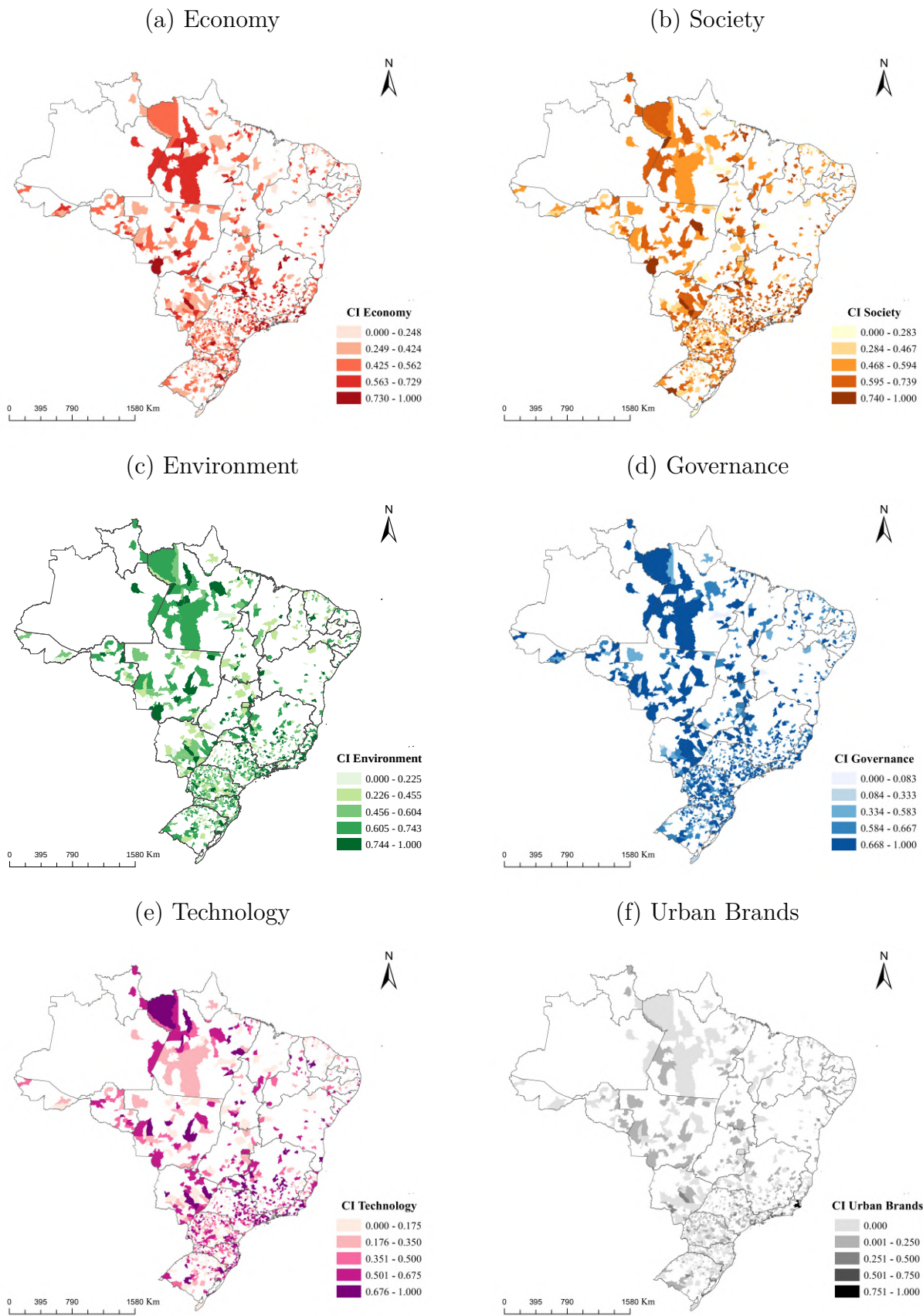
The analysis presented in the previous section highlighted the existence of heterogeneity in both the levels and the composition of the citation indices across Brazilian municipalities. In this subsection, the focus shifts to the spatial dimension of this distribution, with the aim of identifying territorial patterns associated with the incorporation of elements related to smart cities into municipal Master Plans.

Figure 5.7 presents the spatial distribution of the citation indices for each of the dimensions considered. In general, the incorporation of these elements does not occur homogeneously across the national territory, and areas of greater relative concentration can be identified, especially in the South and Southeast regions, as well as in specific portions of the Centre-West and along the north-eastern coast.

In the case of the Economy dimension (Figure 5.7a), higher concentrations of elevated values are observed among municipalities in Brazil's Centre-South region. This pattern suggests an association with areas characterised by greater economic dynamism and more diversified productive structures, although it is not limited to the main urban centres.

The Society dimension (Figure 5.7b) displays a more diffuse distribution across the territory, with intermediate and high values present in different regions. Even so, there is a greater relative concentration in the South and Southeast regions, indicating a higher incidence of references related to well-being, urban services and living conditions in these contexts.

Figure 5.7 - Spatial distribution of Smart City Citation Index dimensions in Brazil



Source: Author's own elaboration.

Note: The figure presents the spatial distribution of the six dimensions of the Smart City Citation Index: (a) Economy; (b) Society; (c) Environment; (d) Governance; (e) Technology; and (f) Urban Brands. Indices were constructed from keyword-based content analysis of municipal Master Plans and normalised using min–max scaling, ranging from 0 (lowest incidence) to 1 (highest incidence). Class intervals were defined using the Natural Breaks (Jenks) method. Maps were produced using ArcGIS 10.5.

For the Environment dimension (Figure 5.7c), the spatial pattern remains close to that observed above, with a higher concentration of elevated values in the South and Southeast and occurrences distributed across other regions. This pattern suggests that themes associated with environmental sustainability have been incorporated relatively widely, although with different levels of intensity.

The Governance dimension (Figure 5.7d) stands out for presenting a more concentrated pattern, with a strong presence of municipalities displaying high values in the South and Southeast regions. This result is consistent with the descriptive statistics and indicates greater incorporation of institutional mechanisms, management instruments and participatory practices in these contexts.

In the Technology dimension (Figure 5.7e), greater spatial dispersion can be observed, with municipalities from different regions displaying high values. Although a relative concentration in the South and Southeast persists, the pattern suggests that the incorporation of technological elements occurs more heterogeneously across the territory, and is not restricted to the main urban centres.

Finally, the Urban Brands dimension (Figure 5.7f) presents a generally low incidence, with few municipalities displaying higher values. The spatial distribution of these cases is quite localised, reinforcing the previously identified pattern of lower incorporation of discursive strategies associated with symbolic construction and urban positioning in Master Plans.

The joint analysis of these dimensions makes it possible to identify the coexistence of different spatial patterns, in which certain regions concentrate a higher incidence of specific references, while others display a lower relative density of these elements. However, reading the dimensions in isolation does not fully capture the overall distribution of the phenomenon.

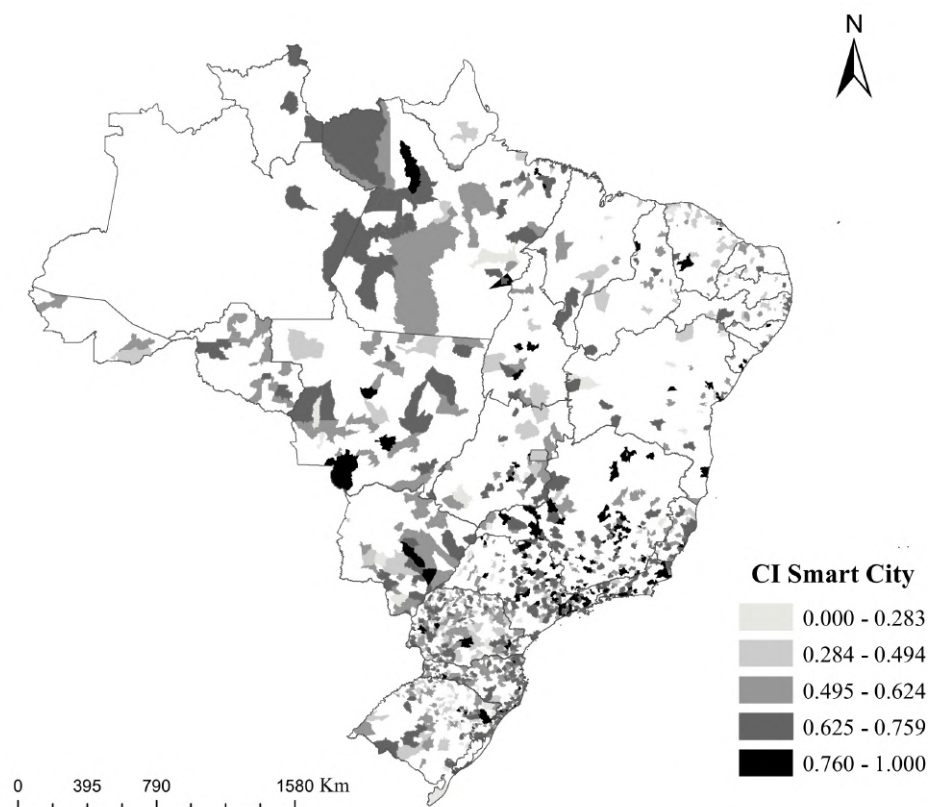
In this regard, Figure 5.8 presents the spatial distribution of the aggregate smart city citation index, providing a synthetic view of the territorial patterns associated with the incorporation of these agendas into municipal Master Plans.

The distribution of the aggregate index reinforces the patterns observed in the individual dimensions, showing a greater concentration of municipalities with high values in the South and Southeast regions, as well as isolated occurrences in other parts of the country. At the same time, extensive areas with low index levels can be observed,

especially in the North and in parts of the Northeast, indicating a lower relative incidence of references associated with smart city agendas in these contexts.

Overall, this pattern (Figure 5.8) suggests that the incorporation of these elements into Master Plans is associated with broader territorial dynamics, reflecting regional differences in the diffusion of urban planning practices and guidelines.

Figure 5.8 - Spatial distribution of the Smart City Citation Index in Brazil



Source: Author's own elaboration.

Note: The figure presents the spatial distribution of the composite Smart City Citation Index across Brazilian municipalities. The index is computed as the average of six dimensions: Economy, Society, Environment, Governance, Technology, and Urban Brands. Values are normalised using min-max scaling, ranging from 0 (lowest incidence) to 1 (highest incidence). Class intervals are defined using the Natural Breaks (Jenks) method. Maps were produced using ArcGIS 10.5.

In addition to the spatial analysis discussed above, a complementary examination is also conducted of the relationship between the smart city indicators constructed in Chapter 4 and the citation indices derived from the analysis of Master Plans. To this end, Correspondence Analysis is employed as an exploratory tool aimed at identifying associations between categories in the two sets of indicators.

Correspondence Analysis is a multivariate technique used to represent associations between categories of qualitative variables in a low-dimensional space, based on the decomposition of a contingency matrix (Bartholomew et al., 2008; Johnson; Wichern, 2014). In the present context, the technique is used to map the proximity between the

categories of the smart city indices and the citation indices, both previously classified into four groups, defined on the basis of the mean and standard deviation of their distributions.

More specifically, the analysis is conducted using the 1,236 municipalities that make up the sample of this chapter, corresponding to the subset for which it was possible to obtain the Master Plans. Although the smart city indicators were originally calculated for the full set of 5,570 Brazilian municipalities in Chapter 4, the descriptive statistics used for the categorisation — mean and standard deviation — were recalculated considering only this subsample, in order to ensure the internal comparability of the classifications.¹⁴

Based on this procedure, municipalities were classified into four categories for each indicator: (i) Low (values below the mean minus one standard deviation), (ii) Lower-middle, (iii) Upper-middle and (iv) High (values above the mean plus one standard deviation). On the basis of this categorisation, contingency tables were constructed between the indicators from the two chapters, allowing Correspondence Analysis to be applied to each dimension considered, as well as to the aggregate index.

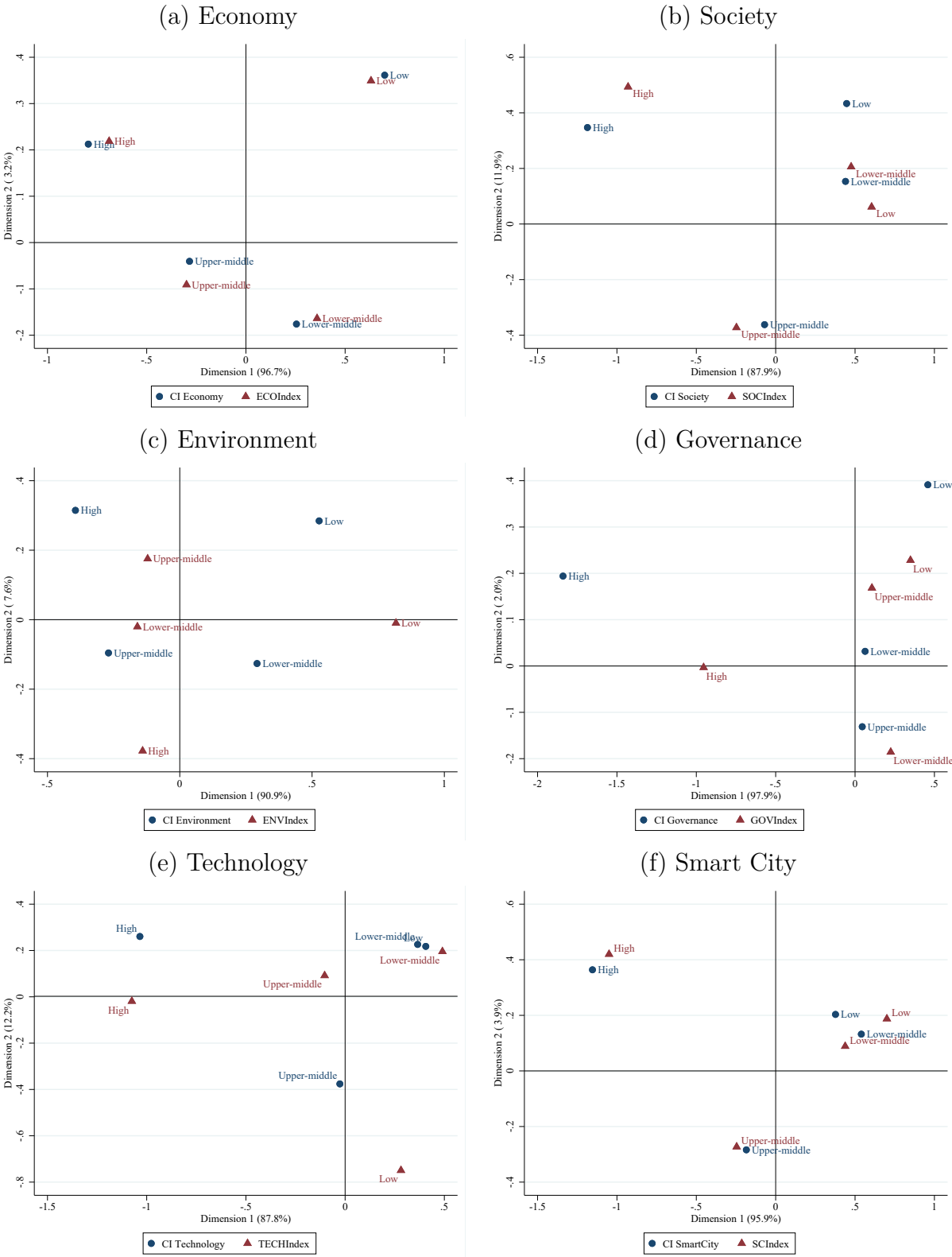
Figure 5.9 presents the results of this analysis, indicating the relative position of the categories of the smart city indicators (Chapter 4) and the citation indices (Chapter 5) in a two-dimensional space. In general, the first dimension accounts for most of the explained variance, suggesting that the main differentiation between groups occurs along an axis associated with a gradient of relative indicator intensity.

One of the most consistent aspects across the different dimensions concerns the proximity between the highest categories of the indicators. In particular, the “High” category of the smart city indices tends to be located close to the “High” category of the citation indices, indicating that municipalities with higher levels of performance in the urban smartness indicators also display a greater incidence of references to elements associated with smart cities in their Master Plans.

This pattern suggests a positive association between the two sets of indicators, especially at higher levels, although this relationship does not manifest itself in a perfectly symmetrical way across all intermediate categories. Indeed, greater relative dispersion is observed between the “Lower-middle” and “Upper-middle” groups, indicating that, at intermediate levels of performance, the correspondence between the indicators tends to be less clearly defined.

¹⁴ Restricting the analysis to the subsample of municipalities with Master Plans means that the categories of the indicators are defined on the basis of the distribution observed within this subset, and not within the full universe of Brazilian municipalities. This choice prioritises internal comparability between the indicators used in the correspondence analysis, although it limits direct comparability with the national distribution presented in Chapter 4.

Figure 5.9 - Correspondence analysis between Smart City indicators (Chapter 4) and Citation Indices derived from Master Plans (Chapter 5), by dimension



Source: Author's own elaboration based on Smart City indicators (Chapter 4) and Citation Indices derived from municipal Master Plans (Chapter 5).

Note: Panels (a)–(f) display the results of the correspondence analysis for each dimension and for the composite index. CI Economy, CI Society, CI Environment, CI Governance, CI Technology, and CI Smart City refer to the Citation Indices derived from the content analysis of municipal Master Plans (Chapter 5). EcoIndex, SOCIndex, ENVIndex, GOVIndex, TECHIndex, and SCIndex correspond to the Smart City indicators constructed in Chapter 4. All indicators were classified into four categories based on the mean and standard deviation of their distributions within the sample of municipalities with available Master Plans ($n = 1,236$). The analysis is exploratory and based on cross-sectional associations between indicators constructed from distinct data sources and time frames.

With regard to the specific dimensions, the results reinforce this general tendency, although with some nuances. In the Economy and Society dimensions, for example, there is a clear proximity between the upper categories of the two indicators, while the lower-performing groups also cluster relatively consistently. In the Environment and Technology dimensions, by contrast, dispersion among the intermediate categories is more pronounced, suggesting greater heterogeneity in the relationship between the indicators.

The Governance dimension, in turn, displays a pattern in which separation along the first dimension is particularly marked, indicating that differences between performance levels are more clearly captured along this axis. This result is consistent with the patterns observed in the descriptive analysis, which point to greater variation in the incorporation of institutional and planning-related elements into Master Plans.

When the aggregate index is considered, the proximity between the upper categories of the two indicators is also observed, indicating a closer correspondence between the upper categories of the structural and documentary measures.

This result indicates that, despite the methodological differences and the distinct data sources used in the construction of the indicators, there is a non-negligible correspondence between the two sets of measures, especially in the upper tail of the distribution.

This analysis should, however, be interpreted with caution, since the indicators compared are of different natures. The smart city indices in Chapter 4 are constructed from largely contemporary data, reflecting a cross-sectional picture of municipal conditions, whereas the citation indices derive from Master Plans prepared or revised at different points over the 2010–2020 period.

In this sense, Correspondence Analysis does not allow causal relationships between the indicators to be established and should be understood only as an exploratory exercise in identifying associations between measures constructed from different sources. The observed proximity between categories indicates correspondence within the analysed sample, rather than evidence that one measure produces or validates the other.

This association is not evidence that the plans were implemented. It may also reflect common determinants of municipal conditions and documentary content, including economic development, administrative resources and regional position. The different reference years prevent the structural scores from being treated as a direct before-and-after validation of the plans. The exercise describes correspondence between two measures; it does not identify the direction of influence between them.

Taken together, the results presented in this section indicate that the incorporation of elements associated with the smart city agenda into municipal Master Plans does not occur homogeneously across the Brazilian territory, varying both spatially and in terms of the composition of the documented content. The exploratory comparison with the structural indicators identifies partial correspondence between the two sets of measures, particularly in their upper categories, but does not establish whether this relationship reflects implementation, common underlying conditions or other municipal and regional characteristics.

Furthermore, the exploratory analysis of the association between the indices constructed in this chapter and those derived from structural indicators suggests the existence of partial alignments between the discursive dimension of urban planning and the conditions observed in municipalities, especially at the higher levels of the indicators. Although this evidence should be interpreted with caution, it points to the relevance of considering planning instruments as an integral part of the dynamics of urban and regional development, a theme that will be explored in greater depth in the following chapter.

5.7 Conclusion

This chapter examined how the smart city agenda is structured and materialised within the Brazilian institutional context, with emphasis on the role of formal urban planning instruments. The analysis began from the observation that, in Brazil, the diffusion of these initiatives takes place in an environment characterised by institutional fragmentation, the absence of national coordination and the predominance of decentralised strategies, conducted at the municipal level and associated with different local capacities and trajectories. In this context, the systematic identification of policies and strategies related to smart cities poses empirical challenges, since these initiatives are neither standardised nor directly observable.

Against this background, the chapter used the Master Plan as a common documentary basis for observing how themes associated with the smart city agenda enter formal municipal planning. As the main normative instrument of Brazilian urban planning, the Master Plan provides a comparable record of the language through which municipalities express guidelines and priorities. The analysis therefore shifts from heterogeneous concrete initiatives to documented agenda content. This improves comparability across territorial

units, but does not imply that the themes identified correspond to implemented strategies, budgetary commitments or effective service delivery.

Building on this premise, an empirical strategy based on the textual analysis of municipal Master Plans was developed, making it possible to systematically identify the presence of elements associated with the different dimensions of urban smartness. The construction of a citation indicator, hierarchically structured and grounded in a dictionary of terms derived from the literature and from the reading of the documents, made it possible to measure the breadth and composition of documented thematic content across the municipalities analysed. The results show that this documentary incorporation varies across the territory, both in its extent and in the combination of dimensions represented.

The descriptive and spatial analysis revealed relevant patterns in the distribution of the indicators, with a higher relative concentration of elevated values in certain regions of the country, while also highlighting the existence of distinct trajectories of incorporation of these agendas among municipalities of different sizes and positions in the urban hierarchy. In addition, the examination of the internal composition of the indices indicated that high levels of the aggregate indicator may result from different combinations of dimensions, suggesting the absence of a single smart city model in the Brazilian context. These results are consistent with the literature that emphasises the multifaceted and context-dependent nature of urban smartness strategies.

Taken together, the evidence indicates that the formal incorporation of contemporary urban agendas into Master Plans is uneven across municipalities. The observed variation documents differences in the themes incorporated into municipal planning, but does not by itself establish differences in implementation, expenditure or policy effectiveness. By providing a systematic measure of documented agenda content, the chapter establishes the empirical basis for examining, in the following chapter, whether this formal incorporation is associated with subsequent economic outcomes.

By offering a systematic measure of the presence of elements associated with the smart city agenda in urban planning instruments, this chapter establishes an empirical basis for analysing the relationships between planning, urban strategies and economic outcomes. The investigation of these relationships constitutes the next step of the analysis, allowing a more in-depth examination of how the observed heterogeneity in the incorporation of these agendas is articulated with patterns of development and inequality among municipalities within the regional context.

The following chapter builds on this basis to examine whether the documentary incorporation of the smart city agenda into Master Plans is associated with changes in the relative economic position of municipalities within their regional contexts.

6 INCORPORATION OF THE SMART CITY AGENDA INTO MUNICIPAL MASTER PLANS AND INTRA-REGIONAL ECONOMIC INEQUALITY

6.1 Introduction

The incorporation of the smart city agenda into formal urban planning instruments raises an empirical question that goes beyond the presence of terms, guidelines, or normative references in municipal documents. If Master Plans express public priorities, organise instruments of urban regulation, and guide territorial decision-making, a stronger presence of this agenda may be associated with changes in the way municipalities position themselves within their regional contexts (Bodnar; Priess; Bianchi, 2019). This relationship, however, is not direct. Between the normative text and observable economic outcomes lie differences in institutional capacity, planning trajectories, position within the urban network, and the intensity of thematic incorporation (Healey, 1998; Santos Junior; Montandon, 2011).

This chapter investigates this relationship in the case of Brazilian municipalities. The analysis draws on the dataset constructed in the previous chapter, which measures the presence of elements associated with the smart city agenda in Master Plans, and examines whether stronger incorporation of this agenda is associated with changes in the municipal additive contribution to the intra-regional component of GDP per capita inequality. The analysis therefore shifts from the city viewed in isolation to the position of the municipality within its Immediate Geographic Region (ImGR), recognising that flows, urban functions, and differences in scale organise economic relations that extend beyond municipal administrative boundaries (Galindo; Tavares, 2020).

The empirical strategy distinguishes between two institutional events: the initial adoption of the Master Plan and the revision of a previously existing plan. This distinction is central to the argument of the chapter. Initial adoption may represent the municipality's entry into a formal urban planning regime, whereas revision takes place within an already established normative structure. The incorporation of the smart city agenda may therefore carry different meanings in these two contexts, especially when observed across municipalities occupying different positions in the urban hierarchy.

The dependent variable is constructed from the decomposition of generalised entropy measures, with emphasis on the Theil T index. Rather than measuring only the region's aggregate inequality, the chapter examines the additive contribution of each municipality to the intra-regional component of inequality. This choice makes it possible to assess whether the incorporation of the smart city agenda is associated with a reconfiguration of the municipality's relative economic position within its functional region. The treatment, in turn, is defined by the intensity with which the agenda is incorporated into the document in the year of the institutional event, using percentile thresholds of the composite Smart

City index.

The analysis uses a multi-period Difference-in-Differences design, suited to the staggered entry of municipalities into treatment. The results are presented separately for the initial adoption and revision of the Master Plan, with additional exercises by intensity threshold, urban hierarchy, prior documentary maturity, thematic composition, and alternative inequality measures. Throughout the chapter, the results are interpreted with caution, distinguishing incorporation into the document, effective implementation, and regionally observable economic effects.

The chapter is organised into eleven further sections, in addition to this introduction. Section 6.2 develops the conceptual argument and presents the hypotheses. Section 6.3 defines the dependent variable through the decomposition of intra-regional inequality. Sections 6.4 and 6.5 detail the policy definition and the empirical strategy. Section 6.6 describes the data, the sample, and the distribution of treatments. Sections 6.7 to 6.9 present the main results, heterogeneities, and exploratory exercises on thematic composition and relative economic position. Section 6.10 brings together robustness checks and complementary diagnostics. Section 6.11 discusses the scope of the findings, and Section 6.12 concludes the chapter.

6.2 From normative incorporation to regional effects: conceptual argument and hypotheses

This section sets out the conceptual argument underpinning the chapter's empirical strategy. The incorporation of the smart city agenda into Master Plans is treated as a potential institutional change whose capacity to produce effects depends on the trajectory of local urban planning, the way in which the municipality absorbs the normative content, and the position it occupies within the regional network. The discussion brings together the Master Plan as a normative instrument, the smart city agenda as multidimensional content within urban planning, and the municipal additive contribution as a way of observing changes in the intra-regional composition of economic inequality. On this basis, the hypotheses guiding the empirical analysis are formulated.

6.2.1 Master Plans, institutional change and the maturity of urban planning

In the institutionalist literature, institutions are understood as rules that structure social, economic, and political interactions, defining incentives, constraints, and the scope for action available to agents (Fiani, 2011). North (1990) defines them as socially constructed rules that shape human behaviour, which may take a legal form when inscribed in norms, contracts, and formal provisions, or an informal form when associated with habits, conventions, routines, and consolidated practices. This distinction is particularly useful for analysing urban planning, since the existence of a legal instrument does not,

in itself, imply that the administrative practices, technical capacities, and coordination routines required for its operationalisation are in place (Healey, 1997, 1998).

This interpretation brings the institutional discussion closer to regional economics. The institutional environment affects transaction costs, the coordination among agents, investment decisions, and the organisation of production, so that differences in institutional arrangements may, over time, translate into distinct territorial trajectories (Acemoglu; Johnson; Robinson, 2005; Capello, 2015; North, 1990).

According to Acemoglu, Johnson and Robinson (2005), economic institutions shape incentives, influence the allocation of resources, and affect both economic performance and the future distribution of those resources. In the urban context, this mediation takes place in a particularly sensitive field, in which legal instruments, landed interests, administrative capacities, participatory disputes, and local development strategies overlap in the production of space (Follador; Duarte; Carrier, 2020, 2022; Healey, 1997).

In Brazil, the Master Plan occupies a central position in this arrangement. Under the Federal Constitution of 1988 (BRASIL, 1988) and the *Estatuto da Cidade* (City Statute), instituted by Law No. 10,257/2001¹, it constitutes the basic instrument of urban development and expansion policy. Its function is not limited to the technical organisation of the municipal territory. The plan articulates land-use guidelines, urban planning instruments, social participation, development strategies, and guidance for the actions of public authorities and private actors. It is therefore a normative device through which different agendas may be incorporated into municipal planning, including sustainability, innovation, urban governance, and digital transformation (Bodnar; Priess; Bianchi, 2019).

The institutional character of the Master Plan becomes clearer when placed within the trajectory of Brazilian urban policy. Caldeira and Holston (2015) show that the City Statute reframed urban planning in the country by linking the preparation and revision of Master Plans to public participation and to the fulfilment of the social functions of the city. From this perspective, the plan ceases to be merely a technical instrument for territorial ordering and becomes an arena of contestation over the direction of urban development. Walker and Friendly (2024) reinforce this interpretation by treating master planning as a process, rather than merely a legal product, involving approval, implementation, monitoring, complementary regulations, programmes, and projects that carry the document forward in the day-to-day practice of urban governance.

This distinction between plan, process, and implementation is decisive for the argument of this chapter. The planning literature shows that the existence of a plan should not be confused with its practical effectiveness (Caldeira; Holston, 2015). In the Brazilian case, the assessment of post-City Statute Master Plans indicates that the broad

¹ In this study, the edition consulted is Brasil (2008a), which brings together the *Estatuto da Cidade* (City Statute) and related legislation.

formal incorporation of the instruments provided for in urban legislation coexisted, in many cases, with limited regulation, insufficient territorial delimitation, and difficulties in translating guidelines into concrete action (Santos Junior; Montandon, 2011).

Mastop and Faludi (1997) also criticise the evaluation of plans based solely on the conformity between planned content and observed outcomes, since plans operate as reference points for subsequent decisions, guiding interpretations, justifications, and choices in concrete situations. Berke et al. (2006), in turn, emphasise that implementation depends on the quality of the document, the practices of the agencies responsible for applying it, technical capacity, monitoring instruments, and the institutional conditions that allow guidelines to be translated into effective decisions.

The notion of institutional capacity proposed by Healey (1998) allows this argument to be taken further. For the author, the transformative capacity of urban policies is associated with the quality of local public policy cultures, social and institutional networks, access to knowledge, the ability to mobilise actors, and the construction of shared discourses about the future of places. Urban policies that seek to alter territorial trajectories therefore require more than formal documents. They depend on capacities accumulated within local policy communities, forms of coordination among actors, and the existence of arenas in which different forms of knowledge can be articulated.

This framework makes it possible to distinguish between two events that, although closely related from a legal standpoint, have distinct institutional meanings: the initial adoption and the revision of a Master Plan. Adoption represents the municipality's formal entry into an urban planning regime. It creates a normative basis, defines principles, organises instruments, and establishes guidelines that may not previously have existed in a systematic form. However, because it corresponds to an initial stage of institutionalisation, its approval does not necessarily imply accumulated experience, consolidated technical routines, administrative capacity, or stable mechanisms for articulating planning, budgeting, and execution. The first plan may inaugurate the institutional language of planning, but it does not ensure that this language has already been incorporated into the day-to-day operation of local administration.

Revision, in turn, takes place within a pre-existing institutional framework. Even if the previous plan had limitations, its existence indicates that the municipality has already gone through some process of preparing, debating, approving, and possibly applying urban planning guidelines. Revision tends to mobilise an earlier trajectory, composed of documents, diagnoses, administrative practices, political disputes, participatory channels, regulated instruments, and organisational learning. Revising a Master Plan is not simply a matter of producing a new law. It involves altering a normative structure already familiar to local actors, with some degree of embeddedness in the functioning of municipal urban policy.

The Brazilian literature on urban planning reinforces this interpretation by showing that the effects of plans depend on the relations between formal institutions, local practices, and concrete conditions of implementation (Rocco; Royer; Gonçalves, 2019). Studies on the preparation and revision of Master Plans indicate that planning processes are influenced by enduring formal and informal institutions, which shape technical repertoires, administrative practices, and forms of participation over time (Follador; Duarte; Carrier, 2022). Similarly, analyses of participatory planning show that the existence of legal instruments and institutional channels does not eliminate disputes, economic interests, and power relations that condition urban decisions (Friendly, 2019).

Against this background, the maturity of urban planning can be understood as an accumulated institutional condition. It is not limited to the age of the plan or to the number of formal revisions, but involves administrative experience, normative familiarity, coordination capacity, participatory practices, organisational learning, and recognition of the plan as a reference for public and private decisions. Municipalities adopting their first Master Plans tend to be at an initial stage of planning institutionalisation, whereas municipalities revising the instrument may have greater capacity to absorb new agendas, reinterpret priorities, and coordinate changes from an already established basis.

This distinction matters for analysing the incorporation of contemporary agendas into municipal planning. In the case of smart cities, the presence of terms and guidelines in the legal text should be interpreted as a normative and programmatic inscription, not as direct evidence of full implementation. The literature on smart cities has drawn attention to the gap between discourse, strategy, and practice, especially when broad initiatives are converted into sectoral or fragmented projects, or into projects dependent on specific local capacities (Caragliu; Del Bo, 2022; Chen; Deng; Schneider, 2024; Fernandez-Anez; Fernández-Güell; Giffinger, 2018).

The literature on smart city maturity points in the same direction, highlighting that the uptake of new practices depends on administrative resources, technical knowledge, documentation, trust in engagement processes, and the social conditions for participation (Anschütz; Ebner; Smolnik, 2024; Bouzguenda; Alalouch; Fava, 2020).

The analytical implication is that institutional change associated with the Master Plan does not operate automatically. It depends on the municipality's capacity to translate guidelines into instruments, decisions, investments, and forms of territorial coordination. When this conversion takes place, the plan ceases to be merely a normative document and begins to bear on urban attributes that affect the municipality's relative position within its regional context. This is where the discussion of the maturity of urban planning converges with regional and urban economics, since the effects of municipal institutional change also depend on the forces of concentration, diffusion, and differentiation that structure relations between cities and regions.

6.2.2 Smart cities, regional forces and intra-regional economic equilibrium

The preceding discussion makes it possible to treat the incorporation of the smart city agenda into Master Plans as a potential institutional change, conditioned by the maturity of local urban planning. The question, then, is why this change may have effects beyond the municipality that alters its planning instrument. The starting point is that the smart city agenda, when incorporated into urban planning, may reorganise expectations, guidelines, and priorities related to attributes that affect the municipality's attractiveness, public-sector coordination, service provision, infrastructure, and territorial articulation.

For this argument to hold, the smart city must be understood as a multidimensional concept, rather than as a synonym for urban digitalisation. The well-established literature on the subject associates urban smartness with a combination of economy, mobility, governance, environment, quality of life, human capital, technological infrastructure, and social participation (Caragliu; Del Bo; Nijkamp, 2011; Giffinger et al., 2007; Yigitcanlar et al., 2019).

This interpretation also appears in recent studies that highlight how definitions and models of smart cities vary according to regional, cultural, technological, and institutional contexts (Vanli; Akan, 2023; Yang; Zhen, 2024). In Brazil, the *Carta Brasileira para Cidades Inteligentes* (Brazilian Charter for Smart Cities) follows a similar orientation by linking digital transformation, sustainable urban development, inclusion, governance, the responsible use of data, the reduction of inequalities, and multi-scalar territorial articulation (BRASIL, 2021).

This broad conception is particularly important in contexts marked by structural heterogeneities. In their discussion of Latin American cities, Marchetti, Oliveira and Figueira (2019) argue that models formulated on the basis of experiences in the Global North cannot simply be transplanted to realities characterised by infrastructure deficits, urban inequalities, fragile governance, and persistent socioeconomic constraints. The argument shifts the analysis away from a generic question of whether a city “is” or “is not” smart, towards a more situated question, concerned with how this agenda is appropriated by municipalities with different capacities, hierarchical positions, and regional conditions.

Understood in this way, the smart city agenda can be understood as an urban policy capable of modifying locational attributes. Investments in connectivity, mobility, environmental management, governance, public services, innovation, and quality of life may alter how households, workers, and firms perceive the net benefits of locating in a given municipality. This interpretation brings the smart cities literature closer to urban and regional economics, especially to approaches that relate locational choice, agglomeration economies, transport costs, accessibility, and territorial differentials (Capello, 2015; Fujita; Thisse, 2002, 2009; Krugman, 1991).

From an urban perspective, these decisions depend on the relationship between

agglomeration advantages, accessibility, the availability of labour, infrastructure, service quality, and economic opportunities. Cities concentrate urbanisation economies, diversified markets, and expanded possibilities for interaction among agents, but these benefits may be counterbalanced by diseconomies associated with congestion, rising land prices, and environmental costs (Alonso, 1971; Camagni; Capello; Caragliu, 2013; Fujita; Thisse, 2002; Glaeser, 2011). Smart city strategies may affect some of these attributes by changing conditions of mobility, connectivity, public management, service provision, and environmental quality.

The literature offers evidence consistent with this interpretation. Thite (2011) emphasises that cities and regions increasingly compete to attract and retain skilled workers through the provision of urban amenities, connectivity, and quality of life. Chen et al. (2023) show that smart city initiatives may influence population flows by improving environmental conditions and expanding access to information. These results should not be mechanically transposed to the Brazilian case, but they suggest a plausible transmission channel: by altering urban attributes as perceived by economic agents, the smart city agenda may affect locational decisions and, consequently, the relative position of municipalities within their regional contexts.

The focus of this chapter is not isolated urban performance, but the way in which changes in the locational attributes of municipalities may modify their participation in the regional economic structure. Municipalities are part of territorial systems marked by economic, functional, and institutional interdependencies (Galindo; Tavares, 2020). Changes in the attractiveness, service provision, coordination capacity, or locational conditions of a locality may affect the spatial distribution of population, economic activities, and opportunities in its surroundings. Tranos and Gertner (2012) reinforce this interpretation by arguing that cities do not exist in isolation, but within networks of interdependence in which they compete, collaborate, and position themselves in relation to other centres.

This interpretation is in dialogue with the tradition of regional economics that understands development as a spatially selective process. In Perroux, Hirschman, and Myrdal, growth tends to emerge from poles, sectors, or urban centres capable of organising relations of attraction, dependence, spread, and backwash (Hirschman, 1958; Myrdal, 1957; Perroux, 1955, 1982). This tradition makes it possible to distinguish situations in which urban centrality favours the diffusion of opportunities and productive complementarities from those in which concentration reinforces asymmetries without producing proportional transformations in the surrounding area.

The New Economic Geography reformulates part of this intuition in terms of increasing returns, transport costs, factor mobility, and market effects (Fujita; Thisse, 2002, 2009; Krugman, 1991). In this approach, the spatial concentration of economic activity emerges from cumulative processes in which firms and workers respond to the density

of demand, economies of scale, and interaction costs. At the same time, concentration itself may generate dispersion forces associated with the rising cost of less mobile factors, congestion, and the reduction of the net benefits of urban location (Alonso, 1971; Camagni; Capello; Caragliu, 2013; Capello, 2015). Intra-regional economic equilibrium therefore results from the tension between forces of attraction and dispersion.

The literature on smart cities suggests that the effects of this agenda also depend on the characteristics of places and of the territorial networks in which cities are embedded. Caragliu and Del Bo (2012) show that the effects of smart attributes on urban performance vary according to specific spatial characteristics. Hao, Chen and Min (2021) indicate that smart city development does not operate, in isolation, as an automatic mechanism of regional coordination, since its effects depend on interactions with broader processes of urban expansion and spatial reorganisation. Taken together, these contributions support a cautious interpretation: urban smartness may affect regional equilibrium, but its effects are conditioned by place, network position, and mode of implementation.

In the Brazilian case, this caution carries even greater weight. As discussed in the previous chapters, the smart city agenda appears in municipalities of different sizes, with varied solutions that are strongly conditioned by local sociocultural, institutional, and territorial realities (BRASIL, 2021a). This heterogeneity occurs within an urban network marked by different administrative capacities, economic densities, degrees of centrality, and hierarchical positions (Galindo; Tavares, 2020; IBGE, 2019b). Thus, the incorporation of smart city strategies tends to assume different meanings according to the regional function performed by each locality, which is consistent with the territorially sensitive conception adopted by the Brazilian Charter for Smart Cities (BRASIL, 2021).

The incorporation of the smart city agenda into the Master Plans of Brazilian municipalities can therefore be understood as a possible change in the institutional and locational conditions that structure intra-regional economic equilibrium. This change may reinforce centralities, foster diffusion, or remain confined to the normative level, depending on the municipality's institutional maturity, its position within the urban network, and the regional forces that condition its relations with other municipalities.

6.2.3 Synthesis of the argument and research hypotheses

The discussion developed so far makes it possible to translate the relationship between urban planning, the smart city agenda, and regional dynamics into a specific empirical formulation. The argument does not assume that smart cities produce homogeneous effects on economic inequalities, nor that the mere presence of the agenda in the Master Plan is sufficient to alter territorial trajectories. The more specific hypothesis is that the incorporation of this agenda may modify the institutional and locational attributes of municipalities when it encounters conditions of implementation, coordination capacity,

and some degree of maturity in local urban planning.

This formulation shifts the focus from a conventional urban evaluation to a regional perspective. The interest is not in verifying whether municipalities become “smarter” following changes to the Master Plan, but in observing whether the stronger incorporation of this agenda alters the way in which they participate in the economic composition of their regions. The planning literature informs the role of institutions, implementation, and maturity; regional economics informs the channels² through which local changes may affect centrality, diffusion, concentration, and territorial dependence.

It also guides the way in which intra-regional inequality is observed empirically. Since Brazilian municipalities are not treated as isolated units, but as parts of a nested regional structure (IBGE, 2017), the interest does not lie in a counterfactual in which the municipality is removed from its region. The aim is to observe how its economic position, weighted by the territorial structure in which it is embedded, contributes to the composition of the intra-regional component of inequality. This choice is compatible with the urban network perspective mobilised in this study (Galindo; Tavares, 2020), as it simultaneously preserves the municipal scale of the treatment, the immediate scale of functional interactions, and the intermediate scale of regional articulation.

Accordingly, the empirical question of this chapter should not be framed as a general question of whether smart cities increase or reduce inequalities. The central point is more specific: to understand whether the stronger incorporation of this agenda into Master Plans alters the way in which municipalities participate in the economic composition of their regions. In terms of the variable of interest adopted in the chapter, this means investigating whether such incorporation modifies the municipal additive contribution to the intra-regional component of GDP per capita inequality. The research question can therefore be formulated as follows: does the stronger incorporation of the smart city agenda into municipal Master Plans alter the additive contribution of municipalities to the intra-regional component of economic inequality?

This question has three analytical implications. First, the treatment of interest is not the existence of the Master Plan, nor the formal act of approving, revising, or adopting it. The focus lies on the relative intensity with which the smart city agenda is incorporated into the document at the moment of institutional change. Second, revised plans and initially adopted plans are not treated as equivalent events, since they correspond to different stages in the institutionalisation of urban planning. Third, the expected effects are not uniform, as they depend both on the maturity of municipal planning and on the position occupied by the municipality within the urban and regional network.

On this basis, the first hypothesis distinguishes the revision of the Master Plan as an institutional context in which the incorporation of the smart city agenda tends to

² For a more detailed discussion of the channels of regional change, see Chapter 2.

encounter greater absorptive capacity. The literature on the implementation and evaluation of plans suggests that planning instruments do not produce effects automatically, but operate as references for subsequent decisions, depending on the capacities, practices, and institutional arenas that allow them to be used effectively (Berke et al., 2006; Mastop; Faludi, 1997).

Municipalities that revise their plans already have, to some extent, a prior planning trajectory, composed of documents, administrative repertoires, participatory experiences, urban planning instruments, and coordination routines. This trajectory may expand the knowledge resources, relational ties, and mobilisation capacity that Healey (1998) associates with the construction of institutional capacity in urban planning. Under these conditions, the stronger incorporation of the smart city agenda is more likely to be converted into decisions and practices that alter urban attributes and regional relations. Thus:

H1. In municipalities that revise their Master Plans, the stronger incorporation of the smart city agenda tends to reduce the municipal additive contribution to the intra-regional component of economic inequality.

The negative sign proposed in H1 is a directional conjecture for this application, rather than a general implication of urban economics or of the inequality decomposition. Planning changes can influence production, residential location and the economic weight of a municipality in different directions. Moreover, the dependent variable is a signed additive term. A reduction in that term need not imply convergence or a fall in aggregate inequality. The conjecture is therefore assessed jointly with the auxiliary outcomes and the identification diagnostics, and its interpretation remains conditional on the economic position of the municipality and on changes elsewhere in the region.

The second hypothesis builds on the distinction between revision and adoption. The initial adoption of the Master Plan represents the municipality's formal entry into an urban planning regime, but it does not ensure that technical capacities, administrative routines, regulated instruments, and coordination mechanisms are consolidated. This caution is consistent with the literature on plan implementation and evaluation, according to which planning instruments do not produce effects automatically, since their capacity to guide change depends on how they are mobilised in subsequent decisions and on the institutional conditions that sustain their implementation (Berke et al., 2006; Mastop; Faludi, 1997).

From the perspective of institutional capacity, the approval of the first plan may create a normative basis, but it does not yet ensure the existence of the knowledge resources, relational ties, and mobilisation capacity required to transform guidelines into public action (Healey, 1998). Thus, even when the smart city agenda appears more strongly in the document, its incorporation may remain closer to an initial programmatic orientation than to an institutional change effectively absorbed into local planning. Therefore, it is

assumed that:

H2. The stronger incorporation of the smart city agenda into initially adopted Master Plans tends to produce less systematic effects on the municipal additive contribution to the intra-regional component of economic inequality.

This hypothesis derives from the literature that distinguishes between the plan, implementation, and institutional capacity. The first Master Plan may inaugurate a normative language of planning, but its effects depend on subsequent processes of regulation, administrative learning, political coordination, and resource mobilisation (Santos Junior; Montandon, 2011). For this reason, the incorporation of the smart city agenda into initially adopted plans is expected to produce less consistent effects than those observed in revision processes.

The third hypothesis introduces the territorial dimension of the argument. The literature in regional and urban economics indicates that the position of a locality within the urban network conditions its capacity to attract resources, organise flows, concentrate functions, generate linkages, and diffuse effects to surrounding areas (Fritsch; Wyrwich, 2021; McCann, 2008; Shearmur; Doloreux, 2008). This interpretation is compatible with approaches to urban systems and agglomeration economies, in which urban size, functional specialisation, accessibility, and network position condition the distribution of firms, workers, services, and economic opportunities (Capello, 2015; Henderson, 1986).

In the Brazilian case, this interpretation is in dialogue with IBGE's *Regiões de Influência das Cidades* (Areas of Influence of Cities, REGIC) study (IBGE, 2019b) and with the *Divisão Regional do Brasil* (Regional Division of Brazil) (IBGE, 2017), both of which draw on the urban network, management flows, and the supply of urban functions to understand the territorial articulation of municipalities.

Thus, higher-order centres may convert smart city strategies into gains in centrality and greater capacity for regional articulation; intermediate municipalities may strengthen their intermediation functions; and local centres may face greater constraints in transforming normative changes into regionally observable economic effects. The direction of these effects, however, should not be defined *a priori*, since the tradition of regional polarisation shows that dynamic centres may generate both diffusion and backwash effects (Hirschman, 1958; Krugman, 1991; Perroux, 1955). Accordingly, it is hypothesised that:

H3. The effects of incorporating the smart city agenda are heterogeneous according to the municipality's position in the urban hierarchy.

This premise makes it possible to assess whether the smart city agenda operates differently according to the regional function performed by the municipality. It also avoids a linear interpretation whereby larger cities would necessarily generate positive regional effects, while smaller cities would merely reinforce dependencies. The argument is more cautious, suggesting that the urban hierarchy conditions the policy transmission channels,

but that the direction and intensity of the effects depend on the relationships established between centrality, institutional capacity, economic base, and territorial articulation.

Finally, the fourth hypothesis returns to the idea of maturity discussed in the previous subsection. The revision of the Master Plan may occur in municipalities with different degrees of prior familiarity with the smart city agenda. When the previous plan already contained more frequent references to themes associated with urban smartness, the new incorporation of the agenda may rely on partially established normative and administrative repertoires. When this prior presence is low, revision may represent a more incipient change, with less capacity to produce observable effects in the short term. Therefore:

H4. Among municipalities that revise their Master Plans, the effects of incorporating the smart city agenda may vary according to the degree of prior documentary maturity of this agenda within local urban planning.

This hypothesis should be interpreted as an extension of the institutional argument, rather than as a complete measure of municipal state capacity. Prior documentary maturity indicates the degree to which the smart city agenda was already present in the normative vocabulary of the previous plan. It does not exhaust the municipality's administrative, fiscal, or political capacities, but it makes it possible to observe whether revision builds on a prior planning repertoire or represents a more recent incorporation of the theme.

The hypotheses concerning institutional event, urban hierarchy and documentary maturity organise exploratory comparisons. They do not identify the mechanisms that generate any differences found. Initial adoption and revision also use different documentary margins, respectively the content of the initial plan and newly appearing content relative to a previous plan. Their estimates should not be interpreted as the effects of an identical intervention applied to otherwise comparable groups. Failure to reject a zero effect is not evidence of equivalence, and differences in statistical significance across groups are not themselves tests of differences between effects.

Taken together, these hypotheses organise the chapter's analytical strategy. The first two distinguish revision and adoption as distinct institutional events. The third incorporates the territorial dimension, associated with the urban hierarchy and regional forces. The fourth qualifies the interpretation of the effects among municipalities that revise their plans, considering their prior normative familiarity with the smart city agenda. The empirical analysis therefore does not start from the assumption that smart cities produce homogeneous effects on regional inequality, but from the hypothesis that their effects depend on the interaction between institutional change, the maturity of urban planning, and the municipality's position within the regional structure, expressed by the municipal additive contribution to the intra-regional component of inequality.

6.3 Intra-regional inequality, generalised entropy and the municipal additive contribution

The previous section defined the municipal additive contribution to the intra-regional component of inequality as the empirical object of the chapter. This section presents the construction of this dependent variable. To this end, it discusses the choice of decomposable inequality measures, the adoption of the Theil T index as the main indicator, the use of $GE(0)$ and $GE(2)$ as consistency exercises, and the nested regional decomposition that links municipalities, Immediate Geographic Regions, and Intermediate Geographic Regions.

6.3.1 Why use decomposable measures of inequality?

Measuring economic inequality involves, first and foremost, a conceptual choice. As Atkinson (1970) argues, inequality indices are not neutral descriptive instruments, since they incorporate specific properties, different degrees of sensitivity to parts of the distribution, and different ways of representing distances from a situation of equality. Cowell (2000) reinforces this point by showing that the choice of a measure depends on the type of question to be answered, the unit of analysis, the variable observed, and the properties desired for comparing distributions. In this chapter, the choice of indicator follows from the need to measure the municipal contribution to the composition of an inequality defined at the regional scale.

This requirement makes additive decomposability a central property. In the inequality literature, a measure is considered additively decomposable when total inequality can be expressed as the sum of one component associated with inequality within groups and another associated with differences between groups. Bourguignon (1979), Cowell (1980), and Shorrocks (1980) show that this property is not trivial, as it restricts the set of appropriate measures when the research question involves separating inequality into components internal and external to the groups under analysis. As Shorrocks (1980) emphasises, additive decomposition makes it possible to express total inequality as a weighted sum of the inequalities calculated for subgroups, plus the contribution derived from differences between the means of those subgroups.

This property is particularly suitable for regional analyses. Shorrocks and Wan (2005) argue that, when the interest lies in spatial disparities, it is necessary to separate the share of inequality associated with geographical location. Spatial decomposition makes it possible to distinguish the inequality observed within regions from that associated with differences between regions, avoiding the treatment of territory as merely a descriptive category.

Akita (2003), in turn, shows that the nested decomposition of Theil indices makes it possible to work with hierarchical territorial structures, such as country, region, province, and district, decomposing total inequality into components at different spatial levels. This

logic is close to that adopted in this study, in which municipalities belong to Immediate Geographic Regions, which in turn are nested within Intermediate Geographic Regions.

The choice of decomposable measures also justifies not using the Gini index as the main indicator. The Gini has a long tradition in distributional analysis, especially because of its relationship with the Lorenz curve and its intuitive interpretation in terms of mean differences between units. Works such as Pyatt (1976) and Dagum (1997) show that the index can be explored in decomposition exercises. However, its structure does not generally offer the same direct additive decomposition observed in generalised entropy indices. When there is overlap between subgroup distributions, the decomposition of the Gini tends to generate a residual interaction term, associated with transvariation or re-ranking between groups (Lambert; Aronson, 1993). Shorrocks and Wan (2005) also observe that the Gini is not generally subgroup consistent, which limits its use when the aim is to decompose inequality in a way that is directly compatible with territorial groupings.

The issue, therefore, is not the general inadequacy of the Gini, but its more limited suitability for the specific question addressed in this chapter. Since the interest lies in the municipal additive contribution to the intra-regional component of inequality, the measure used must allow inequality to be decomposed additively and coherently with the spatial structure of the analysis. The generalised entropy family meets this requirement, as it combines desirable properties for distributional comparisons, such as scale independence, transfer sensitivity, and decomposability by subgroups. For this reason, its indices constitute the basis of the dependent variable used in this study.

6.3.2 The Theil T index as the main measure: GE(1)

The main measure adopted in this chapter is the Theil T index, corresponding to the GE(1) member of the generalised entropy family. The origin of this approach lies in Theil (1967), who introduced inequality measures based on information theory, associating inequality with the distance between an observed distribution and a situation of equality. In the subsequent literature, the Theil T index came to occupy a central position among decomposable measures, precisely because it allows an additive separation between within-group and between-group components, a feature explored by Bourguignon (1979), Cowell (1980), and Shorrocks (1980).

Considering a population distributed across n municipalities, let y_i denote the GDP per capita of municipality i , μ the population-weighted mean, and p_i the municipality's population share within the group under consideration. For $\alpha \neq 0$ and $\alpha \neq 1$, the generalised entropy family can be represented as:

$$GE(\alpha) = \frac{1}{\alpha(\alpha - 1)} \sum_{i=1}^n p_i \left[\left(\frac{y_i}{\mu} \right)^\alpha - 1 \right] \quad (6.1)$$

For $\alpha = 1$, the Theil T index is obtained:

$$GE(1) = T = \sum_{i=1}^n p_i \left(\frac{y_i}{\mu} \right) \ln \left(\frac{y_i}{\mu} \right) \quad (6.2)$$

Since $p_i(y_i/\mu)$ corresponds to the municipality's share of the group's total income, the Theil T index can be interpreted as a sum weighted by the economic share of the units. This property makes the index sensitive to relative differences between income share and population share, which is particularly appropriate when working with GDP per capita inequality. In regional terms, the index makes it possible to observe the extent to which certain municipalities concentrate an economic share above or below that which would be consistent with their population share.

The decomposability of the Theil T index is the main reason for adopting it as the central measure. When the population is divided into mutually exclusive and exhaustive groups, the index can be written as the sum of a within-group component and a between-group component. In the regional context, this makes it possible to separate inequality between regions from inequality observed within regions. Akita (2003) explores precisely this property in a nested territorial decomposition, showing that the Theil T index can be applied to hierarchical spatial structures in order to distinguish components between large regions, between intermediate units, and within the most disaggregated units. This feature is central to the present application, since the analysis is based on a territorial structure in which municipalities are contained within Immediate Geographic Regions, which in turn are nested within Intermediate Geographic Regions.

The adoption of the Theil T index is compatible with the nature of the dependent variable constructed in this chapter. Since the analysis observes the additive term through which each municipality participates in the composition of the intra-regional component of inequality, the measure must preserve the contribution of territorial units within a nested regional structure. The Theil T index provides an appropriate basis for this measurement by combining decomposability, interpretation in terms of relative economic participation, and a long-standing tradition in studies of regional inequality.

Even so, the choice of $GE(1)$ does not eliminate the need to examine whether the results depend on the distributional sensitivity of the index. For this reason, $GE(0)$ and $GE(2)$ are used as alternative measures within the same generalised entropy family, as discussed in the following subsection.

6.3.3 Alternative measures: $GE(0)$ and $GE(2)$

The use of $GE(0)$ and $GE(2)$ as alternative measures aims to assess the robustness of the results to the choice of parameter in the generalised entropy family. As Shorrocks (1980) observes, the class of additively decomposable and mean-independent measures can

be represented by a one-parameter family, which makes it possible to vary the index's sensitivity to different parts of the distribution. This property is useful because regional inequality may be affected both by differences associated with relatively less dynamic municipalities and by gaps associated with municipalities located at the top of the GDP per capita distribution.

The first alternative indicator is $GE(0)$, also known as the Mean Logarithmic Deviation. Its population-weighted form is defined as:

$$GE(0) = \sum_{i=1}^n p_i \ln \left(\frac{\mu}{y_i} \right) \quad (6.3)$$

Unlike the Theil T index, which uses weights associated with income shares, $GE(0)$ is weighted by population shares. Akita (2003) observes that this feature makes the index more sensitive to changes at the lower end of the distribution, that is, to units with lower relative income. Shorrocks and Wan (2005) also emphasise that $GE(0)$ has a particularly attractive property in decomposition exercises, since its separation between within-group and between-group components is less sensitive to the order in which these differences are eliminated. In the context of this application, $GE(0)$ makes it possible to verify whether the main results hold when the inequality measure gives greater relative weight to municipalities with lower GDP per capita.

The second alternative indicator is $GE(2)$, which corresponds to half the squared coefficient of variation:

$$GE(2) = \frac{1}{2} \sum_{i=1}^n p_i \left[\left(\frac{y_i}{\mu} \right)^2 - 1 \right] \quad (6.4)$$

By assigning greater weight to differences in the upper part of the distribution, $GE(2)$ is more sensitive to the presence of municipalities with relatively high GDP per capita. This property makes it useful as a robustness exercise, as it allows an assessment of whether the estimated effects are influenced by units located further from the regional mean. While $GE(0)$ shifts attention to the lower part of the distribution, $GE(2)$ increases sensitivity to municipalities located in the upper part, providing an appropriate contrast to the Theil T index.

The choice of $GE(0)$ and $GE(2)$ does not alter the central logic of the analysis, since both belong to the generalised entropy family and preserve the property of decomposition by subgroups. What changes is the way in which each measure weights relative distances from the mean. Thus, the three indicators make it possible to assess the same question under different distributional sensitivities.

If the results obtained for $GE(1)$ also hold under $GE(0)$ and $GE(2)$, the interpretation gains greater stability. If there are differences between the indicators, these

differences may be read as evidence that the effects of incorporating the smart city agenda are concentrated in specific parts of the regional GDP per capita distribution.

6.3.4 Municipal additive contribution to the intra-regional component of inequality

The definition of the regional scale constitutes a central step in the construction of the dependent variable. Since the treatment of interest occurs at the municipal level, while the substantive hypothesis involves possible effects on the municipality's position within its economic surroundings, the regional reference unit should neither be so broad as to dilute local interactions nor restricted to a purely contiguous neighbourhood, unable to capture functional links between cities. For this reason, the analysis uses the Immediate Geographic Regions, here abbreviated as ImGRs, as the intra-regional reference layer, embedded within the Intermediate Geographic Regions, abbreviated in this study as IntGRs.

The 2017 Regional Division of Brazil defines ImGRs on the basis of the urban network, taking as reference nearby urban centres that organise the fulfilment of the population's immediate needs, such as the consumption of goods, the search for work, access to health and education services, and the use of public services. IntGRs, in turn, correspond to a scale situated between the Federative Units and the ImGRs, articulating the latter through higher-order centres, public and private management flows, and more complex urban functions (IBGE, 2017). This structure is particularly suitable for the problem investigated because it combines territorial proximity, urban centrality, and functional links between municipalities.

From an operational standpoint, the dependent variable does not correspond to the inequality index calculated directly for each ImGR, nor to a counterfactual in which the municipality is removed from the regional distribution. The measure used corresponds to the municipal additive term that makes up the intra-regional component of inequality in the decomposition of generalised entropy indices. This choice is consistent with the nature of the treatment analysed. The incorporation of the smart city agenda into the Master Plan does not remove the municipality from its region, but it may alter its relative position in the observed economic distribution. The interest therefore lies in the way in which the municipality participates in the composition of the within component of inequality, while preserving the nested structure between municipalities, ImGRs, and IntGRs.

Formally, let h be an IntGR, r an ImGR belonging to h , i a municipality belonging to r , and t the year. Let Y_{it} denote municipal GDP at constant prices, N_{it} municipal population, $y_{it} = Y_{it}/N_{it}$ municipal GDP per capita, Y_{rt} and N_{rt} the GDP and population of the ImGR, and Y_{ht} and N_{ht} the GDP and population of the IntGR. Define $\mu_{rt} = Y_{rt}/N_{rt}$ as the mean GDP per capita of the ImGR, $\mu_{ht} = Y_{ht}/N_{ht}$ as the mean GDP per capita of the IntGR, $s_{rt} = N_{rt}/N_{ht}$ as the population share of the ImGR within the IntGR, and

$b_{rt} = \mu_{rt}/\mu_{ht}$ as the relative mean income of the ImGR.

For $\alpha \neq 0, 1$, inequality within ImGR r is given by:

$$GE_{\alpha,rt} = \frac{1}{\alpha(\alpha-1)} \sum_{i \in r} \frac{N_{it}}{N_{rt}} \left[\left(\frac{y_{it}}{\mu_{rt}} \right)^\alpha - 1 \right] \quad (6.5)$$

In the decomposition of IntGR inequality, the intra-regional component, or within component, is:

$$W_{\alpha,ht} = \sum_{r \in h} s_{rt} b_{rt}^\alpha GE_{\alpha,rt} \quad (6.6)$$

This expression shows that the intra-regional inequality of the IntGR is formed by the sum of the inequalities within the ImGRs, weighted by the population share and relative mean income of each ImGR. From this decomposition, it is possible to identify the municipal additive term that composes $W_{\alpha,ht}$. For $\alpha \neq 0, 1$, this term is defined as:

$$AC_{irht}^{(\alpha)} = \frac{1}{\alpha(\alpha-1)} \frac{N_{it}}{N_{ht}} b_{rt}^\alpha \left[\left(\frac{y_{it}}{\mu_{rt}} \right)^\alpha - 1 \right] \quad (6.7)$$

By construction:

$$W_{\alpha,ht} = \sum_{r \in h} \sum_{i \in r} AC_{irht}^{(\alpha)} \quad (6.8)$$

In the case of the Theil T index, corresponding to GE(1), the municipal additive term takes the form:

$$AC_{irht}^{(1)} = \frac{Y_{it}}{Y_{ht}} \ln \left(\frac{y_{it}}{\mu_{rt}} \right) \quad (6.9)$$

This is the main variable used in the chapter. It measures the signed additive contribution of the municipality to the intra-regional component of inequality. The expression combines three elements: the municipality's economic share within the IntGR, its relative position in relation to the mean GDP per capita of its ImGR, and the position of this ImGR within the broader regional structure. Therefore, the immediate scale enters as the functional reference for the municipal comparison, while the intermediate scale provides the regional total against which the contribution is weighted.

For the consistency exercises, the additive terms corresponding to GE(0) and GE(2) are also constructed. In the case of GE(0), the term is given by:

$$AC_{irht}^{(0)} = \frac{N_{it}}{N_{ht}} \ln \left(\frac{\mu_{rt}}{y_{it}} \right) \quad (6.10)$$

In the case of GE(2), the term is given by:

$$AC_{irht}^{(2)} = \frac{1}{2} \frac{N_{it}}{N_{ht}} \left(\frac{\mu_{rt}}{\mu_{ht}} \right)^2 \left[\left(\frac{y_{it}}{\mu_{rt}} \right)^2 - 1 \right] \quad (6.11)$$

The interpretation of these terms requires caution. Unlike an aggregate inequality index, which is non-negative, the municipal term of the decomposition may take positive or negative values. In the case of GE(1), municipalities with GDP per capita above the mean of their ImGR tend to have positive terms, whereas municipalities below this mean may present negative terms. These signs do not, in isolation, indicate that a given municipality is “good” or “bad” for the region. They indicate only the direction of the municipality’s algebraic contribution to the intra-regional component of inequality, given its relative economic position and its weight in the regional structure.

The municipal term is an accounting contribution to a nested decomposition, rather than a stand-alone non-negative inequality index or the causal contribution of the municipality to regional inequality. Consequently, a negative estimated effect on this term cannot, by itself, be interpreted as a reduction in aggregate intra-regional inequality. Its sign and magnitude depend jointly on the municipality’s GDP per capita relative to its ImGR and on its economic weight within the IntGR. Changes elsewhere in the regional distribution can therefore alter the municipal term even when local output and population remain unchanged.

For the Theil T specification, this relational structure can be made explicit by writing the municipal contribution as the product of its economic weight and its relative GDP-per-capita position:

$$\begin{aligned} a_{it} &= \frac{Y_{it}}{Y_{ht}}, & g_{it} &= \ln \left(\frac{y_{it}}{\mu_{rt}} \right), & AC_{irht}^{(1)} &= a_{it} g_{it}. \\ \Delta g_{it} &= \Delta \ln Y_{it} - \Delta \ln N_{it} - \Delta \ln Y_{rt} + \Delta \ln N_{rt}. \\ \Delta AC_{irht}^{(1)} &= \bar{a}_{it} \Delta g_{it} + \bar{g}_{it} \Delta a_{it}. \end{aligned}$$

The first expression separates the municipal term into the municipality’s share of IntGR output, a_{it} , and its log GDP-per-capita gap relative to the ImGR mean, g_{it} . Changes in the latter depend not only on municipal output and population, but also on changes in the corresponding ImGR totals. The relational nature of the outcome therefore makes compositional movements observable without identifying their economic source. In particular, it does not establish whether adjustment occurs through production, population or changes among regional peers, nor does movement towards the regional mean necessarily imply a welfare improvement.

Here, a bar denotes the arithmetic mean of the beginning- and end-period values. The final expression is an exact accounting identity for the change in the product $a_{it} g_{it}$, not a mediation decomposition of the estimated treatment effect.

This choice aligns the measurement of inequality with the municipal nature of the treatment. The Master Plan is a municipal instrument, but its possible effects tend to be expressed in economic relations that are not confined to the municipality's administrative boundaries. For this reason, the treatment unit is municipal, while the distributional reference combines two scales: the ImGR, which approximates the immediate functional space, and the IntGR, which organises the regional decomposition within which this space is embedded.

The ImGR is not assumed to constitute an absolute boundary for municipal economic effects. Municipalities may relate to broader scales, especially when they occupy higher positions in the urban hierarchy (Marguti et al., 2020). Even so, for assessing the possible effects of a municipal normative change associated with the smart city agenda, the ImGR offers a scale consistent with the channels discussed in this chapter, such as functional proximity, daily flows, access to services, urban centrality, and articulation among neighbouring municipalities.

In this way, the municipal additive contribution makes it possible to observe whether the incorporation of the smart city agenda into urban planning alters the way in which the municipality participates in the regional economic structure, without presupposing broad, homogeneous, or unidirectional effects.

6.4 Policy definition, treatment groups and eligibility

This section defines the policy analysed empirically in the chapter and sets out the rules used to construct the comparison groups. The strategy takes as its starting point the events of initial adoption and revision of the Master Plan, but treatment is defined by the content incorporated into the document approved in each event. The identification of treated municipalities therefore combines the institutional timing of urban planning with the relative intensity of incorporation of the smart city agenda. The following subsections present the composite citation index, the treatment rule based on percentile thresholds, and the eligibility criteria used to approximate comparable groups.

6.4.1 Initial adoption and revision of the Master Plan as institutional events

In the empirical design of this chapter, the initial adoption and revision of the Master Plan are used as temporal markers of municipal institutional change. This definition follows from the legal nature of the instrument. In Brazil, the Master Plan is approved by municipal law and constitutes the basic instrument of urban development and expansion policy, guiding the action of public authorities on the use, occupation, and organisation of the municipal territory (Bodnar; Priess; Bianchi, 2019; BRASIL, 1988, 2008b; Gouvea; Ramos Junior; Ramos, 2026). Its approval or amendment therefore does not correspond

to a one-off administrative initiative, but to the normative formalisation of guidelines, instruments, and priorities for local urban planning.

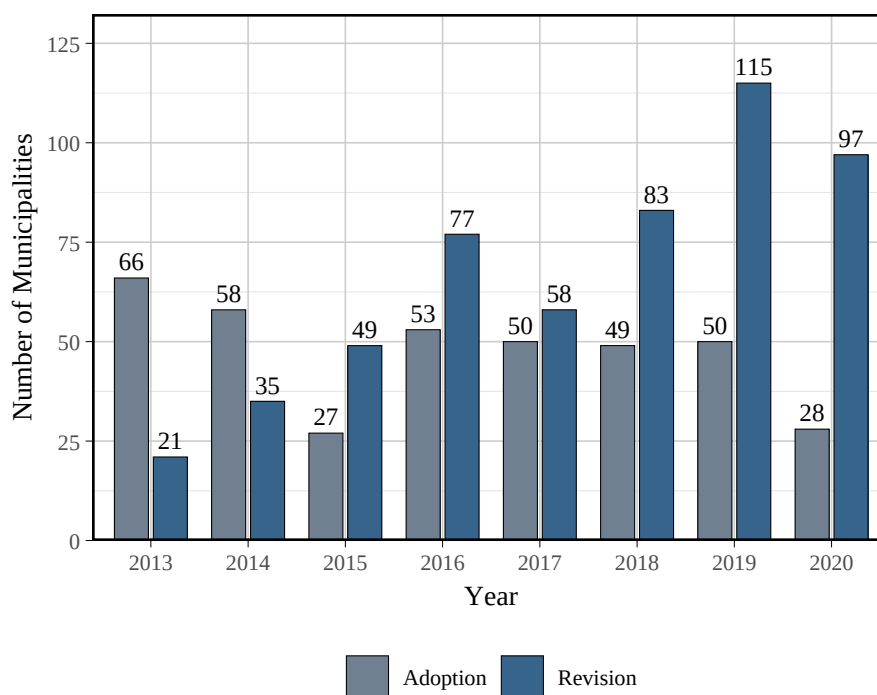
Initial adoption and revision, however, do not have the same institutional meaning. Adoption corresponds to the moment when the municipality formalises, for the first time, a legal framework for urban planning. Revision occurs when the municipality amends or replaces a previously existing plan, reassessing guidelines, instruments, and strategies in light of new urban, economic, environmental, technological, and social conditions. This distinction is consistent with the *Guia para Elaboração e Revisão de Planos Diretores* (Guidelines for Preparing and Revising Master Plans), which treats revision as a process that starts from the plan in force in order to assess its alignment with local reality, the degree of regulation of the instruments provided for, and the need to incorporate new issues into municipal planning (BRASIL, 2023).

This difference guides the analytical separation between the two events. Initial adoption identifies the municipality's formal entry into the institutional regime of the Master Plan. Revision identifies a normative change carried out within an already established planning trajectory. This distinction does not imply assuming that revision always produces stronger effects, nor that initial adoption is incapable of producing change. It merely recognises that the two events correspond to different stages in the municipal trajectory of urban planning.

In the case of the smart city agenda, institutional events perform a specific function. They indicate the year in which the content of the Master Plan is observed and make it possible to distinguish municipalities exposed to changes in planning documents at different points in time. The policy analysed, however, does not correspond simply to the act of approving, adopting, or revising a Master Plan. Treatment is defined by the relatively more intense incorporation of content associated with the smart city agenda into the document approved in that event. Thus, adoption and revision organise the temporality of the analysis, while the content incorporated into the plan defines the empirical exposure of interest.

The temporal distribution of these events reinforces the suitability of the design. Between 2013 and 2020, the adoption and revision of Master Plans occurred in a staggered manner, with municipalities reorganising their planning instruments in different years. As shown in Figure 6.1, revisions become more frequent over the period, especially from 2016 onwards, whereas initial adoptions follow a less uniform trajectory. This temporal variation makes it possible to distinguish cohorts of municipalities exposed to the institutional event in different years, a condition compatible with the application of a multi-period Difference-in-Differences design.

Figure 6.1 - Municipalities adopting and revising Master Plans, 2013-2020



Source: Author's own elaboration based on IBGE (2022b).

Note: The figure reports the number of municipalities that adopted or revised their Master Plans in each year between 2013 and 2020. Adoption refers to the first legal approval of a municipal Master Plan. Revision refers to the approval of a new or amended Master Plan when a previous plan was already in force.

6.4.2 The composite Smart City citation index and its dimensions

Defining the treatment requires a measure capable of capturing the intensity with which the smart city agenda is incorporated into the Master Plan approved in the year of the institutional event. To this end, the citation-based index constructed from the textual analysis of urban planning documents is used. Its logic was presented in the previous chapter; here, only the procedure required for the empirical definition of the policy is revisited.

The index does not measure effective implementation, nor the execution of projects associated with the smart city agenda. It measures the relative presence of content linked to urban smartness in the formal vocabulary of municipal planning. This interpretation is sufficient for the design of this chapter, since the treatment of interest corresponds to the agenda's incorporation into the document at the moment of adoption or revision of the Master Plan.

The measurement is based on a dictionary of terms organised into six dimensions: Economy, Society, Environment, Governance, Technology, and Urban Brands. Each dimension is composed of thematic groups and keyword subgroups, defined on the basis of the smart cities literature and an exploratory reading of Brazilian Master Plans. This

structure makes it possible to align the multidimensional approach to the concept with the language actually used in municipal documents, reducing the risk of treating generic expressions and terms directly associated with urban smartness as equivalent.

For each Master Plan d , a binary variable $S_{d,s}$ is defined for each subgroup s :

$$S_{d,s} = \begin{cases} 1, & \text{if at least one term from subgroup } s \text{ appears in document } d, \\ 0, & \text{otherwise.} \end{cases}$$

This choice prevents documents with excessive repetition of the same expression from receiving an artificially high score. The index therefore does not measure the raw frequency of words, but the thematic diversity of the agenda incorporated into the legal text. The subgroups are then aggregated into thematic groups. For each group g , one has:

$$G_{d,g} = \frac{1}{N_g} \sum_{s \in g} S_{d,s} \quad (6.12)$$

where N_g represents the number of subgroups belonging to group g . The groups are then aggregated into dimensions:

$$D_{d,k} = \frac{1}{N_k} \sum_{g \in k} G_{d,g} \quad (6.13)$$

where N_k represents the number of groups that make up dimension k . This procedure preserves the conceptual structure of the indicator, allowing each dimension to express the relative presence of content associated with its thematic domain.

In the previous chapter, the aggregate Smart City citation index was defined as the average of the six dimensions. For the impact analysis developed in this chapter, this index is adjusted in order to reinforce the presence of subgroups more directly associated with smart city terminology. The reason is substantive. Since the policy of interest is the stronger incorporation of the smart city agenda into the planning document, it would not be appropriate to treat in the same way a plan that mentions only broad terms related to sustainability, mobility, or governance and another that, in addition to these elements, incorporates expressions directly associated with smart systems, equipment, buildings, or urban brands.

Thus, the multidimensional component of the index is initially defined as:

$$B_d = \frac{1}{K} \sum_{k=1}^K D_{d,k} \quad (6.14)$$

where $K = 6$ corresponds to the dimensions Economy, Society, Environment, Governance, Technology, and Urban Brands. Next, a specific component of urban smartness is defined, composed of the simple average of the subgroups most directly associated with smart city terminology:

$$I_d = \frac{1}{6} (S_{d,SE4} + S_{d,L7} + S_{d,L10} + S_{d,UM10} + S_{d,T5} + S_{d,UB2}) \quad (6.15)$$

These subgroups, detailed in Tables 5.6 to 5.11 of Chapter 5, correspond respectively to references to the “smart economy” (*SE4*), smart urban equipment such as smart bins, lighting, drains, and water meters (*L7*), smart or green buildings and green roofs (*L10*), smart systems for urban control and mobility, such as smart control, smart bus stops, and smart traffic lights (*UM10*), smart systems in the Technology dimension (*T5*), and expressions directly associated with smart city branding, such as “smart city”, “zona urbana inteligente”, and “cidade inteligente” (*UB2*).

The composite index used in this chapter is obtained by summing the multidimensional component and the specific component:

$$SC_d^* = B_d + I_d \quad (6.16)$$

This specification preserves the multidimensional nature of the smart city concept, while assigning greater sensitivity to terms that indicate a more explicit incorporation of the agenda. This choice does not replace the substantive dimensions with a technocentric reading of the phenomenon. On the contrary, it preserves the broad structure of the index and adds a component that distinguishes plans whose vocabulary remains within more general urban agendas from those that incorporate terms directly associated with the debate on urban smartness. When necessary to maintain comparability across documents, the index may be rescaled using min-max normalisation:

$$\widetilde{SC}_d^* = \frac{SC_d^* - \min(SC^*)}{\max(SC^*) - \min(SC^*)} \quad (6.17)$$

Since the definition of the treated groups, presented in the following subsection, is based on the relative position of municipalities in the distribution of the index, this transformation does not alter the ordering of the documents. It only facilitates the interpretation of values on a common scale.

The construction of the indicator differs according to the type of institutional event. For municipalities that adopt the Master Plan during the period analysed, the index is calculated directly from the document approved in the year of adoption. In these cases, there is no previous plan from which newly appearing content can be identified. The indicator therefore expresses the degree to which the smart city agenda is present in the first formal framework of municipal urban planning.

For municipalities revising a Master Plan, the measure records positive thematic additions relative to the immediately preceding document. A subgroup receives a value of one when it is present in the revised plan and absent from the previous version, and zero

otherwise. A subgroup that disappears also receives zero under this rule. The measure therefore captures newly appearing content rather than a signed net change in the agenda. It distinguishes additions from the inherited documentary stock, but does not deduct content that has been removed.

$$S_{m,t,s}^{\text{add}} = \max \{0, S_{m,t,s}^{\text{new}} - S_{m,s}^{\text{prev}}\} \quad (6.18)$$

where $S_{m,t,s}^{\text{new}}$ indicates the presence of subgroup s in the Master Plan revised by municipality m in year t , and $S_{m,s}^{\text{prev}}$ indicates its presence in the immediately preceding version of the plan. This definition is appropriate for an estimand concerning the introduction of new themes. It does not imply that the agenda expanded on balance or that a revision with many additions contains more overall thematic content than its predecessor. The incidence of removals and the sensitivity of treatment classification to a signed-change measure are separate measurement questions. References to this measure throughout the chapter therefore use “new thematic incorporation” in this restricted sense.

Constructing this measure required pairing each revised Master Plan with its immediately preceding version. The text attributed to the event year was the full plan resulting from that revision, rather than a later compilation containing subsequent amendments. A consolidated version was used only when its content corresponded to the legal provisions applicable at the relevant reference date. The same temporal criterion applied to the preceding document, preserving the distinction between inherited content and themes introduced by the observed revision.

For transparency, two municipalities identified as revising their plans during the period were excluded from the final count because the immediately preceding version of the Master Plan was unavailable in the repositories consulted and because there was no response to formal requests for access. These cases are Ibicoara, in Bahia, for which Law No. 191/2013 was located, but not Law No. 096/2008, and Tapiraí, in São Paulo, for which Complementary Law No. 087/2016 was located, but not Complementary Law No. 049/2011. The municipality of Nioaque, in Mato Grosso do Sul, was retained in the sample after the municipal administration responded and the previous document was obtained. This information is presented in A.6.1 of the Appendix.

6.4.3 The policy: incorporation at or above the threshold in the event year

The policy analysed in this chapter is defined by the intensity with which the smart city agenda is incorporated into the Master Plan approved in the year of the institutional event. Initial adoption and revision identify the moment at which the municipality formally reorganises its urban planning framework, but they do not, by themselves, constitute the treatment of interest. The treatment corresponds to the relatively high presence of content associated with the smart city agenda in the document approved at that moment. For

municipalities that initially adopted the Master Plan, the index calculated directly from the approved document is used. For municipalities that revised the instrument, the new thematic incorporation index is used, capturing content that appears in the revised plan but was absent from the immediately preceding version.

Treatment thresholds are defined separately by institutional event and event year. This annual standardisation compares documentary intensity within the relevant event-year distribution, so that a municipality is classified relative to other eligible municipalities undergoing the same type of institutional event in the same year. This rule concerns the construction of the treatment indicator; it does not, by itself, restrict the econometric comparison group to municipalities whose Master Plans changed in the same calendar year. The construction of the estimation groups and the timing of their institutional events are therefore distinct from the rule used to classify documentary intensity.

Formally, let $e \in \{A, R\}$ denote the type of institutional event, where A represents the initial adoption of the Master Plan and R represents the revision of a previously existing plan. Let SC_m^e be the Smart City citation index of municipality m , defined according to the type of event, and let t_m^e be the year in which this event occurs. For each year τ , event type e and percentile p , the threshold is defined as:

$$c_{\tau,p}^e = Q_p(SC_m^e \mid E_m^e = 1, t_m^e = \tau, SC_m^e \neq \emptyset) \quad (6.19)$$

where $E_m^e = 1$ indicates that the municipality is eligible for treatment, according to the criteria described in the following subsection. The condition $SC_m^e \neq \emptyset$ restricts the calculation of the threshold to municipalities for which the Smart City citation index is available. The threshold is calculated among eligible municipalities in the event year, including those with an index equal to zero. This choice is important because a zero value also carries substantive information, indicating the absence of identifiable incorporation of the agenda in the document analysed. The rule uses values greater than or equal to the threshold to avoid the arbitrary exclusion of municipalities tied at the cut-off.

Based on this threshold, the treatment variable in the event year is defined as:

$$D_{m,\tau,p}^e = 1 \left[E_m^e = 1, t_m^e = \tau, SC_m^e > 0, SC_m^e \geq c_{\tau,p}^e \right] \quad (6.20)$$

The municipality is classified as treated in the event year when it simultaneously satisfies four conditions: it belongs to the eligible set, undergoes the institutional event in year τ , has a positive Smart City index, and has a value greater than or equal to the threshold defined for its year and type of event. The requirement that $SC_m^e > 0$ prevents municipalities with no identifiable incorporation of the agenda from being classified as treated in years or distributions in which the threshold takes a value equal to zero.

The choice of percentile thresholds, rather than rules based on deviations from the annual mean, follows from the asymmetric and time-varying nature of the citation indices. Since the diffusion of the smart city agenda does not occur homogeneously across years and event types, the mean of the indicator may carry different meanings depending on the annual distribution of documents. Percentiles, in turn, make it possible to define the relative intensity of incorporation within each cohort, comparing municipalities subject to the same type of institutional event and the same temporal context of agenda diffusion.

The reference threshold adopted for the Smart City citation index is the 50th percentile. Thus, among eligible municipalities that undergo the same institutional event in the same year, those with a positive index and a value equal to or above the median of the distribution are classified as treated. The actual proportion may vary due to ties at the cut-off point and the requirement of a positive index, but the rule preserves the substantive interpretation of the policy: treatment identifies municipalities whose incorporation of the smart city agenda lies in the upper half of the distribution among comparable cases.

The choice of event-year-specific cut-offs also responds to the temporal evolution of the urban planning vocabulary itself. The diffusion of themes associated with smart cities, sustainability, digital transformation, governance, and innovation was not homogeneous between 2013 and 2020. As shown in Chapter 5, average citation indices tend to increase over the decade, with greater incorporation of contemporary planning agendas from the mid-2010s onwards. Thus, an absolute index value observed in 2013 does not have the same substantive meaning as a similar value observed in 2018 or 2020. The use of annual thresholds allows the policy to be defined in relation to the discursive and institutional context of each cohort.

In addition to the reference threshold at the 50th percentile, two alternative thresholds are used: the 25th and 75th percentiles. The former allows a broader definition of incorporation to be assessed, while the latter identifies municipalities located in the upper quartile of the distribution, that is, those with more intensive incorporation of the smart city agenda among comparable cases. This combination makes it possible to assess whether the estimated effects vary according to the intensity of the agenda's incorporation into the document, rather than depending on a single cut-off point.

Once treatment has been defined in the event year, the municipality's treatment cohort is constructed. For each threshold p , the municipality receives $G_{m,p}^e = t_m^e$ when it is treated in the year of adoption or revision of the Master Plan; otherwise, it receives $G_{m,p}^e = 0$. This structure is compatible with the logic of absorbing treatment used in the multi-period Difference-in-Differences strategy. Once classified as treated in the institutional event, the municipality remains associated with that cohort in the subsequent years of the analysis.

The policy is therefore defined by the combination of the type of institutional

event, the year in which this event occurs, and the relative intensity of incorporation of the smart city agenda into the approved document. This definition avoids treating all revised or initially adopted plans as equivalent, takes into account the temporal evolution of urban planning language, and compares only municipalities undergoing the same type of institutional change.

6.4.4 Eligibility diagrams and construction of comparable groups

The definition of comparable groups requires an additional step beyond the identification of municipalities that adopted or revised their Master Plans between 2013 and 2020. The starting point of the analysis consists of 381 municipalities that initially adopted the instrument and 535 municipalities that revised it during the period. Not all of these cases, however, can be incorporated directly into the empirical exercise. Since the dependent variable is regional and additive, municipalities subject to competing territorial shocks, recent administrative changes, or very close interactions among planning documents may make the interpretation of the treatment more difficult.

The eligibility criteria were defined to reduce this risk. They do not seek to eliminate every form of interaction between municipalities, which would be incompatible with the regional nature of the phenomenon investigated. The aim is to exclude situations in which the incorporation of the smart city agenda into the Master Plan could be confused with territorial changes, standardisation of planning documents, or institutional events occurring in close temporal proximity in municipalities with greater centrality within the same Immediate Geographic Region (ImGR).

Before applying the eligibility diagrams, three groups of general exclusions were defined. The first refers to territorial changes associated with municipalities incorporated into IBGE databases from 2013 onwards. Until 2012, the institute's municipal databases counted 5,565 municipalities; from 2013 onwards, they began to count 5,570. This increase resulted from the incorporation of Mojuí dos Campos, in Pará; Pescaria Brava and Balneário Rincão, in Santa Catarina; Pinto Bandeira, in Rio Grande do Sul; and Paraíso das Águas, in Mato Grosso do Sul. Since the creation of a municipality involves a new political-administrative structure, the redefinition of territorial boundaries, the creation of elected offices, departments, an autonomous budget, and the redistribution of constitutional responsibilities, both the emancipated municipalities and the municipalities from which territory was detached were excluded whenever they appeared in the set of Master Plan adoptions or revisions.

The second group of exclusions aims to prevent the economic effects associated with municipal emancipation from being confused with the effects of the Master Plan. The creation of a new municipality constitutes a deeper institutional change than the adoption or revision of a planning instrument. In addition to altering the administrative structure,

it may modify, even if temporarily, flows of population, firms, public employment, service provision, and local investment decisions. For this reason, municipalities belonging to the same ImGR as an emancipated municipality and that adopted or revised their Master Plans in 2013 or 2014 were excluded. This is a conservative rule: it does not claim that all these municipalities were effectively affected by emancipation, but that their temporal and functional proximity makes it difficult to safely distinguish the effect of the territorial event from the effect of incorporating the smart city agenda into the Master Plan.

The third group of exclusions follows from the structure of the dependent variable. Since the municipal additive contribution is constructed from the decomposition of the intra-regional component of inequality, the interpretation of municipal terms becomes less informative in ImGRs with a very small number of municipalities. In an ImGR with only one municipality, there is no internal inequality to be decomposed. In ImGRs with two or three municipalities, the relative position of each unit tends to depend excessively on a small number of observations, making the additive contribution highly sensitive to the specific configuration of the region. For this reason, the analysis restricts the sample to municipalities located in ImGRs with at least four municipalities. This criterion preserves a minimum degree of internal variation in the immediate regional layer, consistent with the decomposition logic adopted in this chapter.

Table 6.1 presents the 16 municipalities excluded under these general criteria before the application of the eligibility diagrams.

After these general exclusions, eligibility is defined separately for municipalities undergoing initial adoption and for municipalities undergoing revision. This separation preserves consistency with the strategy presented in the previous subsections: the two events have distinct institutional meanings, the citation index is calculated differently in each case, and the policy thresholds are defined separately by event type and year.

For municipalities undergoing initial adoption, the first level of the diagram identifies cases in which the Master Plan of municipality i presents very high similarity with the document of another municipality j , belonging to the same ImGR, which also adopted a Master Plan in year t or in year $t - 1$. This verification was carried out using the most disaggregated version of the citation indices, that is, the subgroups of the dictionary of terms used to construct the Smart City index (Tables 5.6 to 5.11 of Chapter 5).

Table 6.1 – Municipalities excluded before the eligibility diagrams

Municipality	State	ImGR name	Reason for exclusion	Event	Year
Vitória do Jari	Amapá	Laranjal do Jari	ImGR with fewer than four municipalities	Adoption	2019
Tauá	Ceará	Tauá	ImGR with fewer than four municipalities	Adoption	2016
Paraíso das Águas	Mato Grosso do Sul	Paranaíba – Chapadão do Sul – Cassilândia	Emancipated municipality	Adoption	2017
Chapadão do Sul	Mato Grosso do Sul	Paranaíba – Chapadão do Sul – Cassilândia	Territory subdivided by municipal emancipation	Adoption	2013
Balneário Rincão	Santa Catarina	Criciúma	Emancipated municipality	Adoption	2018
Laguna	Santa Catarina	Tubarão	Territory subdivided by municipal emancipation	Adoption	2013
Gravatal	Santa Catarina	Tubarão	Same ImGR as an emancipated municipality that adopted a Master Plan in 2013 or 2014	Adoption	2013
Imaruí	Santa Catarina	Tubarão	Same ImGR as an emancipated municipality that adopted a Master Plan in 2013 or 2014	Adoption	2013
Treviso	Santa Catarina	Criciúma	Same ImGR as an emancipated municipality that adopted a Master Plan in 2013 or 2014	Adoption	2013
Jaguaruna	Santa Catarina	Tubarão	Same ImGR as an emancipated municipality that adopted a Master Plan in 2013 or 2014	Adoption	2014
Morro da Fumaça	Santa Catarina	Criciúma	Same ImGR as an emancipated municipality that adopted a Master Plan in 2013 or 2014	Adoption	2014
Ponta Porã	Mato Grosso do Sul	Ponta Porã	ImGR with fewer than four municipalities	Revision	2020
Santarém	Pará	Santarém	Territory subdivided by municipal emancipation	Revision	2017
Bento Gonçalves	Rio Grande do Sul	Bento Gonçalves	Territory subdivided by municipal emancipation	Revision	2018
Campo Alegre	Santa Catarina	São Bento do Sul – Rio Negrinho	ImGR with fewer than four municipalities	Revision	2019
Tubarão	Santa Catarina	Tubarão	Same ImGR as an emancipated municipality that revised a Master Plan in 2013 or 2014	Revision	2013

Source: Author's own elaboration based on IBGE (2021, 2022) and the municipal Master Plan database constructed for this study.

Note: ImGR stands for Immediate Geographic Region. The table reports municipalities that adopted or revised a Master Plan between 2013 and 2020 but were excluded before the application of the eligibility rules. The exclusion criteria refer to territorial changes associated with municipal emancipations, ImGRs with fewer than four municipalities, and municipalities located in the same ImGR as emancipated municipalities during the first two years of the analysis period.

Formally, let $\mathbf{x}_{it}^A = (x_{it1}^A, x_{it2}^A, \dots, x_{itS}^A)$ be the vector of disaggregated citations from the Master Plan adopted by municipality i , where S represents the set of subgroups in the dictionary. The document similarity between i and j is defined as:

$$\sigma_{ij}^A = \frac{\sum_{s=1}^S x_{its}^A x_{j\tau s}^A}{\sqrt{\sum_{s=1}^S (x_{its}^A)^2} \sqrt{\sum_{s=1}^S (x_{j\tau s}^A)^2}}, \quad \tau \in \{t, t-1\} \quad (6.21)$$

Values close to one indicate that the two documents have a very similar citation composition across the dictionary subgroups. When $\sigma_{ij}^A \geq 0.90$, the documents were manually checked. Exclusion was not defined solely by a mechanical value of the index, but by the combination of high statistical similarity and direct verification of the textual proximity between the Master Plans.

This criterion seeks to address a specific feature of Brazilian municipal planning. Nearby municipalities may hire the same consultancy, enter into agreements, share technical teams, or use similar document templates in preparing their Master Plans. This type of coordination may be legitimate from an administrative standpoint, especially in small municipalities. However, when textual similarity is very high, there is a risk that the document reflects technical-administrative standardisation more than the specific incorporation of the municipality's demands, capacities, and priorities. For an analysis that interprets the Master Plan as an institutional expression of the local incorporation of the smart city agenda, these cases should be treated with caution.

The application of this criterion identified almost identical documents among Lindóia do Sul, Arabutã, and Ipira, in Santa Catarina, all with Master Plans adopted in 2013. High similarity was also identified between Figueirão, in Mato Grosso do Sul, which adopted the Master Plan in 2017, and Pedro Gomes, a municipality in the same ImGR that had adopted its plan in 2016. The corresponding documents were checked manually, and the access links are presented in Table A.6.2 of the Appendix. Among these cases, only Pedro Gomes was not excluded at the first level, since its adoption preceded the event used to identify the high similarity with Figueirão.

On this basis, a municipality i that initially adopts the Master Plan is not considered eligible if, within the same ImGR, there is a municipality j identified as a hub that also adopted its Master Plan in t or $t-1$. The reason is that the initial adoption of the plan by the hub may be associated with economic and administrative dynamics that extend beyond its municipal boundaries, especially in regions where this hub organises access to services, work, commerce, and public functions. Since the locational choices of firms and individuals respond to infrastructure, accessibility, interaction costs, institutions, and economic opportunities, an institutional change in the centre of influence of the ImGR

may modify expectations and nearby regional flows. This interpretation is consistent with the tradition of regional and urban economics discussed in Chapter 2, in which urban hierarchy, agglomeration forces, and locational decisions condition the spatial distribution of economic activity.

The third level addresses possible interference from revisions carried out by neighbouring municipalities occupying higher positions in the hierarchy. A municipality i undergoing initial adoption is excluded if there is a municipality j , in the same ImGR, that revised its Master Plan in t or $t - 1$ and simultaneously satisfies three conditions:

- $SC_j^{R,\text{add}} > 0$;
- $SC_j^{R,\text{new}} > SC_i^A$;
- $\lambda_j > \lambda_i$.

The first condition requires municipality j to have at least one positive thematic addition associated with the smart city agenda in the revision. The second requires the total index of j 's revised plan, calculated from the consolidated version of the document, to be higher than the index of the plan adopted by i . The third requires j to occupy a higher position in the REGIC urban hierarchy (IBGE, 2019).

The urban hierarchy is represented by λ , defined as:

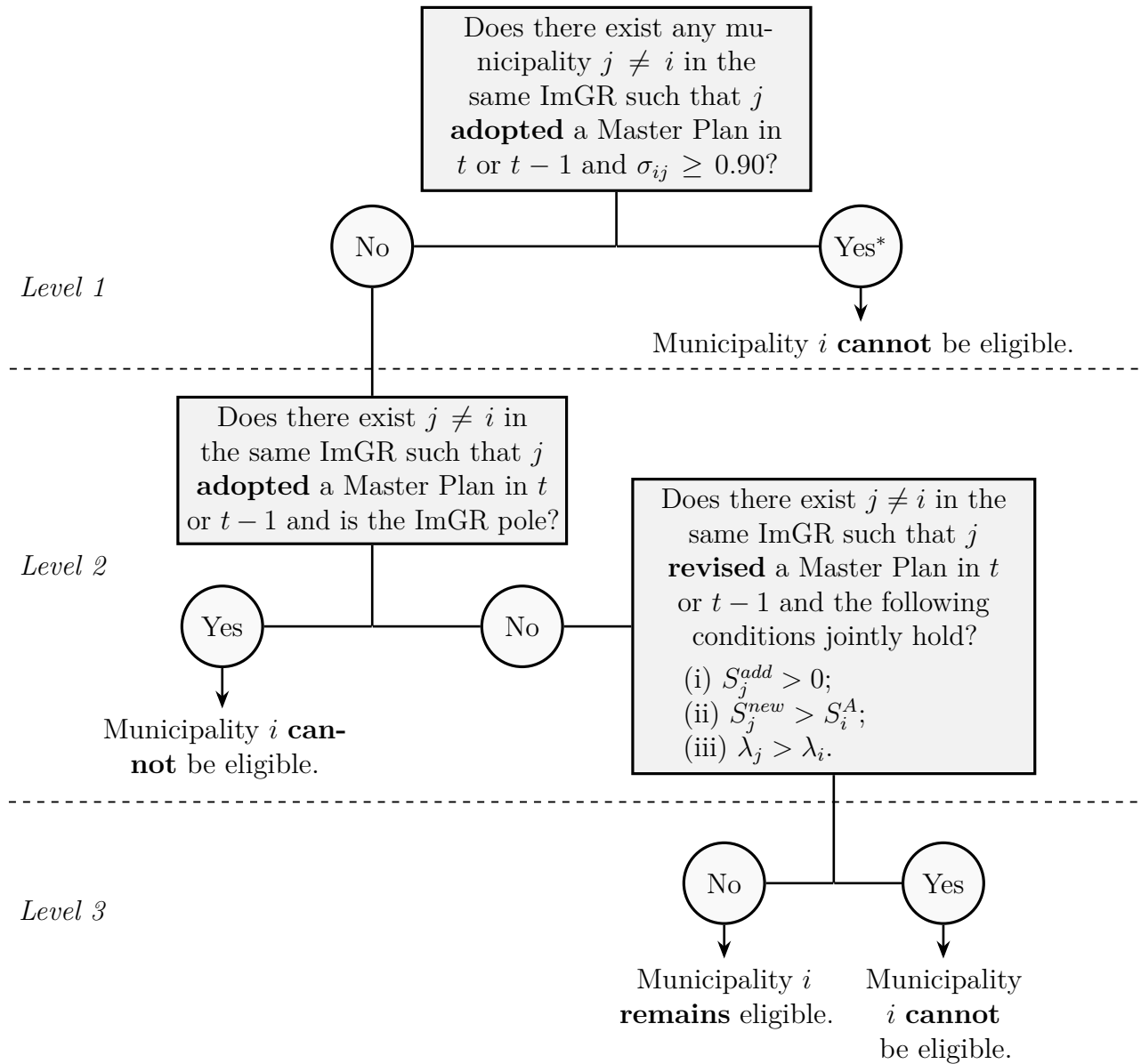
$$\lambda_m = \begin{cases} 1.0, & \text{Metropolis;} \\ 0.7, & \text{Regional Capital;} \\ 0.5, & \text{Sub-regional Centre;} \\ 0.2, & \text{Zone Centre or Local Centre.} \end{cases} \quad (6.22)$$

This filter is conservative. It does not assume that any revision by a neighbouring municipality affects municipality i . Exclusion occurs only when the neighbouring municipality revises its plan within a close temporal window, has positive new thematic incorporation of the smart city agenda, has a higher total index, and occupies a higher hierarchical position. The combination of these conditions identifies situations in which the neighbour's institutional change has greater potential to alter flows, expectations, services, and relative attractiveness within the ImGR. In terms of identification, retaining these municipalities could attribute to the Master Plan of i effects that may, in fact, be associated with the institutional reorientation of a more influential neighbouring centre.

The t and $t - 1$ window also responds to the annual nature of the data and to the process of approving the Master Plan itself. The adoption or revision of a municipal law is preceded by diagnosis, public hearings, disputes, technical preparation, legislative processing, and expectations among local agents. Moreover, when the law is approved at

the end of a given year, its most immediate institutional and economic effects may appear only in the subsequent annual statistics. Thus, the inclusion of $t - 1$ should not be read as a claim that the effects of the Master Plan are fully materialised within one year, but as a safeguard against temporally proximate interference in functionally articulated regions.

Figure 6.2 – Eligibility diagram for municipalities adopting a Master Plan



Source: Author's own elaboration.

Notes: t denotes the year in which municipality i adopted its Master Plan. ImGR stands for Immediate Geographic Region. σ_{ij} denotes the similarity index between the citation-subindex vectors of municipalities i and j . S_j^{add} denotes the new thematic incorporation index of municipality j in the revised plan; S_j^{new} denotes the total citation index of municipality j in the consolidated version of the revised plan; S_i^A denotes the citation index of municipality i in the adopted plan; and λ denotes the regional hierarchy score. * Municipality pairs satisfying $\sigma_{ij} \geq 0.90$ were manually verified through direct comparison of the corresponding Master Plan documents before municipality i was classified as non-eligible.

The filtering procedures described above are summarised in Figure 6.2. For municipalities undergoing revision, the logic of the diagram is analogous, but adapted to the nature of the event. The first level also identifies very high similarity between documents from municipalities in the same ImGR that revised their Master Plans in t or $t - 1$. In this case, however, similarity is calculated from the consolidated version of the revised plans, rather than from the new thematic incorporation index. The reason is that the objective of the first level is not to measure newly appearing content, but to identify final documents that are excessively similar.

Formally, let $\mathbf{x}_{mt}^{R,\text{new}}$ be the vector of disaggregated citations from the revised, consolidated plan of municipality m . The similarity between m and j is given by:

$$\sigma_{mj}^R = \frac{\sum_{s=1}^S x_{mts}^{R,\text{new}} x_{j\tau s}^{R,\text{new}}}{\sqrt{\sum_{s=1}^S (x_{mts}^{R,\text{new}})^2} \sqrt{\sum_{s=1}^S (x_{j\tau s}^{R,\text{new}})^2}}, \quad \tau \in \{t, t - 1\} \quad (6.23)$$

When $\sigma_{mj}^R \geq 0.90$, the documents were also checked manually. This procedure identified high similarity between Santos and São Vicente, in São Paulo, both with revisions in 2018; between Tapejara and São Manoel do Paraná, in Paraná, with revisions in 2020; between Vitor Meireles and Ibirama, in Santa Catarina, with revisions in 2020 and 2019, respectively; and between Chapadão do Lageado and Petrolândia, also in Santa Catarina. Ultimately, Santos, São Vicente, Tapejara, São Manoel do Paraná, Vitor Meireles, and Chapadão do Lageado were excluded. The links to the documents are provided in Table A.6.2.

It should be noted that the criterion was not applied in a purely automatic manner. Although Apiúna and Benedito Novo, in Santa Catarina, presented very similar versions of their Master Plans revised in 2016, manual checking identified substantive particularities, including terms covered by the dictionary of the Smart City index. These municipalities were retained in the sample. This decision is important because it shows that statistical similarity was used as a screening mechanism, not as a blind exclusion rule.

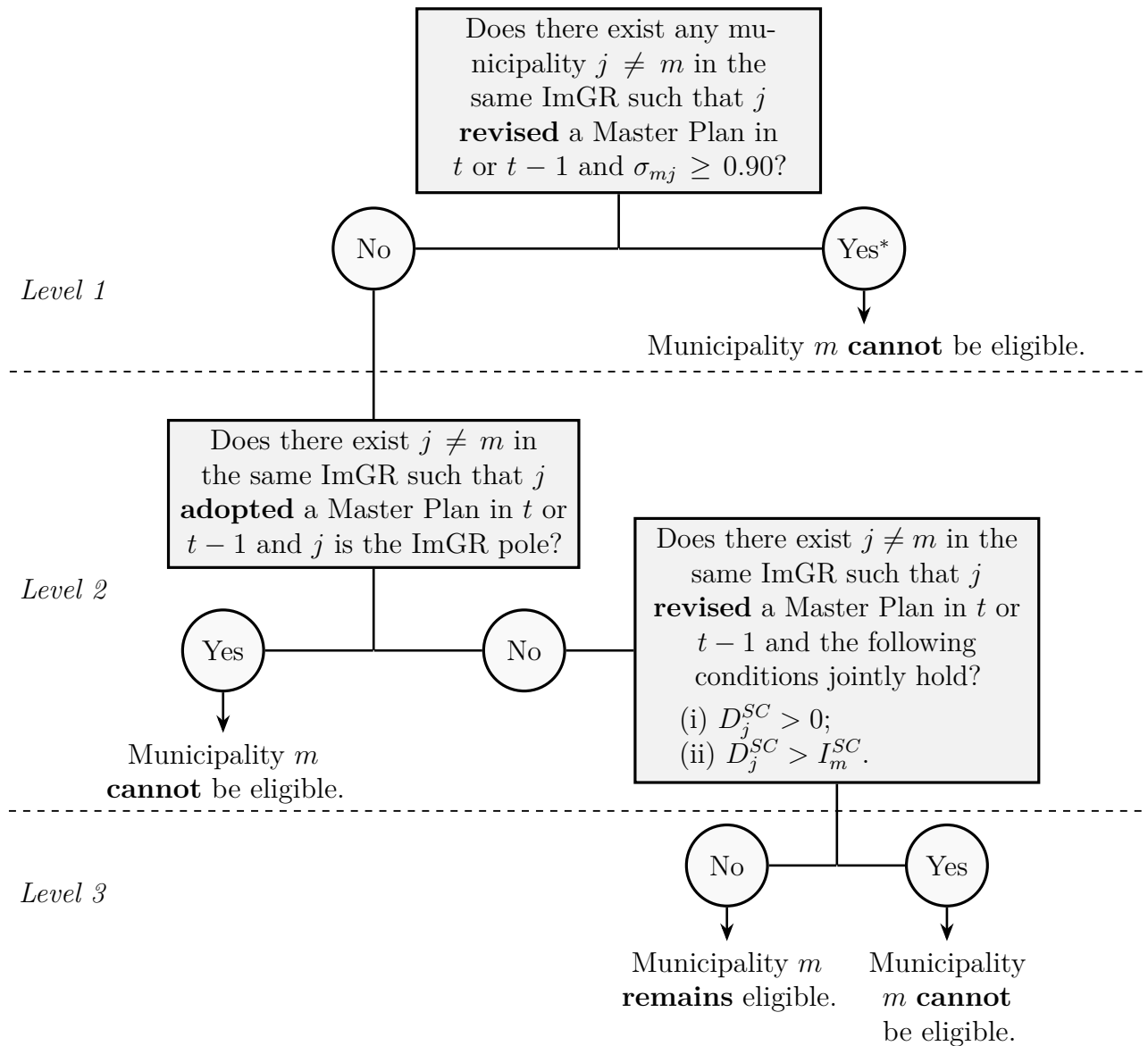
The second level of the revision diagram excludes municipalities m when, within the same ImGR, there is a municipality j identified as a hub that initially adopted its Master Plan in t or $t - 1$. The justification follows the logic adopted for the adoption diagram: the approval of the first Master Plan by the hub may generate administrative dynamics, expectations, and economic reorganisations capable of affecting nearby municipalities, especially in regions in which this hub concentrates urban functions and management flows (IBGE, 2019b).

The third level addresses temporally proximate revisions in other municipalities of the same ImGR. A municipality m undergoing revision is excluded when there is another

municipality j that revised its Master Plan in t or $t - 1$ and simultaneously satisfies $D_j^{SC} > 0$ and $D_j^{SC} > I_m^{SC}$. The first condition requires a positive value for the Smart City revision-difference measure of municipality j , while the second requires this value to exceed the Smart City index used as the comparison term for municipality m in the eligibility procedure. Unlike the corresponding filter for initial adoption, this rule does not impose an additional condition based on REGIC hierarchy. The criterion therefore screens cases in which a temporally proximate neighbouring revision presents a stronger documentary change under the eligibility metric, without assuming that the neighbouring municipality occupies a higher hierarchical position.

Figure 6.3 systematises these filtering steps for the set of municipalities that revised their formal urban planning instruments.

Figure 6.3 – Diagram of eligibility rules for each municipality m revising a Master Plan



Source: Author's own elaboration.

Notes: t denotes the year in which municipality m revised its Master Plan. ImGR stands for Immediate Geographic Region. σ_{mj} denotes the similarity index between the citation-subindex vectors derived from the consolidated revised plans of municipalities m and j . D_j^{SC} denotes the Smart City revision-difference measure for municipality j , corresponding to the documentary-change measure used in the eligibility procedure. I_m^{SC} denotes the Smart City index of municipality m used as the comparison term in the third eligibility level. * Municipality pairs satisfying $\sigma_{mj} \geq 0.90$ were manually verified through direct comparison of the corresponding Master Plan documents before municipality m was classified as non-eligible.

Taken together, the eligibility diagrams serve empirical and conceptual purposes. Empirically, they remove cases in which the municipal additive contribution could be affected by territorial shocks, highly standardised documents, or temporally proximate institutional events in more central municipalities. Conceptually, they preserve coherence between treatment definition, the additive outcome, and the functional structure of the ImGRs. The objective is not to eliminate intermunicipal interaction, which is inherent to the regional setting, but to restrict comparisons to cases in which the incorporation of the smart city agenda into the Master Plan is less exposed to competing documentary, institutional, or territorial interference.

Thus, the treatment and control groups are constructed only after the eligibility criteria have been applied. Eligible municipalities that incorporate the smart city agenda at or above the threshold defined in the previous subsection form the treated cohorts. Eligible municipalities that do not reach the threshold, or that do not positively incorporate the agenda in the event year, remain as potential comparison units, subject to the identification strategy presented in the following section. This sequence allows the analysis to proceed to the multi-period Difference-in-Differences model with more comparable groups, defined on the basis of the same type of institutional event, the same regional reference scale, and explicit filtering rules.

6.5 Empirical strategy: multi-period Difference-in-Differences (DiD)

This section presents the empirical strategy used to estimate the effects of incorporating the smart city agenda into Master Plans. The design exploits the staggered entry of municipalities into treatment and estimates the effects separately for the initial adoption and revision of the instrument. The discussion focuses on the choice of estimator, the parameters of interest, the comparison groups, the identification assumptions, and the specifications that guide the interpretation of the results.

6.5.1 Identification design and choice of estimator

The empirical strategy exploits temporal and cross-municipal variation in the incorporation of the smart city agenda into Master Plans. As defined in the previous

section, initial adoption and revision identify the year of the institutional event, while treatment is determined by the content incorporated into the document approved at that moment. This structure is suited to a multi-period Difference-in-Differences design, since municipalities enter the treatment group in different years between 2013 and 2020, according to the moment at which they adopt or revise the Master Plan and reach the threshold of incorporation of the smart city agenda (Callaway; Sant’Anna, 2021).

Staggered entry makes a canonical two-period, two-group DiD design inappropriate, as in that setting all treated units receive treatment simultaneously (Roth et al., 2023). In addition, within the window analysed, the treatment is specified as absorbing. Once classified as treated in the institutional event, the municipality remains associated with that cohort in the subsequent years. This decision is compatible with the normative nature of the Master Plan during the period observed, although it does not imply assuming that its content is immutable over longer horizons.

The application of Difference-in-Differences seeks to identify whether the trajectory of the municipal additive contribution to the intra-regional component of inequality changes after the stronger incorporation of the smart city agenda, compared with eligible municipalities that do not exceed the treatment threshold. The causal interpretation depends on the assumption that, in the absence of the policy, treated municipalities would have followed a trajectory similar to that of the municipalities used for comparison. This assumption is discussed in the following subsection.

The choice of the Callaway and Sant’Anna (2021) estimator follows from the limitations of traditional two-way fixed effects models in contexts of staggered treatment. In designs with multiple cohorts, the two-way fixed effects (TWFE) estimator may combine comparisons between not-yet-treated and already-treated units with comparisons between groups treated at different points in time.

Goodman-Bacon (2021) shows that, when there is variation in treatment timing, TWFE can be decomposed into a weighted average of multiple 2Ö2 DiD estimators, including comparisons in which already-treated units serve as controls for units treated later. When effects vary across cohorts or over time, these comparisons may generate opaque weights and, in some cases, negative weights. Sun and Abraham (2021) demonstrate a similar problem in event studies with leads and lags estimated by TWFE, in which dynamic coefficients may be contaminated by treatment effects from other periods when there is treatment-effect heterogeneity.

These issues are relevant to this study. There is no substantive reason to assume that the incorporation of the smart city agenda produces homogeneous effects across municipalities, years, types of institutional event, and positions in the urban hierarchy. On the contrary, the theoretical argument developed in Section 6.2 suggests that the effects may depend on the maturity of local planning, the previous institutional trajectory,

the municipality's position in the urban network, and the regional context in which the Master Plan is approved. In this situation, an estimator that imposes an opaque average of heterogeneous effects could obscure precisely the dimension that this chapter seeks to investigate.

The Callaway and Sant'Anna (2021) estimator is better suited to this setting because it separates the identification of group-time effects, the aggregation of these effects, and inference. Rather than summarising the entire design in a single TWFE coefficient, the method estimates average treatment effects for each entry cohort and for each subsequent period, allowing effects to vary with the treatment year and with exposure time. These effects can then be aggregated into parameters of interest, such as the overall average effect, cohort-specific effects, calendar-year effects, and dynamic effects in event time. This structure is compatible with the question addressed in this chapter, as it makes it possible to assess both the existence of an average effect of incorporating the smart city agenda and its temporal evolution and heterogeneity across groups.

Recent applied literature has used similar designs to evaluate public policies with staggered entry in territorial, urban, environmental, and institutional contexts. Cattani et al. (2024) apply staggered Difference-in-Differences to assess public solid waste consortia in Brazilian municipalities; Liu et al. (2023) use multi-period DiD to analyse China's smart city policy; Merkus (2024) explores the staggered introduction of environmental monitoring in Brazilian municipalities; and Büchler and Lutz (2024) analyse urban zoning reforms with variation in treatment timing. These studies are not identical to the design proposed here, but they illustrate the suitability of multi-period DiD for policies whose implementation occurs in a staggered manner across space and time.

6.5.2 Parameters of interest, comparison groups and identification assumptions

The unit of observation is municipality i , observed annually over the period of analysis. The dependent variable, Y_{it} , corresponds to the municipal additive contribution to the intra-regional component of GDP per capita inequality. The main parameter is estimated separately for the initial adoption and revision of the Master Plan, preserving the institutional distinction that guides the definition of the policy.

Let $e \in \{A, R\}$ denote the type of institutional event, where A represents the initial adoption of the Master Plan and R represents the revision of a previously existing plan. For each municipality, G_i^e is defined as the year in which the municipality becomes treated, that is, the year in which the institutional event occurs and the Smart City index reaches or exceeds the threshold defined in Subsection 6.4.3. If the municipality is not treated within the analysis window, $G_i^e = 0$. The treatment exposure variable can be represented as in Equation 6.24. To simplify the notation, the percentile threshold p is omitted from the expressions below, although the estimations are carried out separately

for each treatment definition.

$$D_{it}^e = 1 [G_i^e > 0, t \geq G_i^e] \quad (6.24)$$

This notation highlights the absorbing nature of the treatment. The municipality does not alternate between treated and untreated status after entering the cohort. Once the smart city agenda is incorporated above the threshold in the event year, the municipality remains classified as treated in the subsequent years considered in the panel. In the main estimations, cohorts treated in 2013 are excluded, since the panel for the dependent variable begins in that same year and, therefore, no pre-treatment observation is available for these municipalities.

The disaggregated parameter of interest is the average treatment effect for group g in period t , defined by Callaway and Sant'Anna (2021) as the group-time average treatment effect. In the context of this study, it can be written as:

$$ATT^e(g, t) = E[Y_{it}(g) - Y_{it}(0) \mid G_i^e = g], \quad t \geq g \quad (6.25)$$

where $Y_{it}(g)$ represents the potential outcome of municipality i in period t if it is treated in year g , and $Y_{it}(0)$ represents the potential outcome if the municipality is not treated within the analysis window. The comparison concerns municipalities meeting the selected intensity rule relative to eligible municipalities that do not meet that rule within the analysis window. A never-treated municipality in this design may have adopted or revised a Master Plan and may contain content associated with the smart city agenda below the selected threshold. Thus, the contrast is not between planning and no planning, nor between the complete presence and absence of the agenda. Its interpretation depends on the specified intensity margin and on the comparability of the institutional trajectories represented in the two groups.

Identifying this parameter requires the construction of a counterfactual. In the main specification, the comparison group is formed by eligible municipalities that are never treated within the analysis window. This choice is consistent with the design of the study, as it avoids using already-treated municipalities as controls for other municipalities treated later. Recent literature recommends caution with this type of comparison in staggered designs, since already-treated units may carry accumulated treatment effects and therefore may not provide a good approximation to the counterfactual trajectory of not-yet-treated units (Goodman-Bacon, 2021; Roth et al., 2023; Sun; Abraham, 2021).

The use of never-treated municipalities as the comparison group does not, by itself, eliminate all identification concerns. The central assumption is that of parallel trends. In substantive terms, it is assumed that, in the absence of the incorporation of the smart city agenda above the threshold, treated municipalities and eligible never-treated municipalities

would have followed similar average trajectories in the municipal additive contribution to the intra-regional component of inequality. In its conditional form, this assumption allows comparability to be established after accounting for relevant observable characteristics, such as population size, belonging to a metropolitan region, or position in the urban hierarchy.

Callaway and Sant’Anna (2021) emphasise that their approach allows covariates to be incorporated into staggered designs, including through regression-based estimators, propensity score weighting, or doubly robust procedures. Sant’Anna and Zhao (2020) show that doubly robust estimators are attractive in conditional DiD designs because they remain consistent if at least one of the auxiliary models, either the outcome model or the treatment propensity model, is correctly specified.

The empirical design seeks to make this assumption more credible through choices already incorporated into the construction of the policy and the sample. The treatment definition separates adoption and revision, the cut-offs are calculated within the event year, the eligibility diagrams reduce situations with a higher risk of territorial or document-related contamination, and the event-study analyses make it possible to examine systematic differences in trajectories before treatment.

The timing and content of a Master Plan are not assumed to be randomly assigned. They may reflect prior development, fiscal and administrative capacity, political priorities, local interests and expected economic change. The participatory and legislative character of the planning process does not make documentary incorporation exogenous, since collective decisions may respond to forces that also shape subsequent economic trajectories. In this application, this concern should be interpreted in relation to the outcome actually analysed. The dependent variable is not municipal GDP per capita, but a signed relational term that depends jointly on the municipality’s economic weight and on its GDP-per-capita position relative to its regional reference. The identification threat therefore arises if factors associated with the intensity of documentary incorporation also predict the untreated trajectory of one or more components of this municipal additive contribution.

Difference-in-differences does not require treatment to be randomly assigned, nor treated and comparison municipalities to have identical outcome levels. Its causal interpretation requires instead the specified parallel-trends condition for untreated changes, together with the other identification assumptions (Callaway; Sant’Anna, 2021). Persistent differences associated with treatment selection are therefore conceptually distinct from selection associated with differential future trajectories. The latter remains an identification threat in this application. The doubly robust estimator does not remove this threat merely by combining outcome regression and propensity-score weighting. Accordingly, pre-treatment diagnostics and sensitivity exercises delimit the interpretation rather than establish that documentary incorporation is exogenous.

The no-anticipation assumption requires additional attention. In a strict sense, it states that treatment does not affect the outcome before its implementation. In the case of Master Plans, the process of preparation or revision may involve diagnostic studies, public hearings, public debates, expectations among private agents, and legislative processing before the formal approval of the law. This does not automatically invalidate the design, but it recommends interpreting the event year as the institutional marker observable in annual data. The treatment, as defined in this study, exists only when the smart city agenda is formally incorporated into the approved legal text. Prior movements of discussion and expectation may occur, but the operational assumption is that they do not produce, before the event, a systematic differential break in the trajectory of the dependent variable between treated and comparable municipalities. This assumption will be examined through the pre-treatment coefficients in the event studies.

The third identification assumption concerns the stability of group composition and the absence of uncontrolled competing sources of interference. The stability of group composition requires caution in a regional application. Nearby municipalities share flows of labour, consumption, services, population, and investment, so that institutional or territorial events in neighbouring localities may affect the trajectory of the outcome. The eligibility rules in Section 6.4.4 were defined precisely to reduce situations in which the trajectory of the dependent variable could be confounded with recent emancipations, highly standardised Master Plans, or temporally proximate institutional events in municipalities with greater centrality.

Regional interdependence also enters mechanically through the construction of the outcome. The municipal Theil term depends on the IntGR GDP total and on the mean GDP per capita of the ImGR, so municipalities embedded in the same regional structure share changing reference values. If treatment changes the output or population of one municipality, these regional references may also change for other municipalities even when their own output and population remain unchanged. Substantive interference remains possible as well: a planning change may affect employment, residence, service use or economic activity in neighbouring municipalities, thereby altering the outcomes of comparison units. The eligibility filters reduce selected configurations of exposure, but do not establish the absence of all such effects. Spatial spillovers can change both the relevant counterfactual and the interpretation of a difference-in-differences estimand (Butts, 2023). The estimates are therefore not interpreted as the total effect of the agenda on the regional system. Likewise, excluding municipality i from the peer mean used in the auxiliary outcomes removes mechanical self-inclusion, but does not eliminate shared shocks or behavioural spillovers.

The absorbing treatment assumption is maintained only for the observed empirical window. A subsequent revision could alter the content of the Master Plan, but, in the period analysed, treatment classification is defined by the observed institutional event.

The analysis estimates what happens to the trajectory of the dependent variable after the relatively more intense incorporation of the smart city agenda, compared with eligible municipalities that do not reach this intensity within the same type of event.

The estimated $ATT^e(g, t)$ can be aggregated in different ways. The overall average effect, used as the main summary parameter, corresponds to a weighted average of the group-time effects:

$$ATT^{e, \text{overall}} = \sum_g \sum_{t \geq g} w_{g,t}^e ATT^e(g, t) \quad (6.26)$$

where $w_{g,t}^e$ are weights determined by cohort composition and the available periods. In addition to the overall average effect, treatment-group effects, calendar-year effects, and event-time effects are estimated. The latter are defined as:

$$ATT_\ell^{e, \text{event}} = \sum_{g: g+\ell \in \mathcal{T}} w_{g,\ell}^e ATT^e(g, g + \ell) \quad (6.27)$$

where $\ell = t - g$ represents event time. This aggregation is used to construct the event studies, allowing the evolution of effects before and after the incorporation of the smart city agenda to be assessed. As Roth et al. (2023) recommend, in staggered designs these graphs should be constructed using estimators appropriate for treatment-effect heterogeneity, rather than simple TWFE regressions with leads and lags, in order to avoid problems of weighting and contamination across periods.

6.5.3 Empirical specifications and complementary analyses

The baseline specification estimates the effects of incorporating the smart city agenda on the municipal additive contribution to the intra-regional component of GDP per capita inequality, using $GE(1)$, or the Theil T index, as the central measure. The estimations are carried out separately for the initial adoption and revision of the Master Plan. In both cases, the reference threshold is the 50th percentile ($p50$) of the composite Smart City index, calculated among eligible municipalities in the same year and event type.

The estimation of group-time effects uses the doubly robust approach proposed in the context of multi-period Difference-in-Differences. This choice is in line with Callaway and Sant'Anna (2021) and Sant'Anna and Zhao (2020), as it combines information on the evolution of the outcome and on the probability of treatment, reducing dependence on a single auxiliary specification. This feature is relevant to the proposed application, given that the incorporation of the smart city agenda may be associated with observable municipal attributes, while the trajectory of the dependent variable may reflect prior urban and regional dynamics.

The conditional specifications incorporate variables associated with municipal size, metropolitan integration and urban hierarchy. The logarithm of population is constructed from annual municipal population estimates and captures differences in scale. In the balanced-panel implementation, time-varying covariates enter each two-period comparison at their earlier-period value; for post-treatment $ATT(g, t)$, the population covariate therefore corresponds to the pre-treatment base period. Metropolitan membership and REGIC hierarchy, in turn, are included in separate conditional specifications as fixed territorial classifications. These variables are used as comparability adjustments rather than as identified transmission mechanisms.

Because the metropolitan and REGIC classifications are not cohort-specific pre-treatment measures, the corresponding specifications are interpreted as robustness adjustments to territorial composition rather than as conditioning exclusively on predetermined characteristics.

Event studies are used to examine the dynamics of the effects in event time. These exercises make it possible to assess the existence of systematic differences before the institutional event and to observe whether subsequent effects appear immediately, gradually, or remain close to zero. The absence of statistically significant pre-treatment coefficients does not, by itself, prove the validity of parallel trends, but it provides a useful diagnostic when combined with joint tests of pre-treatment effects (Roth et al., 2023).

The complementary analyses examine the sensitivity of the results to different definitions of intensity, inequality measures, and substantive breakdowns. For treatment intensity, the 25th and 75th percentiles (p_{25} and p_{75}) are used in addition to the reference threshold at the 50th percentile. For the dependent variable, the results are re-estimated using additive terms based on $GE(0)$ and $GE(2)$, which assign different sensitivities to the lower and upper parts of the GDP per capita distribution. Territorial heterogeneity is assessed across REGIC groups, while the internal composition of the Smart City index is explored through its dimensions: Economy, Society, Environment, Governance, Technology, and Urban Brands.

Taken together, the specifications follow an analytical sequence: baseline estimation with $GE(1)$ and p_{50} , dynamic and pre-treatment diagnostics, conditional specifications, sensitivity to treatment thresholds, alternative generalised entropy measures, territorial heterogeneities, and exercises by dimension of the Smart City index. This organisation makes it possible to assess treatment intensity, dynamics, heterogeneity, and the consistency of the estimates without shifting the focus away from the main specification.

6.6 Data, sample and descriptive statistics

This section presents the empirical dataset used in the estimations. The construction of the panel combines documentary information from Master Plans, municipal GDP and

population data, IBGE territorial classifications, and variables associated with municipal size, metropolitan integration, and urban hierarchy. The discussion is organised into four parts: data sources, construction of the analytical sample, descriptive statistics for the dependent variable, and the temporal and territorial distribution of treatments.

6.6.1 Data sources

The empirical application uses, for the most part, information from the Instituto Brasileiro de Geografia e Estatística (Brazilian Institute of Geography and Statistics, IBGE), complemented by the documentary database of Master Plans constructed for this study and by data from the Banco Central do Brasil (Central Bank of Brazil). The Pesquisa de Informações Básicas Municipais (Municipal Basic Information Survey), in its 2021 edition, was used to identify the existence of Master Plans in Brazilian municipalities, distinguish cases of initial adoption and revision, and recover the respective years of the municipal laws (IBGE, 2022b). This information also served as the starting point for searching the legal documents in municipal governments' institutional repositories, from which citation indices for words and terms associated with the smart city agenda were calculated.

The documentary database constructed in this study contains the citation indices associated with the dimensions Economy, Society, Environment, Governance, Technology, and Urban Brands, as well as the composite Smart City index. These indicators were used to define the intensity with which the smart city agenda was incorporated into Master Plans. For municipalities that revised their plans, the database also includes the comparison with the immediately preceding version of the document, making it possible to identify positive thematic additions at the moment of revision. Information on adoption, revision, and citations was organised for the period from 2012 to 2020, since the eligibility diagrams use a one-year lag in part of their filtering criteria.

The dependent variable was constructed from data on municipal Gross Domestic Product and municipal population estimates, made available by IBGE for the period from 2013 to 2020 (IBGE, 2021). Municipal GDP, originally reported at current prices, was deflated to 2020 values using the Índice Nacional de Preços ao Consumidor Amplo (Extended National Consumer Price Index, IPCA), obtained from the Central Bank of Brazil (BACEN, 2026). The combination of deflated GDP and municipal population made it possible to calculate GDP per capita and, subsequently, the municipal additive terms associated with the intra-regional component of the generalised entropy indices. The regional GDP and population aggregates entering the decomposition are calculated from the full set of municipalities belonging to each regional unit before the eligibility and treatment restrictions used in the DiD sample are applied.

Territorial information was also obtained from IBGE databases. The codes of the

Intermediate Geographic Regions (IntGRs) and Immediate Geographic Regions (ImGRs) were used to organise the spatial decomposition of inequality and to define the nested regional structure within which the municipal additive contribution is calculated. The municipality's position within its ImGR, distinguishing hubs from surrounding municipalities, and the REGIC urban hierarchy were used in the construction of eligible groups, in the conditional specifications, and in the heterogeneity analyses. This information is important because the empirical strategy depends on separating comparable municipalities within functionally articulated regional structures.

The control variables were also constructed from IBGE databases. The municipal population estimate was log-transformed as a measure of size; the REGIC urban hierarchy was converted into dummy variables; and belonging to a Metropolitan Region was used to capture differences associated with metropolitan integration. Table 6.2 summarises the sources, variables, and uses of each database in the empirical analysis.

Table 6.2 - Data sources and variables used in the empirical analysis

Data source	Variables/information	Spatial unit	Period/reference	Use in the analysis
IBGE (2022), MUNIC 2021	Existence of a municipal Master Plan; year of adoption or revision of the Master Plan law	Municipality	Event years from 2012 to 2020	Identifies institutional events, separates Adoption and Revision cases, and supports the construction of eligible groups
Municipal Master Plan citation database constructed for this study	Citation indices for Economy, Society, Environment, Governance, Technology, Urban Brands, and the composite Smart City index	Municipality/ document	2012 to 2020	Defines Smart City incorporation, treatment status, treatment thresholds, and selected eligibility filters
IBGE (2021), Municipal GDP	Municipal GDP at current prices	Municipality	2013 to 2020	Used to construct municipal GDP per capita and the municipal additive contribution to the intra-regional component of inequality
IBGE (2021), municipal population estimates	Annual municipal population estimates	Municipality	2013 to 2020	Used to construct GDP per capita, population weights in the inequality decomposition, and the log population control

Table 6.2 - Continued

Data source	Variables/information	Spatial unit	Period/reference	Use in the analysis
IBGE (2021), regional classification	Codes of Intermediate Geographic Regions (IntGRs) and Immediate Geographic Regions (ImGRs)	Municipality assigned to IntGRs and ImGRs	2020 regional structure	Defines the spatial nesting used in the inequality decomposition and in the construction of comparable regional groups
IBGE (2021), REGIC and ImGR structure	Urban hierarchy and municipality position within the ImGR, distinguishing hubs and surrounding municipalities	Municipality	Time-invariant regional classification	Used in eligibility diagrams, hierarchy-based heterogeneity analyses, and conditional specifications
IBGE (2021), metropolitan region classification	Municipality membership in a Metropolitan Region	Municipality	2020	Used as a control variable in conditional specifications
BACEN (2026), IPCA	National Consumer Price Index (IPCA)	National	2013 to 2020	Used to deflate municipal GDP to 2020 prices

Source: Author's own elaboration based on IBGE (2021, 2022), BACEN (2026), and the municipal Master Plan database constructed for this study.

Note: MUNIC refers to the Pesquisa de Informações Básicas Municipais. IntGR stands for Intermediate Geographic Region, and ImGR stands for Immediate Geographic Region. REGIC refers to the Brazilian urban hierarchy classification. The citation database was constructed from municipal Master Plan documents collected from institutional repositories. The 2012–2020 window is used for institutional events and citation indicators because the eligibility rules include one-year lag filters. The outcome panel covers 2013–2020.

6.6.2 Construction of the analytical panel

The analytical panel follows Brazilian municipalities annually between 2013 and 2020. The initial year follows the stabilisation of the municipal territorial framework used in the IBGE databases, which increased from 5,565 municipalities up to 2012 to 5,570 municipalities from 2013 onwards. This choice reduces the possibility that recent administrative changes are confounded with economic variations associated with the policy analysed.

The 2013–2020 panel provides a limited horizon for assessing the economic consequences of planning changes. For later cohorts, it contains few post-event observations, so the estimates cannot establish the longer-run consequences potentially associated with regulation, infrastructure provision or institutional learning. Short-run changes in GDP

per capita and in the additive contribution may reflect changes in output, population and economic conditions elsewhere in the region. Their timing does not identify which adjustment margin dominates. The inclusion of 2020 also introduces exposure to the Covid-19 pandemic, whose economic consequences need not have been homogeneous across municipalities. This is a limitation of the observation window, rather than a reason to interpret the short-run estimates as a complete assessment of the plans.

The unit of observation is the municipality. The initial set consists of 381 municipalities that initially adopted the Master Plan and 535 municipalities that revised the instrument between 2013 and 2020, totalling 916 institutional events. After applying the eligibility criteria defined in Section 6.4, the final eligible sample comprises 864 municipalities, 348 in the initial adoption group and 516 in the revision group.

Under the reference rule based on the 50th percentile of the Smart City index, 177 municipalities are classified as treated in the adoption group and 257 in the revision group. Cohorts treated in 2013 are excluded from the main DiD estimations, as they have no pre-treatment observation within the dependent-variable panel. With this restriction, the final estimation sample under $p50$ consists of 830 municipalities, of which 400 belong to treated cohorts retained for estimation and 430 remain never treated within the analytical window. Table 6.3 summarises this construction.

Table 6.3 - Construction of the analytical and DiD estimation samples

Sample restriction	Adoption	Revision	Total
Municipalities with Master Plan event between 2013 and 2020	381	535	916
Exclusions due to municipal emancipation or territorial subdivision	4	2	6
Exclusions due to same ImGR as emancipated municipalities in 2013 or 2014	5	1	6
Exclusions due to ImGRs with fewer than four municipalities	2	2	4
Exclusions due to high textual similarity after manual checking	4	6	10
Exclusions due to an ImGR pole adopting a Master Plan in t or $t - 1$	16	8	24
Exclusions under the event-specific Level 3 rule for neighbouring Master Plan revisions in t or $t - 1$	2	0	2
Final eligible sample	348	516	864
Treated under $p50$	177	257	434

Table 6.3 - Continued

Sample restriction	Adoption	Revision	Total
Municipalities in first-year treated cohorts excluded from DiD estimations	26	8	34
Municipalities in treated cohorts used in DiD estimations	151	249	400
Never treated	171	259	430
Final DiD estimation sample under <i>p50</i>	322	508	830

Source: Author's own elaboration based on IBGE (2021, 2022d) and the municipal Master Plan database constructed for this study.

Note: The table reports the sequential construction of the analytical sample and the final DiD estimation sample under the *p50* Smart City treatment rule. Adoption refers to municipalities that initially adopted a Master Plan, while Revision refers to municipalities that revised a previously existing Master Plan. ImGR stands for Immediate Geographic Region. The notation t denotes the year of the Master Plan event, and $t - 1$ denotes the previous year. "Treated under *p50*" refers to eligible municipalities whose Smart City citation index is positive and equal to or above the 50th percentile cutoff, defined by event type and year. First-year treated cohorts are excluded from the main DiD estimations because no pre-treatment observation is available within the 2013–2020 outcome panel. "Never treated" refers to eligible municipalities that do not meet the *p50* treatment rule within the analytical window. The Level 3 conditions differ between Adoption and Revision and are detailed in Figures 6.2 and 6.3, respectively.

6.6.3 Descriptive statistics for the municipal additive contribution

Table 6.4 presents the descriptive statistics for the dependent variable used in the main estimations. The statistics are calculated at the municipality-year level, considering the 2013–2020 panel and the estimation sample under the *p50* reference threshold, after excluding the cohorts treated in 2013. The separation by type of institutional event and treatment status makes it possible to observe the distribution of the municipal additive contribution before the estimation of effects, distinguishing between municipalities in the initial adoption and revision groups, as well as those classified as treated or never treated according to the reference rule of the Smart City index.

The variable described in Table 6.4 corresponds to the municipal additive term that makes up the intra-regional component of economic inequality. Since this contribution may enter the decomposition with either a negative or a positive sign, its values should be interpreted as algebraic terms, rather than as isolated effects reducing or increasing regional inequality.

Table 6.4 - Descriptive statistics for the municipal additive contribution to the intra-regional component of GDP per capita inequality

Inequality measure	Event	Treatment status	N obs.	Mean	SD	Min	P25	Median	P75	Max
<i>GE</i> (1)	Adoption	Treated	1,208	0.003	0.020	-0.040	-0.003	-0.001	0.001	0.140
<i>GE</i> (1)	Adoption	Never	1,368	0.005	0.047	-0.068	-0.002	-0.001	0.001	0.765
<i>GE</i> (1)	Revision	Treated	1,992	0.012	0.037	-0.065	-0.003	0.000	0.011	0.277
<i>GE</i> (1)	Revision	Never	2,072	0.003	0.029	-0.174	-0.003	0.000	0.003	0.384
<i>GE</i> (0)	Adoption	Treated	1,208	0.001	0.015	-0.090	-0.001	0.001	0.004	0.075
<i>GE</i> (0)	Adoption	Never	1,368	0.001	0.015	-0.104	-0.001	0.001	0.003	0.082
<i>GE</i> (0)	Revision	Treated	1,992	-0.004	0.022	-0.107	-0.009	0.000	0.004	0.141
<i>GE</i> (0)	Revision	Never	2,072	0.002	0.020	-0.091	-0.003	0.001	0.004	0.244
<i>GE</i> (2)	Adoption	Treated	1,208	0.004	0.026	-0.036	-0.003	0.000	0.001	0.253
<i>GE</i> (2)	Adoption	Never	1,368	0.011	0.130	-0.120	-0.002	0.000	0.000	2.553
<i>GE</i> (2)	Revision	Treated	1,992	0.015	0.056	-0.070	-0.003	0.000	0.010	0.654
<i>GE</i> (2)	Revision	Never	2,072	0.004	0.048	-0.186	-0.003	0.000	0.003	0.834

Source: Author's own elaboration based on IBGE (2021), BACEN (2026), and the municipal Master Plan database constructed for this study.

Note: Descriptive statistics are computed at the municipality-year level for the 2013–2020 analytical panel used in the main DiD estimations under the *p*50 Smart City treatment rule. Municipalities in first-year treated cohorts are excluded because no pre-treatment observation is available within the outcome panel. Treated refers to municipalities classified as treated under the *p*50 Smart City cutoff, i.e., municipalities whose Smart City citation index is positive and equal to or above the 50th percentile cutoff in the year of the institutional event and that enter the DiD estimation sample. Never refers to eligible municipalities that do not meet the *p*50 treatment rule within the analytical window. *GE*(1) corresponds to the Theil T index, *GE*(0) to the mean logarithmic deviation, and *GE*(2) to the half-squared coefficient of variation. Treatment status is defined at the municipality level.

The values indicate means of small magnitude and medians close to zero. For *GE*(1), the chapter's main measure, the means range from 0.003 among treated municipalities in the initial adoption group to 0.012 among treated municipalities in the revision group. The medians remain close to zero across all groups, a pattern consistent with the nature of the variable, whose interpretation depends on the municipality's relative position within its ImGR and on its weight in the broader regional structure.

The comparison between treated and never-treated municipalities is strictly descriptive. The observed differences in levels do not indicate a policy effect, as they combine years before and after the institutional event and reflect structural characteristics of the municipalities and their regions. In the revision group, for example, the mean of *GE*(1) is higher among municipalities treated under *p*50 than among never-treated municipalities, which suggests differences in group composition rather than a causal effect of incorporating the smart city agenda. Empirical identification depends on comparing trajectories over time, as carried out in the Difference-in-Differences estimations.

Dispersion varies according to the entropy measure adopted. As expected, the terms associated with *GE*(2) exhibit greater dispersion, reflecting this measure's greater

sensitivity to observations located in the upper part of the distribution. This pattern justifies retaining $GE(1)$ as the reference measure and using $GE(0)$ and $GE(2)$ as consistency checks within the same family of indices.

6.6.4 Temporal, territorial and cohort distribution of treatments

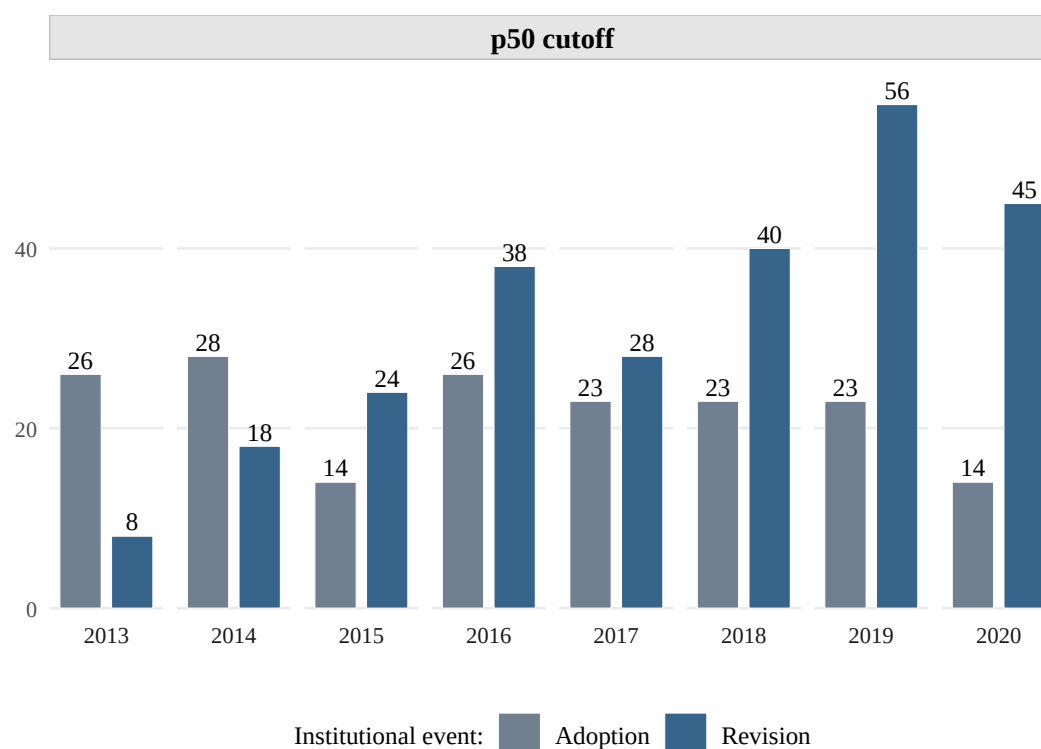
The distribution of treatments by year and type of institutional event is presented in Figure 6.4. The graph considers the reference threshold based on the 50th percentile ($p50$) of the Smart City index and shows the number of municipalities classified as treated in the year of initial adoption or revision of the Master Plan. The corresponding distributions for the $p25$ and $p75$ thresholds are reported in Figure A.6.1 in the Appendix. The figure situates the formation of treated cohorts over the period analysed.

Figure 6.4 shows that treatments are distributed throughout the period from 2013 to 2020, although with distinct patterns between initial adoption and revision. In the initial adoption group, the number of treated municipalities is higher in 2013, 2014, and 2016, remains relatively stable between 2017 and 2019, and falls again in 2020. In the revision group, by contrast, treated municipalities are more concentrated from the middle of the decade onwards, with higher values in 2018, 2019, and 2020. This pattern is consistent with the gradual diffusion of smart city terminology in urban planning instruments, especially among municipalities that already had a prior history of Master Plans and revised their documents in a context in which this agenda was more widely circulating.

Figure A.6.1 complements this interpretation by showing how the distribution of cohorts changes when alternative treatment thresholds are adopted. The $p25$ threshold increases the number of treated municipalities and makes the diffusion of the smart city agenda in revisions more visible over the second half of the decade. The $p75$ threshold, in turn, selects a smaller set of municipalities, consistent with a more restrictive definition of incorporation. The comparison across panels indicates that changing the threshold alters the size of the cohorts, but preserves the distinction between initial adoption and revision observed under the reference threshold.

The cohorts treated in 2013 call for a specific caveat. Since the dependent-variable panel begins in that same year, municipalities treated in 2013 have no pre-treatment observation within the estimation window. For this reason, these cases are shown in Figure 6.4 and Figure A.6.1 for descriptive purposes, but are not included in the main Difference-in-Differences estimations.

Figure 6.4 - Smart City-treated municipalities by institutional event and cohort year under the $p50$ cutoff, 2013–2020



Source: Author's own elaboration based on IBGE (2021, 2022b) and the municipal Master Plan database constructed for this study.

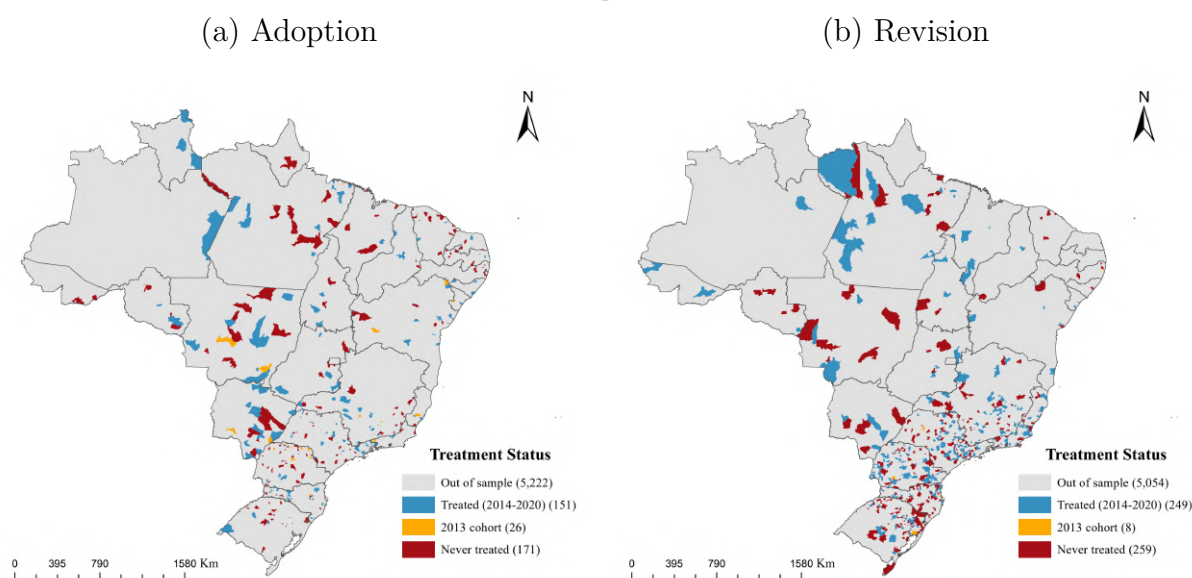
Note: The figure reports the number of eligible municipalities classified as treated under the $p50$ Smart City treatment rule by institutional event and year. Adoption refers to municipalities that initially adopted a Master Plan, while Revision refers to municipalities that revised a previously existing Master Plan. The $p50$ rule classifies as treated eligible municipalities whose Smart City citation index is positive and equal to or above the 50th percentile cutoff defined by event type and year. The 2013 treated cohorts, 26 municipalities in Adoption and 8 in Revision, are shown for descriptive purposes but excluded from the main DiD estimations because no pre-treatment observation is available within the 2013–2020 outcome panel. The never-treated control groups contain 171 municipalities in Adoption and 259 municipalities in Revision.

In addition to the distribution of treated municipalities by year, Figures A.6.2 and A.6.3 trace the average annual evolution of the municipal additive contribution by treatment cohort, separately for initial adoption and revision, considering the $p25$, $p50$, and $p75$ thresholds. In each panel, the trajectory of treated cohorts is compared with that of eligible never-treated municipalities. These graphs serve a descriptive purpose and make it possible to observe the raw behaviour of the outcome before the estimation of effects, without replacing the event studies and formal pre-treatment tests presented in the following sections.

The territorial distribution of the groups is presented in Figure 6.5. The map distinguishes, separately for initial adoption and revision, municipalities treated between 2014 and 2020, cohorts treated in 2013, never-treated municipalities, and those outside the

corresponding analytical sample. This representation complements the temporal distribution by showing that the treatment and comparison groups are not merely econometric categories, but municipalities embedded in a heterogeneous territorial network, marked by strong regional differentiation and distinct positions within the Brazilian urban system.

Figure 6.5 - Spatial distribution of eligible municipalities by Smart City treatment status under the $p50$ cutoff



Source: Author's own elaboration based on IBGE (2021, 2022d) and the municipal Master Plan database constructed for this study.

Note: The figure maps municipalities according to their Smart City treatment status under the $p50$ cutoff. Panel (a) refers to Adoption, and Panel (b) refers to Revision. Treated municipalities are those whose Smart City citation index is positive and equal to or above the 50th percentile cutoff defined by event type and year. Treated cohorts from 2014 to 2020 enter the main DiD estimations. The 2013 treated cohorts, 26 municipalities in Adoption and 8 in Revision, are mapped separately because they are excluded from the main DiD estimations due to the absence of a pre-treatment observation within the outcome panel. Never-treated municipalities are eligible municipalities that do not meet the $p50$ treatment rule within the analytical window, corresponding to 171 municipalities in Adoption and 259 in Revision. Grey areas represent municipalities outside the corresponding event-specific analytical sample and are shown for geographic reference.

Figure 6.5 indicates that eligible municipalities are not evenly distributed across the national territory. There appears to be a greater concentration of treated and never-treated municipalities in the Centre-South of Brazil, as well as cases in specific areas of the North and Northeast regions. This pattern should not be interpreted as causal evidence, but rather as a descriptive feature of the sample and of the diffusion of Master Plans in the country. The presence of municipalities outside the sample across much of the territory reflects, among other factors, the absence of an institutional event in the period, lack of eligibility, or exclusion under the criteria defined in the diagrams presented above.

Taken together, the temporal and territorial distributions indicate that treat-

ment status varies across years, types of institutional event, municipalities, and intensity thresholds. This variation supports the construction of treated cohorts, preserves the separation between initial adoption and revision, and makes it possible to use eligible never-treated municipalities as a comparison group within the analytical window. Building on this sample structure, the following section presents the empirical results.

6.7 Main results: composite Smart City index

This section presents the main results for the composite Smart City index. The analysis starts from the municipal additive contribution to the intra-regional component of inequality, calculated using GE(1), and compares the estimated effects for the initial adoption and revision of the Master Plan. The $p50$ threshold is used as the reference cutoff, while $p75$ is used to examine more intensive incorporation of the agenda into municipal documents. The interpretation combines average effects, dynamics in event time, and comparison between the two types of institutional change.

6.7.1 Average effects by intensity of incorporation and type of institutional event

Table 6.5 presents the average effects estimated for the composite Smart City index, considering two intensity thresholds: the 50th percentile ($p50$), used as the reference threshold, and the 75th percentile ($p75$), which identifies municipalities located in the upper quartile of the annual distribution among comparable cases. In addition to specifications without controls, conditional specifications are reported that separately incorporate the logarithm of population and the REGIC urban hierarchy. The table also presents the p -value of the joint test of pre-treatment group-time effects, used as a complementary diagnostic of the parallel trends assumption. The broader definition, based on the 25th percentile ($p25$), is reported in Table A.6.3 in the Appendix.

The thresholds are alternative empirical definitions of documentary intensity rather than sources of exogenous variation. Accordingly, the results are read jointly across cutoffs, while the greater attention subsequently given to $p75$ reflects both its interpretation as a more intensive margin of incorporation and the diagnostics observed in that specification.

The results under the $p50$ threshold do not indicate a robust average change in the municipal additive contribution to the intra-regional component of inequality. At the $p50$ threshold, the estimated coefficients for initial adoption are close to zero and statistically indistinguishable from zero in all specifications. For revision, the coefficients are negative, but the evidence is not fully stable: the effect appears only marginally in the specification without controls and in the specification with urban hierarchy, while the joint pre-treatment test rejects the null hypothesis in all three specifications. Thus, the $p50$ estimates point in a negative direction for municipalities in the revision group, but do not provide sufficiently stable evidence to support a stronger substantive interpretation.

Table 6.5 - Average treatment effects of Smart City incorporation under reference and intensive cutoffs

Institutional event	Cutoff	Specification	Estimate	SE	p-value	95% CI	Pre-test p-value	N obs.
Adoption	<i>p</i> 50	Baseline	0.0006	0.0014	0.6370	[-0.0020; 0.0033]	0.12981	2,576
Adoption	<i>p</i> 50	log(Pop)	0.0006	0.0012	0.6341	[-0.0018; 0.0030]	0.10368	2,576
Adoption	<i>p</i> 50	REGIC	0.0005	0.0011	0.6650	[-0.0017; 0.0027]	0.32797	2,576
Adoption	<i>p</i> 75	Baseline	0.0001	0.0011	0.9569	[-0.0020; 0.0021]	0.06021	2,680
Adoption	<i>p</i> 75	log(Pop)	-0.0001	0.0011	0.9580	[-0.0023; 0.0022]	0.25268	2,680
Adoption	<i>p</i> 75	REGIC	-0.0004	0.0011	0.7510	[-0.0026; 0.0019]	0.26595	2,680
Revision	<i>p</i> 50	Baseline	-0.0018*	0.0010	0.0619	[-0.0038; 0.0001]	0.01180	4,064
Revision	<i>p</i> 50	log(Pop)	-0.0010	0.0011	0.3682	[-0.0031; 0.0012]	0.03022	4,064
Revision	<i>p</i> 50	REGIC	-0.0018*	0.0010	0.0574	[-0.0037; 0.0001]	0.01823	4,064
Revision	<i>p</i> 75	Baseline	-0.0035**	0.0014	0.0106	[-0.0062; -0.0008]	0.04407	4,088
Revision	<i>p</i> 75	log(Pop)	-0.0028*	0.0014	0.0515	[-0.0055; 0.0000]	0.13357	4,088
Revision	<i>p</i> 75	REGIC	-0.0036**	0.0014	0.0110	[-0.0064; -0.0008]	0.08333	4,088

Source: Author's own elaboration.

Note: The table reports average treatment effects for the composite Smart City index under the *p*50 reference cutoff and the *p*75 intensive-incorporation cutoff. The outcome is the municipal additive contribution to the intra-regional component of GDP per capita inequality, computed using GE(1), the Theil T index. Estimates are obtained separately by institutional event using eligible never-treated municipalities as the comparison group. Baseline refers to the model without covariates; log(Pop) controls for the logarithm of municipal population; REGIC controls for urban-hierarchy categories. Municipalities in first-year treated cohorts are excluded because no pre-treatment observation is available within the 2013–2020 outcome panel. SE denotes standard error. The pre-test p-value refers to the joint Wald test for the null hypothesis that all pre-treatment group-time effects are equal to zero. Negative estimates indicate a reduction in the municipality's additive contribution to the intra-regional component of inequality. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Under the *p*75 rule, the population-conditioned estimate for revisions is -0.0028 , with a p-value of 0.0515. This is a change in units of the signed municipal Theil contribution, not a percentage reduction in regional inequality or an increase in municipal income. The estimate is not statistically distinguishable from zero at the 5% level, although it is at the 10% level, and its interpretation remains conditional on the comparison and measurement assumptions. The *p*50 results and the alternative specifications remain part of the evidence. The difference between the *p*50 and *p*75 findings is therefore treated as sensitivity to the treatment definition, rather than as evidence that the threshold itself provides exogenous variation.

The meaning of the dependent variable guides the interpretation of these results. As discussed in Section 6.3, the municipal additive contribution does not correspond to a counterfactual effect of removing the municipality from the regional distribution. It represents the term through which the municipality participates, in a signed and weighted manner, in the composition of the intra-regional component of GDP per capita inequality. In this sense, a negative coefficient indicates a reduction in this municipal additive term over the post-treatment period, rather than a direct and aggregate reduction in regional

inequality as a whole. The negative estimate therefore concerns a change in the signed municipal term of the decomposition and should not be read, by itself, as evidence of a reduction in aggregate intra-regional inequality.

For municipalities that initially adopted a Master Plan, the estimated average effects remain small and statistically indistinguishable from zero under both $p50$ and $p75$. This result suggests that the initial adoption of the instrument, even when accompanied by more intensive incorporation of the Smart City agenda, does not translate into a detectable change in the municipal additive contribution over the period analysed.

6.7.2 Dynamics of the effects and pre-treatment trends

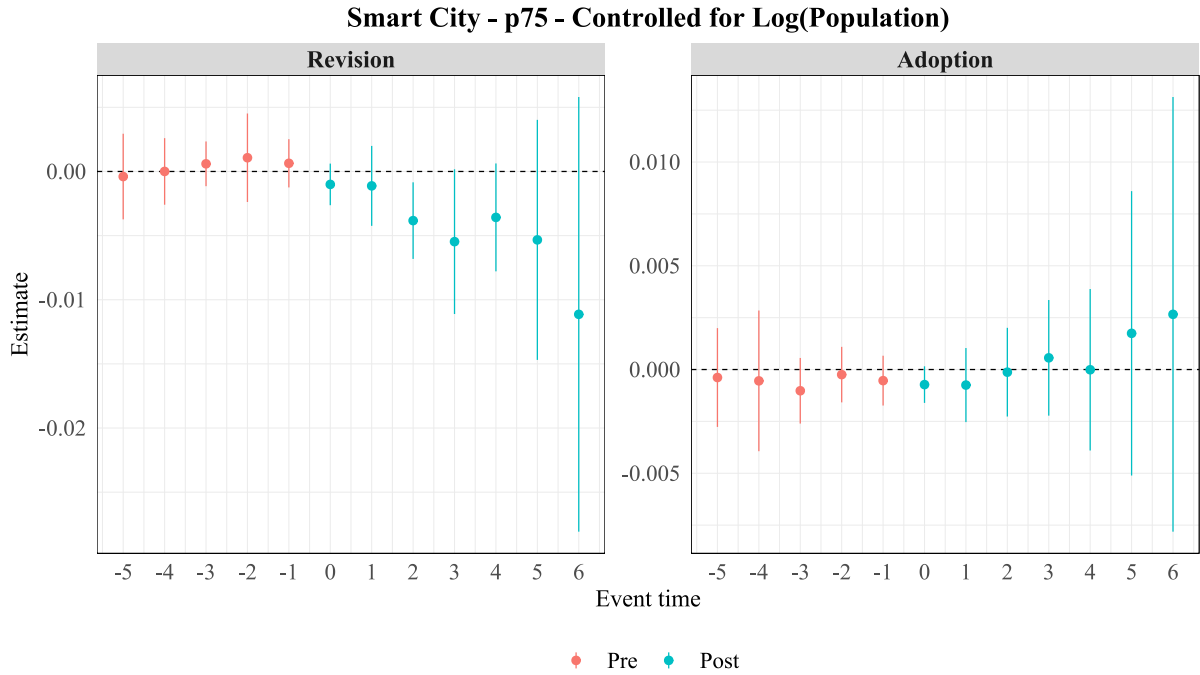
Figure 6.6 presents the dynamics of the effects in event time for the intensive $p75$ threshold, in the specification conditioned on the logarithm of population. The figure focuses on this specification because $p75$ represents the intensive treatment margin and, among the estimated revision specifications, the population-conditioned model combines a negative average estimate with a comparatively more favourable pre-treatment diagnostic. This choice is used to organise the presentation of the dynamic results and does not imply that the $p75$ threshold constitutes an exogenous source of treatment variation. The coefficients that make up Figure 6.6 are reported in Table A.6.4 in the Appendix, while additional dynamics by intensity threshold and specification are presented in Figures A.6.5 and A.6.6.

The interpretation of the pre-treatment coefficients remains a visual diagnostic of the plausibility of the empirical design. In the case of revision, the pre-treatment coefficients in Figure 6.6 are close to zero and do not suggest a systematic shift before the event. The formal pre-treatment diagnostics, reported in full in Table A.6.5 in the Appendix, qualify this visual interpretation. For revision under the $p75$ threshold, the specification conditioned on the logarithm of population does not reject the null hypothesis of no pre-treatment group-time effects, whereas the specification without controls presents a less favourable diagnostic. This pattern suggests that part of the pre-treatment differences is associated with municipal size, reinforcing the suitability of interpreting the main dynamics through the conditional specification.

In the post-treatment period, the estimated trajectory for revision shifts towards negative values over a substantial part of the post-event window, especially from the first years after revision onwards. The magnitude of the effects tends to increase in periods farther from the event, although the confidence intervals also become wider. This pattern calls for caution, since dynamic effects over longer horizons rely on a smaller number of cohorts observed over the full post-treatment period. For this reason, Table A.6.6 in the Appendix reports cohort-specific average effects under the $p75$ threshold, making it possible to assess the extent to which the average evidence is distributed across,

or concentrated in, different treatment years. Even so, the direction of the dynamic coefficients is consistent with the negative average effect observed in Table 6.5 for revisions with intensive incorporation of the Smart City agenda.

Figure 6.6 - Dynamic effects of intensive Smart City incorporation under the $p75$ cutoff



Source: Author's own elaboration.

Note: The figure reports event-study estimates for the composite Smart City index under the $p75$ intensive cutoff, controlling for the logarithm of municipal population. The outcome is the municipal additive contribution to the intra-regional component of GDP per capita inequality, computed using GE(1), the Theil T index. Event time is defined relative to the year of treatment. The left panel reports Revision, and the right panel reports Adoption. The control group consists of eligible never-treated municipalities. Municipalities in first-year treated cohorts are excluded because no pre-treatment observation is available within the 2013–2020 outcome panel. Dots report estimated effects, and vertical bars report 95% confidence intervals. Vertical scales are allowed to vary across panels to improve readability. Average treatment effects are reported in Table 6.5, and the full set of joint pre-treatment tests is reported in Table A.6.5.

For initial adoption, Figure 6.6 shows a different dynamic pattern. The pre-treatment coefficients also remain close to zero, but the post-event effects do not indicate a systematic reduction in the municipal additive contribution to the intra-regional component of inequality. In some periods, the estimates approach positive values, but the confidence intervals are wide and do not support an interpretation of a statistically well-defined change. This trajectory is consistent with the average effects reported in Table 6.5, which remain small and indistinguishable from zero for initial adoption under both $p50$ and $p75$.

6.7.3 Revision and initial adoption: a comparative interpretation

The two events do not represent the same intervention at different stages. For initial adoption, treatment is defined from the content of the first Master Plan; for revision,

it records newly appearing themes relative to an earlier document. Comparisons between their estimates therefore combine different documentary margins and municipal planning histories, rather than isolate the effect of prior institutional experience.

The negative estimates observed in selected intensive-revision specifications indicate where the empirical association is more apparent within the comparisons undertaken. They do not establish that revising an existing plan is more effective than adopting a first one, or that initial adoption has no economic consequences. The following section examines whether the estimates vary across urban-hierarchy groups and levels of prior documentary content.

6.8 Effect heterogeneity: urban network and documentary maturity

This section examines whether the estimated effects for the composite Smart City index vary according to institutional and territorial characteristics of municipalities. The analysis considers two dimensions of heterogeneity. The first is position in the urban network, measured through the REGIC hierarchy. The second is the prior documentary maturity of the smart city agenda among municipalities in the revision group. These exercises do not replace the average results, but qualify their interpretation by examining whether intensive incorporation of the Smart City agenda is associated differently with municipalities that occupy distinct regional positions and have different documentary trajectories.

6.8.1 Urban hierarchy and position in the regional network

The first dimension of heterogeneity considers municipalities' position in the urban network. To this end, municipalities are grouped according to IBGE's REGIC hierarchy (2019b), distinguishing higher-order centres, intermediate centres, and local centres. Table 6.6 presents the average effects estimated under the intensive $p75$ threshold, in the specification conditioned on the logarithm of population. Figure 6.7 summarises these coefficients and their confidence intervals. The complementary results for $p25$, $p50$, and $p75$ are reported in Table A.6.7 and Figure A.6.7 in the Appendix.

The results for initial adoption do not indicate a statistically well-defined change in any hierarchical group. The estimated coefficients for higher-order centres and intermediate centres are negative, but with confidence intervals that include zero. Among local centres, the coefficient is positive and also not significant. This pattern preserves the interpretation observed in the average results: the initial adoption of the Master Plan, even when accompanied by intensive incorporation of the Smart City agenda, does not provide evidence of a systematic change in the municipal additive contribution to the intra-regional component of inequality.

Table 6.6 - Average treatment effects under the *p75* Smart City cutoff by urban hierarchy

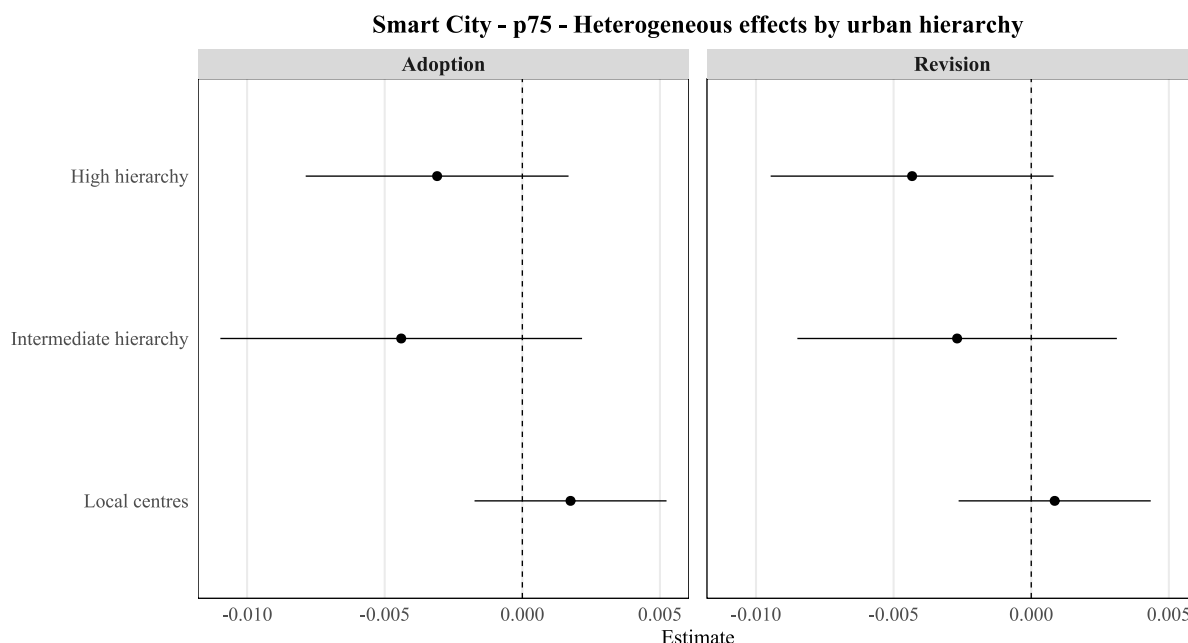
Institutional event	Group	Estimate	SE	P-value	95% CI	Pre-test p-value	N obs.	Treated	Never treated
Adoption	Higher-order centres	-0.0031	0.002	0.204	[-0.0079; 0.0017]	< 0.0001	312	14	25
Adoption	Intermediate centres	-0.0044	0.003	0.189	[-0.0110; 0.0022]	< 0.0001	536	25	42
Adoption	Local centres	0.0018	0.002	0.325	[-0.0017; 0.0052]	< 0.0001	1832	40	189
Revision	Higher-order centres	-0.0043*	0.003	0.099	[-0.0095; 0.0008]	0.0313	1224	56	97
Revision	Intermediate centres	-0.0027	0.003	0.363	[-0.0085; 0.0031]	0.1749	1392	39	135
Revision	Local centres	0.0009	0.002	0.633	[-0.0026; 0.0043]	< 0.0001	1472	30	154

Source: Author's own elaboration.

Note: The table reports heterogeneous average treatment effects for the composite Smart City index under the *p75* intensive cutoff by REGIC urban hierarchy. The specification controls for the logarithm of municipal population. The outcome is the municipal additive contribution to the intra-regional component of GDP per capita inequality, computed using GE(1), the Theil T index. Estimates are obtained separately by institutional event using eligible never-treated municipalities within each subgroup as the comparison group. Municipalities in first-year treated cohorts are excluded because no pre-treatment observation is available within the 2013–2020 outcome panel. The pre-test p-value refers to the joint Wald test for the null hypothesis that all pre-treatment group-time effects are equal to zero. SE denotes standard error, and 95% CI denotes the 95% confidence interval. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

In the case of revision, the pattern by urban hierarchy is clearer. The estimated coefficient for higher-order centres is negative and marginally significant, while intermediate centres and local centres do not show statistically well-defined effects. The estimated magnitude for higher-order centres is consistent with the interpretation that intensive incorporation of the Smart City agenda tends to be reflected more clearly in municipalities occupying more central positions in the urban network. Even so, the pre-treatment diagnostic for this group calls for caution, since the joint test rejects the null hypothesis at the conventional 5% level.

The subgroup estimates differ across positions in the urban hierarchy, but the pre-treatment diagnostic for higher-order centres prevents these differences from being interpreted as evidence that network position causally conditions the effect of revision. The more negative estimate observed for higher-order centres may also reflect differences in productive structure, fiscal resources, administrative capacity and regional functions that are not separately identified in this exercise. The estimates for intermediate and local centres are not statistically well defined.

Figure 6.7 - Heterogeneous effects under the $p75$ Smart City cutoff by urban hierarchy

Source: Author's own elaboration.

Note: The figure reports heterogeneous average treatment effects for the composite Smart City index under the $p75$ intensive cutoff by REGIC urban hierarchy. The specification controls for the logarithm of municipal population. The outcome is the municipal additive contribution to the intra-regional component of GDP per capita inequality, computed using GE(1), the Theil T index. Estimates are obtained separately for Adoption and Revision using eligible never-treated municipalities within each hierarchy group as the comparison group. Municipalities in first-year treated cohorts are excluded because no pre-treatment observation is available within the 2013–2020 outcome panel. Dots report estimated effects, and horizontal bars report 95% confidence interval.

The sensitivity results in the Appendix qualify this interpretation. Table A.6.7 and Figure A.6.7 indicate that the negative pattern for revision in higher-order centres becomes more visible at the $p75$ threshold, while the $p25$ and $p50$ thresholds do not show the same definition. Thus, heterogeneity by urban hierarchy does not alter the main interpretation of the previous section, but delimits its scope. The reduction in the municipal additive contribution associated with revision of the Master Plan with intensive incorporation appears to be more concentrated in municipalities occupying higher hierarchical positions, with no comparable evidence for initial adoption or for local centres.

6.8.2 Prior documentary maturity of the smart city agenda

The second dimension of heterogeneity considers the prior documentary maturity of the smart city agenda. The exercise is restricted to municipalities in the revision group, since the measure depends on the existence of a Master Plan prior to the institutional event. Municipalities are grouped into quartiles according to the Smart City content observed in the previous document, making it possible to assess whether the estimated effect varies according to the prior degree of incorporation of this agenda. Table 6.7 presents the

average effects under the intensive $p75$ threshold, in the specification conditioned on the logarithm of population. Figure 6.8 provides a graphical summary of these coefficients. The complementary results by threshold and specification are reported in Table A.6.8 and Figure A.6.8 in the Appendix.

Table 6.7 - Average treatment effects for Revision under the $p75$ Smart City cutoff by previous documentary maturity

Quartile	Estimate	SE	p-value	95% CI	Pre-test p-value	N obs.	Treated	Never treated
Q1	0.0011	0.002	0.620	[-0.0034; 0.0056]	0.00687	1008	61	65
Q2	-0.0086***	0.003	0.007	[-0.0149; -0.0024]	0.00003	1040	31	99
Q3	-0.0036	0.004	0.368	[-0.0113; 0.0042]	< 0.0001	1064	17	116
Q4	0.0007	0.007	0.913	[-0.0123; 0.0137]	< 0.0001	976	16	106

Source: Author's own elaboration.

Note: The table reports heterogeneous average treatment effects for Revision under the $p75$ intensive cutoff by quartiles of previous documentary maturity. Previous documentary maturity is measured from the Smart City content observed before the Master Plan revision. Q1 denotes the lowest maturity quartile, and Q4 denotes the highest maturity quartile. The specification controls for the logarithm of municipal population. The outcome is the municipal additive contribution to the intra-regional component of GDP per capita inequality, computed using $GE(1)$, the Theil T index. Eligible never-treated municipalities within each maturity quartile are used as the comparison group. Municipalities in first-year treated cohorts are excluded because no pre-treatment observation is available within the 2013–2020 outcome panel. Treated and Never treated report the number of municipalities in each group. The pre-test p-value refers to the joint Wald test for the null hypothesis that all pre-treatment group-time effects are equal to zero. SE denotes standard error, and 95% CI denotes the 95% confidence interval. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

The results do not indicate a monotonic gradient between prior documentary maturity and a reduction in the municipal additive contribution. The negative and statistically well-defined coefficient appears in the second quartile, while the other groups do not show effects statistically different from zero. In the first quartile, the coefficient is positive and small; in the third, it is negative but imprecise; in the fourth, it moves back towards zero, with a wide confidence interval.

The unfavourable pre-treatment diagnostics in Table 6.7 limit the interpretation of the negative estimate for Q2. The additional specifications in Table A.6.8 and Figure A.6.8 likewise show no stable gradient across thresholds and specifications. The exercise therefore leaves open whether prior documentary content is associated with systematically different responses.

Figure 6.8 - Heterogeneous effects under the $p75$ Smart City cutoff by previous documentary maturity



Source: Author's own elaboration.

Note: The figure reports heterogeneous average treatment effects for the composite Smart City index under the $p75$ intensive cutoff by quartiles of previous documentary maturity. The specification controls for the logarithm of municipal population. Estimates are reported for Revision because previous documentary maturity is defined from the Smart City content observed before the Master Plan revision. The outcome is the municipal additive contribution to the intra-regional component of GDP per capita inequality, computed using GE(1), the Theil T index. Eligible never-treated municipalities within each maturity group are used as the comparison group. Municipalities in first-year treated cohorts are excluded because no pre-treatment observation is available within the 2013–2020 outcome panel. Dots report estimated effects, and horizontal bars report 95% confidence intervals.

6.8.3 Joint interpretation of heterogeneities

These subgroup estimates do not identify the mechanisms underlying the aggregate pattern. Under the $p75$ rule, the estimate for higher-order centres in the Revision group is negative and marginally significant, but its joint pre-treatment test rejects the null hypothesis at the 5% level. The statistically significant estimate for the second documentary-maturity quartile is likewise accompanied by rejection of the joint pre-treatment test. These diagnostics prevent the subgroup coefficients from being treated as convincing evidence of causal differences across groups. Urban hierarchy and prior documentary content may proxy several characteristics, including fiscal resources, productive structure and administrative capacity. Distinguishing these explanations would require additional evidence and direct tests of differences between groups.

6.9 Thematic composition and the exploratory nature of the effects

The previous estimates indicate that the more clearly defined patterns are concentrated in revisions of Master Plans with intensive incorporation of the Smart City agenda. This section qualifies this evidence through two complementary steps. The first examines the thematic composition of the treatment, identifying which dimensions are more prominent among municipalities classified by the composite index. The second examines auxiliary outcomes associated with municipalities' regional economic position, distinguishing the level of municipal GDP per capita, its relative position in relation to the leave-one-out mean of the ImGR, and the absolute distance from that regional mean. These exercises are exploratory and help situate the documentary and regional content associated with the main results.

6.9.1 Thematic profile of Smart City incorporation under intensive treatment

Table 6.8 presents the thematic profile of municipalities classified as treated by the composite Smart City index under the intensive $p75$ threshold. The table characterises the documentary composition of the treatment before the dimension-specific exercises. The six dimensions that make up the composite index are considered, making it possible to observe whether classification as intensive treatment reflects broad incorporation of the agenda or concentration in a small number of themes.

Table 6.8 - Thematic profile of intensive Smart City incorporation under the $p75$ composite cutoff

Event	Dimension	Treated	Never treated	Positive treated (%)	Positive never (%)	Mean index treated	Mean index never treated	Median index treated	Mean share treated (%)
Revision	Economy	125	386	99.20	35.23	0.273	0.043	0.254	17.92
Revision	Society	125	386	99.20	45.34	0.266	0.045	0.248	17.36
Revision	Environment	125	386	99.20	51.55	0.324	0.064	0.317	20.41
Revision	Governance	125	386	88.00	16.84	0.273	0.020	0.250	15.88
Revision	Technology	125	386	93.60	29.53	0.379	0.067	0.375	24.82
Revision	Urban Brands	125	386	42.40	9.84	0.046	0.009	0.000	3.61
Adoption	Economy	79	256	100.00	97.27	0.493	0.327	0.496	15.18
Adoption	Society	79	256	100.00	98.44	0.629	0.458	0.662	19.44
Adoption	Environment	79	256	100.00	97.66	0.650	0.458	0.675	20.11
Adoption	Governance	79	256	100.00	98.05	0.744	0.642	0.750	23.11
Adoption	Technology	79	256	100.00	92.58	0.677	0.315	0.675	20.81
Adoption	Urban Brands	79	256	45.57	37.89	0.045	0.035	0.000	1.36

Source: Author's own elaboration.

Note: The table reports the thematic profile of municipalities classified as treated under the *p75* composite Smart City cutoff. The statistics are computed at the event-document level for municipalities included in the analytical sample. Event refers to the institutional event. The dimensions are Economy, Society, Environment, Governance, Technology, and Urban Brands. Positive share indicates the percentage of municipalities with a positive citation index in the corresponding dimension. Mean dimensional share is computed as the dimensional index divided by the sum of the six thematic indices and is reported only as a descriptive measure of thematic composition. Treated and Never treated report the number of municipalities in each group. The table should not be interpreted as evidence of causal mechanisms, but as a descriptive characterisation of the content associated with intensive composite Smart City incorporation.

Among municipalities in the revision group, intensive treatment is multidimensional in nature. Economy, Society, and Environment appear with positive citations in 99.2% of treated municipalities, while Technology and Governance also show a high presence, at 93.6% and 88.0%, respectively. Urban Brands is the clearest exception, with lower presence and a reduced average share in the thematic index. In terms of composition, Technology and Environment account for the highest average shares among treated municipalities, followed by Economy, Society, and Governance.

6.9.2 Exploratory dimension-specific evidence

Table 6.9 presents exploratory estimates by thematic dimension for municipalities in the revision group, using the intensive thresholds defined for each area. The exercise does not seek to decompose the composite effect into independent causal channels. The dimensions of the Master Plans overlap in the normative text and may operate in combination. Even so, dimension-specific estimation helps identify which contents appear more closely aligned with the result obtained for the composite Smart City index.

The dimension-specific estimates provide an exploratory description of which thematic components are more closely associated with the composite pattern. Society and Governance present negative estimates under their respective intensive cutoffs, while the remaining dimensions do not show statistically well-defined coefficients. Given the overlap between dimensions, the different treatment classifications across thematic specifications and the number of estimates examined, these results do not establish that either dimension constitutes a mechanism underlying the composite estimate.

The evidence remains exploratory. The dimension-specific cutoffs follow the distribution of each area, and Urban Brands uses the *p80* threshold because *p75* still includes zero values at the cutoff point. In addition, the dimensions are not mutually exclusive in the documentary design of Master Plans. For this reason, the results in Table 6.9 serve as indications of the thematic content associated with the composite effect, rather than as evidence of isolated mechanisms. The full dimension-specific results, including initial adoption and revision, are reported in Table A.6.10 in the Appendix.

Table 6.9 - Exploratory treatment effects by Smart City dimension for Revision under intensive cutoffs

Dimension	Cutoff	Estimate	SE	p-value	95% CI	Pre-test p-value	N obs.	Treated	Never treated
Economy	<i>p</i> 75	0.0003	0.0014	0.8184	[-0.0025; 0.0031]	0.12697	4,088	130	381
Society	<i>p</i> 75	-0.0029**	0.0014	0.0441	[-0.0056; -0.0001]	0.20658	4,088	132	379
Environment	<i>p</i> 75	-0.0017	0.0013	0.1942	[-0.0043; 0.0009]	0.06384	4,064	128	380
Governance	<i>p</i> 75	-0.0022**	0.0011	0.0430	[-0.0044; -0.0001]	0.08296	4,112	175	339
Technology	<i>p</i> 75	-0.0003	0.0015	0.8420	[-0.0032; 0.0026]	0.13537	4,024	146	357
Urban Brands	<i>p</i> 80	-0.0019	0.0015	0.1862	[-0.0048; 0.0009]	0.07156	3,712	91	373
Smart City	<i>p</i> 75	-0.0028*	0.0014	0.0515	[-0.0055; 0.0000]	0.13357	4,088	125	386

Source: Author's own elaboration.

Note: The table reports exploratory average treatment effects by thematic dimension for Revision. Each row uses the intensive cutoff available for the corresponding dimension in the policy construction. The *p*75 cutoff is used for Economy, Society, Environment, Governance, Technology, and the composite Smart City index. For Urban Brands, the *p*80 cutoff is used because the *p*75 threshold still includes zero citation values. All specifications control for the logarithm of municipal population. The outcome is the municipal additive contribution to the intra-regional component of GDP per capita inequality, computed using GE(1), the Theil T index. Estimates are obtained using eligible never-treated municipalities as the comparison group. Municipalities in first-year treated cohorts are excluded because no pre-treatment observation is available within the 2013–2020 outcome panel. These estimates are intended to provide exploratory evidence on the dimensional content associated with the composite result and should not be interpreted as isolated causal channels. No adjustment for multiple testing is applied across the dimension-specific estimates; individual p-values should therefore not be interpreted as confirmatory evidence of dimension-specific effects. Treated and Never treated report the number of municipalities in each group. The pre-test p-value refers to the joint Wald test for the null hypothesis that all pre-treatment group-time effects are equal to zero. SE denotes standard error, and 95% CI denotes the 95% confidence interval. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

6.9.3 Relative regional position and the nature of the municipal additive contribution

Table 6.10 explores whether the reduction in the municipal additive contribution is associated with changes in the level of municipal GDP per capita or in the municipality's relative distance from the economic pattern of its ImGR. All estimates consider the intensive *p*75 threshold and control for the logarithm of population. Three auxiliary outcomes are considered: the logarithm of municipal GDP per capita, the relative difference between municipal GDP per capita and the leave-one-out mean of the ImGR, and the absolute value of this difference.

In the case of initial adoption, the coefficients remain statistically indistinguishable from zero for all auxiliary outcomes. This pattern is consistent with the previous results, in which intensive incorporation of the Smart City agenda into initially adopted Master Plans does not appear to be associated with detectable changes in the municipal additive contribution or with clear changes in the municipality's relative economic position within its ImGR.

For revision, the evidence is concentrated in the absolute distance from the regional mean. The estimated coefficient for the Absolute GDPpc gap is negative and statistically significant, while the coefficients associated with Log GDPpc and Relative GDPpc gap are not statistically significant. Thus, the auxiliary estimates indicate a more clearly defined change in the absolute distance from the ImGR reference than in municipal GDP per capita, without identifying the economic process producing that difference.

Table 6.10 - Exploratory effects on municipal economic position under the $p75$ Smart City cutoff

Event	Outcome	Estimate	SE	P-value	95% CI	Pre-test p-value	N obs.	Treated	Never treated
Adoption	Log GDPpc	-0.0071	0.0336	0.8319	[-0.0729; 0.0587]	< 0.0001	2,680	79	256
Adoption	Relative GDPpc gap	-0.0105	0.0339	0.7565	[-0.0769; 0.0559]	0.00678	2,680	79	256
Adoption	Absolute GDPpc gap	0.0284	0.0324	0.3812	[-0.0352; 0.0920]	< 0.0001	2,680	79	256
Revision	Log GDPpc	-0.0106	0.0147	0.4700	[-0.0394; 0.0182]	0.09521	4,088	125	386
Revision	Relative GDPpc gap	-0.0091	0.0162	0.5722	[-0.0409; 0.0226]	0.13933	4,088	125	386
Revision	Absolute GDPpc gap	-0.0333**	0.0152	0.0285	[-0.0630; -0.0035]	0.05040	4,088	125	386

Source: Author's own elaboration.

Note: The table reports exploratory average treatment effects for the composite Smart City index under the $p75$ intensive cutoff on auxiliary outcomes related to municipal economic position. All specifications control for the logarithm of municipal population. Event refers to the institutional event. Log GDPpc refers to municipal GDP per capita at 2020 prices. The relative GDPpc gap is defined as the difference between municipal log GDP per capita and the log leave-one-out GDP per capita mean of the Immediate Geographic Region. Positive values indicate that the municipality is above the leave-one-out regional mean, while negative values indicate that it is below that mean. The absolute GDPpc gap measures the distance from the leave-one-out regional mean, regardless of direction. Estimates are obtained separately by institutional event using eligible never-treated municipalities as the comparison group. Municipalities in first-year treated cohorts are excluded because no pre-treatment observation is available within the 2013–2020 outcome panel. These estimates are intended to qualify the economic interpretation of the additive-contribution result and should not be interpreted as formal mediation tests. Treated and Never treated report the number of municipalities in each group. The pre-test p-value refers to the joint Wald test for the null hypothesis that all pre-treatment group-time effects are equal to zero. SE denotes standard error, and 95% CI denotes the 95% confidence interval. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

The auxiliary estimates provide a limited indication of changes in relative economic position. Under the $p75$ rule, the estimated change in the absolute log GDP-per-capita gap is negative, while the estimate for municipal log GDP per capita is not statistically distinguishable from zero. The latter result does not establish the absence of a local output response, and the former does not identify migration, productivity or implementation as a transmission channel. The absolute-gap estimate is expressed in log-distance units, not in monetary units or as a percentage change in GDP per capita. Its pre-treatment diagnostic is close to the 5% rejection threshold, which further limits a causal interpretation. These results qualify the description of the outcome but do not constitute a mediation analysis.

As an additional diagnostic, the municipal GDP-per-capita outcome was decom-

posed into its accounting components, total municipal GDP and population, under the $p75$ specification.³ For Revision, neither total GDP nor population presents a statistically defined average change, and the corresponding estimates are small relative to their uncertainty. This result does not identify the source of the change in the signed additive contribution and provides no evidence that the estimated recomposition is systematically driven by either municipal economic mass or population dynamics. The exercise should therefore be read as an accounting decomposition rather than as a test of transmission mechanisms.

The complementary evidence in the Appendix keeps this interpretation on exploratory ground. Table A.6.11 shows that the pattern for the auxiliary outcomes is not replicated consistently across all treatment thresholds. Table A.6.12 disaggregates the exercise by initial economic position and suggests signals consistent with movement towards the regional mean both among municipalities initially below and above the ImGR average, although the group-specific estimates are imprecise. Taken together, these exercises do not identify a fully specified mechanism, but they reduce the opacity of the dependent variable by indicating that the main result is closer to a relative recomposition within the region than to a direct effect on the municipal economic level.

6.10 Robustness and complementary diagnostics

This section brings together complementary checks aimed at assessing the consistency of the main results. The exercises evaluate the sensitivity of the estimates to the inequality measure used, the comparison group, and the estimator, while also revisiting the pre-treatment diagnostics that shape the causal interpretation of the design. The aim is not to expand the set of substantive results, but to delimit the degree of stability of the evidence associated with intensive incorporation of the Smart City agenda in revisions of Master Plans.

6.10.1 Alternative inequality measures: GE(0) and GE(2)

The first robustness check considers alternative measures from the generalised entropy family. The main specification uses GE(1), corresponding to the Theil T index, but the additive decomposition also allows the municipal contribution to the intra-regional component to be calculated using GE(0) and GE(2). Table 6.11 presents the estimates under the intensive $p75$ threshold, retaining the specification conditioned on the logarithm of population.

³ For Revision under the $p75$ specification controlled by baseline population, the estimated ATT is -0.0121 for log total municipal GDP ($p = 0.423$) and -0.0015 for log population ($p = 0.626$).

Table 6.11 - Sensitivity to alternative generalised entropy measures under the *p*75 Smart City cutoff

Institutional event	Outcome	Estimate	SE	p-value	95% CI	Pre-test p-value	Treated	Never
Adoption	GE(0)	0.0010**	0.0004	0.0148	[0.0002; 0.0018]	0.08662	79	256
Adoption	GE(1) – Theil T	-0.0001	0.0011	0.9580	[-0.0023; 0.0022]	0.25268	79	256
Adoption	GE(2)	0.0011	0.0029	0.7122	[-0.0047; 0.0069]	0.12010	79	256
Revision	GE(0)	0.0005	0.0012	0.6673	[-0.0019; 0.0029]	0.67437	125	386
Revision	GE(1) – Theil T	-0.0028*	0.0014	0.0515	[-0.0055; 0.0000]	0.13357	125	386
Revision	GE(2)	-0.0047*	0.0026	0.0709	[-0.0098; 0.0004]	0.22419	125	386

Source: Author's own elaboration.

Note: The table reports average treatment effects for the composite Smart City index under the *p*75 intensive cutoff using alternative generalised entropy measures. All specifications control for the logarithm of municipal population and use eligible never-treated municipalities as the comparison group. GE(1) corresponds to the Theil T index and is the main outcome used in the baseline estimates. GE(0) corresponds to the mean logarithmic deviation, and GE(2) corresponds to the half-squared coefficient of variation. The outcomes are municipal additive contributions to the intra-regional component of GDP per capita inequality. Municipalities in first-year treated cohorts are excluded because no pre-treatment observation is available within the 2013–2020 outcome panel. Treated and Never report the number of municipalities in each group. The pre-test p-value refers to the joint Wald test for the null hypothesis that all pre-treatment group-time effects are equal to zero. SE denotes standard error, and 95% CI denotes the 95% confidence interval. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

The results partially preserve the interpretation obtained in the main specification, although they indicate sensitivity to the parameter of the inequality measure. In the case of revision, the coefficients remain negative in GE(1) and GE(2), with marginal significance, whereas GE(0) does not reproduce the same pattern. This result suggests that the reduction in the municipal additive contribution appears more clearly in measures that assign greater relative weight to the upper part of the distribution, without being preserved in the same form when using the measure that is more sensitive to the lower part of the distribution.

For initial adoption, the results do not point to a consistent pattern. The coefficient associated with GE(1) remains close to zero, GE(2) is not statistically significant, and GE(0) is positive. This combination reinforces the interpretation that initial adoption does not show a robust pattern of reduction in the municipal additive contribution, even when the parameters of the entropy measure are changed.

The signed municipal terms also differ across entropy measures. In GE(1), a municipality above its Immediate Geographic Region's mean has a positive term; in GE(0), its contribution has the opposite sign. Consequently, agreement in the signs of municipal treatment effects is not a general requirement implied by agreement in aggregate inequality movements. These exercises test sensitivity to distinct municipal accounting outcomes. They do not, on their own, establish a robust effect on aggregate regional inequality.

Taken together, Table 6.11 does not eliminate the sensitivity of the estimate to the way inequality is measured, but it preserves the direction of the main result for revision in the measures closest to the interpretation adopted throughout the chapter. Robustness, in this case, is partial and consistent with the exploratory nature of the application: the effect associated with intensive revision does not depend exclusively on the Theil T index, but nor is it reproduced uniformly across the entire generalised entropy family.

6.10.2 Treatment threshold, comparison groups and estimator

The second check brings together choices associated with the empirical definition of treatment and the comparison strategy. Sensitivity to thresholds already appears in the main estimates, with $p50$ and $p75$ reported in Table 6.5 and $p25$ documented in Table A.6.3 in the Appendix. The most clearly defined pattern remains associated with the $p75$ threshold in revisions of Master Plans. Table 6.12 complements this interpretation by retaining this setting and changing two elements of the design: the comparison group and the estimator.

Table 6.12 - Sensitivity of $p75$ Smart City estimates to comparison group and estimator

Institutional event	Sensitivity check	Estimate	SE	p-value	95% CI	Pre-test p-value
Adoption	Main specification	-0.0001	0.0011	0.9580	[-0.0023; 0.0022]	0.25268
Adoption	Not-yet-treated	0.0000	0.0011	0.9795	[-0.0022; 0.0022]	0.09660
Adoption	IPW estimator	-0.0001	0.0012	0.9636	[-0.0024; 0.0023]	0.25505
Revision	Main specification	-0.0028*	0.0014	0.0515	[-0.0055; 0.0000]	0.13357
Revision	Not-yet-treated	-0.0028*	0.0015	0.0579	[-0.0056; 0.0001]	0.12409
Revision	IPW estimator	-0.0028*	0.0015	0.0598	[-0.0056; 0.0001]	0.13730

Source: Author's own elaboration.

Note: The table reports sensitivity checks for the composite Smart City index under the $p75$ intensive cutoff. The outcome is the municipal additive contribution to the intra-regional component of GDP per capita inequality, computed using GE(1), the Theil T index. All specifications control for the logarithm of municipal population. The main specification uses eligible never-treated municipalities as the comparison group and a doubly robust estimator. The not-yet-treated specification uses municipalities not yet treated as the comparison group when available. The IPW specification keeps eligible never-treated municipalities as the comparison group and replaces the main estimator with inverse probability weighting. Municipalities in first-year treated cohorts are excluded because no pre-treatment observation is available within the 2013–2020 outcome panel. The $p75$ analytical samples contain 79 treated and 256 never-treated municipalities in Adoption, and 125 treated and 386 never-treated municipalities in Revision. The pre-test p-value refers to the joint Wald test for the null hypothesis that all pre-treatment group-time effects are equal to zero. SE denotes standard error, and 95% CI denotes the 95% confidence interval. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Since the conditional specification uses the logarithm of municipal population, Figure A.6.10 presents a complementary diagnostic of overlap for this covariate under the $p75$ threshold. The distributions indicate that treated municipalities tend to be

concentrated in higher population ranges, both in initial adoption and revision, but they also show a common support region between treated and eligible never-treated municipalities. This pattern does not eliminate selectivity associated with municipal size, but suggests that the conditional comparison does not rely solely on extrapolation beyond the observed range of the control municipalities.

The results for initial adoption remain close to zero across the three specifications considered. Changing the comparison group to not-yet-treated municipalities and replacing the main estimator with the inverse probability weighting (IPW) estimator do not alter the interpretation obtained previously. Initial adoption continues to show no evidence of a detectable average effect on the municipal additive contribution.

In the case of revision, the coefficients retain a negative sign and a virtually constant magnitude. The main estimate is close to -0.003; a similar value appears when the comparison group is formed by not-yet-treated municipalities, and the IPW specification preserves both the sign and the order of magnitude. Significance remains marginal, but the stability of the coefficient suggests that the result does not arise solely from the choice of the never-treated group or from the doubly robust estimator used in the main specification.

A separate sensitivity check examined the construction of the treatment measure for revised plans. The additions-based index was compared with an alternative signed-change measure that also deducts thematic subgroups removed from the previous plan, while holding the original eligibility sample fixed. Among the 516 eligible revision events, 412 (79.8%) presented at least one removed subgroup. Despite the frequency of removals, the intensive p75 classification was relatively stable: 18 events (3.5%) changed treatment status, with nine leaving and nine entering the treated group. The number of p75-treated municipalities used in the DiD estimations remained 125 under both definitions, and the Spearman correlation between the two indices was 0.897. These results indicate that removals are common in documentary revisions, but have a comparatively limited effect on the intensive treatment classification within the original eligible sample. This diagnostic concerns treatment classification and does not, by itself, establish the robustness of the estimated treatment effect to the alternative signed-change measure.

A complementary inference check allowing for additional clustering at the ImGR and IntGR levels produced the same point estimate for intensive revision and did not widen the corresponding confidence interval.⁴ This exercise addresses sensitivity of statistical inference to regional dependence, but does not rule out substantive spillovers across municipalities.

Taken together, these checks suggest greater stability in the empirical pattern

⁴ The estimated ATT was -0.00276 under all three specifications; standard errors were 0.00150 with municipal clustering, 0.00135 with additional ImGR clustering, and 0.00139 with additional IntGR clustering.

associated with intensive revision, although along different margins. The comparison-group and estimator exercises preserve the direction and order of magnitude of the coefficient, while the alternative treatment construction produces relatively limited changes in the $p75$ classification. The regional clustering exercise also leaves the point estimate unchanged and does not widen the confidence interval. At the same time, the proximity of the confidence intervals to zero and the changes in treatment status under the signed measure keep the interpretation cautious. These robustness exercises (Table 6.12) therefore delimit the sensitivity of the result without transforming it into strong evidence that is insensitive to measurement and identification choices.

6.10.3 Pre-treatment diagnostics and the limits of identification

The pre-treatment diagnostics indicate that the empirical evidence is more consistent for intensive revisions of the Master Plan, especially at the $p75$ threshold and in the conditional specifications. As shown in Table 6.5, $p50$ presents negative signs for revision, but with less favourable pre-treatment tests. At $p75$, the specification controlling for the logarithm of population combines a negative coefficient, a magnitude close to that of the other specifications, and non-rejection of the joint test of pre-treatment group-time effects. The dynamics presented in Figure 6.6 are consistent with this interpretation, as they do not indicate a systematic shift in the pre-event period for revision in this specification.

The full diagnostics reported in Table A.6.5 show, however, that this condition is not reproduced uniformly across all cutoffs, events, and specifications. In particular, some exercises for initial adoption and some specifications without controls present less favourable pre-tests. This pattern helps delimit the scope of the results. The absence of detectable effects for initial adoption is not only a null result in terms of magnitude; it also appears in a set of estimations whose empirical support is less favourable to a stronger causal interpretation.

The dynamic figures in the Appendix reinforce this interpretation. Figure A.6.5 shows that the event studies vary according to the intensity threshold, while Figure A.6.6 indicates that, at $p75$, the estimated dynamics for revision are more stable in the conditional specifications. Figure A.6.9 complements the diagnostics by presenting the initial distribution of the municipal additive contribution under $p75$, showing strong concentration around zero and right-hand tails, especially among treated municipalities. This asymmetry does not by itself compromise the design, but reinforces the usefulness of checks using alternative generalised entropy measures and conditional specifications.

The sensitivity of the main Revision estimate to the observation window was also examined by restricting the outcome panel to 2013–2019. Because municipalities treated in 2020 have no post-treatment observation in this restricted window, this cohort was excluded from the comparison. The resulting estimate remains close to the main specification: the

ATT is -0.00273 for 2013–2019, compared with -0.00276 in the full 2013–2020 panel. To separate the change in the observation window from changes in treatment composition, an additional specification retained the 2013–2020 outcomes but excluded the 2020 treatment cohort. Under this common cohort composition, the aggregate ATT is -0.00285 . More importantly, the 36 group-time effects observed in both the 2013–2019 and 2013–2020 panels are numerically identical, including 21 post-treatment cells. The small differences between the aggregate estimates therefore reflect changes in the available post-treatment horizon and aggregation weights rather than differences in the common group-time effects. This exercise suggests that the main empirical pattern is not driven by the inclusion of the 2020 observation, while leaving unchanged the limitation imposed by the relatively short post-treatment horizon.

Table A.6.9 complements these diagnostics with a sensitivity exercise for violations of the parallel trends assumption in the main specification for revision under the $p75$ threshold, controlling for the logarithm of population. The target parameter is an equally weighted average of the available post-treatment dynamic effects and therefore does not use the same aggregation weights as the overall ATT reported in Table 6.5. The exercise uses the dynamic coefficients from the event study and the covariance matrix recovered from the influence functions. The robust intervals remain centred on negative values, but include zero even under $\bar{M} = 0$, widening as larger relative deviations from the pre-treatment pattern are allowed. This result reinforces the cautious interpretation adopted in the chapter. The stability observed in the alternative specifications concerns mainly the sign and order of magnitude of the coefficients, while the formal sensitivity exercise indicates that the evidence is not robust to more demanding criteria for violations of the parallel trends assumption.

Taken together, the diagnostics support a cautious interpretation of the main results. The most consistent evidence is concentrated in revisions of Master Plans with intensive incorporation of the Smart City agenda. Even so, the pre-tests, the partial sensitivity to entropy measures, the limited post-treatment horizon, the proximity of some confidence intervals to zero, and the formal sensitivity exercise for the parallel trends assumption recommend treating the coefficients as suggestive empirical evidence, rather than as definitive estimates of a structural effect. This delimitation does not eliminate the observed pattern, but defines its scope. The following discussion interprets the results as indications of a relative recomposition of the municipal contribution within the region, conditioned by the type of institutional change and by the territorial position of municipalities.

6.11 Discussion

The discussion organises the interpretation of the results around three axes. The first concerns the economic meaning of the municipal additive contribution and its relationship with relative recomposition within the ImGR. The second examines why the estimated patterns appear more clearly in revisions of Master Plans and in municipalities occupying higher positions in the urban hierarchy. The third delimits the scope of identification, considering the documentary nature of the Smart City index, the pre-treatment diagnostics, and the limits of the exploratory exercises. This interpretation shifts the focus away from a general relationship between smart cities and regional inequality towards an interpretation conditioned by municipalities' institutional trajectories and by their position in the urban network.

6.11.1 Additive contribution, relative recomposition and intra-regional equilibrium

The reduction in the municipal additive contribution offers a finer interpretation than a direct change in aggregate regional inequality. The estimated result does not describe the disappearance of economic differences between municipalities, nor does it, in isolation, indicate growth in local GDP per capita. It captures a change in the way the municipality participates in the intra-regional composition of inequality, considering its relative position within the ImGR and the weight of that position in the observed regional structure. This distinction shifts the interpretation of the effect towards the field of regional relations, rather than restricting it to the municipality's individual economic performance.

In this chapter, “relative recomposition” denotes a change in the municipality's output-per-resident position or its weight in the regional distribution. It is a description of the measured relationship, not the name of an identified economic mechanism. The main and auxiliary estimates are consistent with some changes in this relative position, but do not establish which part reflects local production, population adjustment or changes in regional peers. A reduction in the signed additive term should therefore remain distinct from claims about convergence, aggregate inequality or welfare.

This interpretation connects with the regional argument that guides the chapter. Municipalities do not operate as isolated units, especially when observed through Immediate Geographic Regions and the REGIC urban hierarchy. A municipality's contribution to intra-regional inequality depends on its position within the set of economic relations that organise the region, on differences in scale between urban centres, and on the way flows, functions, and opportunities are distributed across neighbouring units. In this context, a reduction in the additive contribution suggests a change in the municipality's relationship with its regional reference space, even if this change does not translate, over the period analysed, into a clearly identifiable absolute economic gain.

The result does not suggest that the Smart City agenda operates, directly and linearly, as a vector of urban growth. The evidence does not point to an aggregate and homogeneous effect of documentary incorporation of the smart city agenda. What appears is more restricted and is situated more directly within the regional economics agenda. The estimates for intensive revisions are consistent with a change in the municipality's relative economic position within its ImGR, but do not identify the adjustment margin responsible for that movement. In this case, the Smart City agenda does not appear as an autonomous force of economic transformation, but as content incorporated into a planning instrument that operates within urban networks that are already hierarchical.

This interpretation brings the discussion of smart cities closer to the problem of regional equilibria. Rather than treating the municipality as an isolated recipient of technology, the result suggests that the smart city agenda gains meaning when observed through the relationship between centres, functions, and territorial scales. The reduction in the additive contribution does not settle the question of the economic mechanisms involved, but it indicates that intensive incorporation of this agenda may be associated with movements of relative recomposition within intra-regional space. This interpretation shifts the discussion towards a dimension still little explored by a literature that generally observes smart cities through internal urban attributes and gives less attention to their effects on regional economic organisation.

6.11.2 Institutional events and position in the urban network

The institutional literature discussed in Section 6.2 suggests that prior planning experience may influence how new guidelines enter administrative practice. This remains a possible interpretation of the pattern observed for intensive revisions, rather than an explanation established by the estimates. The comparison with initial adoption also reflects different documentary measures and municipal histories, and does not separate institutional learning from selection into revision. Revision is therefore a feature of the planning context used to define the comparison, not a direct measure of absorptive capacity.

The subgroup estimates by urban hierarchy provide a more tentative qualification of this interpretation. Under the $p75$ rule, the estimate for higher-order centres in the Revision group is negative and marginally significant, while the estimates for intermediate and local centres are not statistically well defined. However, the joint pre-treatment test for higher-order centres rejects the null hypothesis at the 5% level. The result therefore does not establish that urban hierarchy causally conditions the effect of documentary incorporation. It is consistent with the possibility that municipalities occupying different positions in the urban network also differ in productive structure, fiscal resources, administrative capacity and regional functions, dimensions that are not separately identified in this exercise.

The estimates by prior documentary maturity provide no clear monotonic pattern.

Although the second quartile presents a negative and statistically significant coefficient, its joint pre-treatment test strongly rejects the null hypothesis of no pre-treatment differences. The remaining quartiles also show unfavourable pre-treatment diagnostics. The maturity exercise is therefore treated as exploratory and does not support an interpretation in which accumulated documentary content, by itself, explains subsequent differences in the estimated effects.

The dimension-specific estimates offer a complementary descriptive reading of the composite treatment. Society and Governance present negative coefficients in the exploratory exercises, whereas the other dimensions do not show statistically well-defined estimates under their respective intensive cutoffs. These results are not interpreted as isolated mechanisms. The dimensions overlap in the documentary content, the treated samples differ across thematic specifications, and several dimension-specific hypotheses are examined simultaneously. They therefore indicate thematic associations that may guide subsequent investigation, rather than identifying distinct causal channels.

6.11.3 Interpretative scope and limits of identification

The results delimit a more specific field of interpretation than a general relationship between smart cities and the reduction of regional inequality. The evidence is concentrated in revisions of Master Plans, under intensive incorporation of the Smart City agenda, and is manifested in the municipal additive contribution to the intra-regional component of inequality. This framing situates the effect within a particular combination of institutional change, documentary intensity, and the municipality's regional position.

The treatment measure also imposes its own interpretation. The index constructed from Master Plans captures documentary incorporation, not implementation. The presence of terms, guidelines, and content associated with the smart city agenda indicates that the theme entered the normative language of urban planning, but it does not allow direct observation of budget execution, administrative capacity, political continuity, or the effective delivery of projects. The result therefore concerns the relationship between documented normative change and regional economic position, rather than the direct effect of implemented smart city policies.

The identification diagnostics reinforce this delimitation. The most consistent evidence appears in intensive revisions under $p75$, especially in the conditional specifications, while initial adoption remains without a detectable pattern. At the same time, the pre-tests, the partial sensitivity to generalised entropy measures, the proximity of some confidence intervals to zero, and the formal sensitivity exercise for the parallel trends assumption keep the interpretation cautious. The estimates point to an identifiable empirical pattern, recurrent in direction and order of magnitude, but not to a structural effect that is insensitive to measurement and identification choices.

The dimension-specific evidence and the auxiliary outcomes help reduce the opacity of the composite index and of the dependent variable. The signals in Society and Governance bring the result closer to an agenda of public coordination and institutional organisation, while the reduction in the absolute distance from the ImGR economic pattern suggests relative recomposition within intra-regional space. These exercises, however, do not identify isolated mechanisms. They qualify the interpretation of the main results and indicate paths for further analysis, without replacing a direct assessment of implementation or causal transmission.

6.12 Conclusion

This chapter investigated whether the incorporation of the Smart City agenda into municipal Master Plans is associated with changes in municipalities' contribution to intra-regional economic inequality. The question addressed a specific gap. Although the literature on smart cities has advanced in conceptual definition, in the measurement of urban attributes, and in the analysis of local experiences, the regional implications of these agendas remain less explored, especially in countries marked by strong territorial heterogeneity and by federal structures in which municipalities have formal planning autonomy. By shifting the analysis from the isolated city to the municipality's position within its Immediate Geographic Region, the chapter sought to examine whether the documentary incorporation of a contemporary urban agenda may be associated with changes in the way municipalities are embedded in their regional economic contexts.

The empirical strategy combined three central choices. The first was to treat the Master Plan as a comparable documentary instrument for capturing the institutional incorporation of the Smart City agenda at the municipal level. The second was to distinguish between initial adoption and revision of the Master Plan, recognising that these events represent distinct institutional moments. The third was to construct a dependent variable capable of observing the municipal additive contribution to the intra-regional component of GDP per capita inequality. This measure made it possible to shift the analysis from aggregate regional inequality to the relative position of each municipality in the composition of that inequality.

The estimates reveal a negative association between intensive new thematic incorporation in revised Master Plans and the signed municipal contribution to the intra-regional component of GDP per capita inequality in some specifications. The evidence is sensitive to the intensity rule, outcome definition and identification diagnostics. Initial adoption does not display a consistent detectable pattern, while the subgroup exercises do not establish causal differences by hierarchy or documentary maturity. The results therefore do not amount to confirmation of a general inequality-reducing effect. They identify a relationship that warrants further investigation using stronger evidence on implementation,

treatment selection and regional exposure.

The subgroup analyses provide a more limited territorial qualification. The negative estimate for higher-order centres in Revision is accompanied by an unfavourable pre-treatment diagnostic, while the documentary-maturity estimates do not form a stable gradient and also present pre-treatment concerns. These exercises therefore do not identify urban hierarchy or prior documentary content as causal moderators. They instead indicate dimensions along which the aggregate pattern is unevenly distributed and that warrant more direct investigation in future applications.

The complementary exercises help delimit the scope of this interpretation. The thematic composition of the treatment indicates that intensive incorporation of the composite index is not strictly technological, but involves social, environmental, economic, institutional, and governance dimensions. The dimension-specific estimates suggest greater proximity between the results and components linked to governance and the social dimension, although these exercises remain exploratory. The auxiliary outcomes, in turn, indicate that the main result is closer to a recomposition of relative economic distance within the region than to a direct effect on the level of municipal GDP per capita. This interpretation is consistent with the nature of the dependent variable itself, which observes the municipal contribution to intra-regional inequality, rather than the isolated economic growth of the municipality.

The robustness checks reinforce the need for caution. The result for intensive revision shows stability in sign and order of magnitude when the comparison group and estimator are changed, but significance remains marginal in some specifications. Sensitivity to alternative generalised entropy measures indicates that the pattern is not reproduced uniformly across the entire family of indicators. The formal sensitivity exercise for the parallel trends assumption, in turn, shows that the robust intervals remain centred on negative values, but include zero even under the most restrictive scenario considered. In addition, the pre-treatment diagnostics are not equally favourable across all thresholds, events, and specifications. For this reason, the results should be read as suggestive empirical evidence, rather than as definitive estimates of a structural effect. This caution does not reduce the contribution of the chapter. It defines more precisely what the data allow one to support.

The main contribution of the chapter is to open up a still underexplored line of inquiry. Rather than asking only whether a city is more or less smart, the exercise developed here asks whether the incorporation of this agenda into urban planning instruments is associated with municipalities' relative economic position within their regions. This shift in focus brings the smart cities literature closer to regional economics and to debates on urban networks, intra-regional inequality, and municipal federalism. In the Brazilian context, this connection is particularly fruitful, because the formal autonomy of municipalities

coexists with strong differences in institutional capacity, economic scale, and territorial centrality.

This agenda remains open. Future studies may advance in identifying transmission mechanisms, connecting the content of Master Plans to effectively regulated instruments, public investment, administrative capacities, digital policies, changes in land use, the local productive structure, and flows of people, firms, and services. There is also scope to explore the dimensions of the Smart City agenda in greater detail, examining whether technology, governance, the environment, mobility, economic development, and social inclusion operate through distinct channels. Another promising avenue involves investigating spillover effects between municipalities, especially in functional regions where urban centres of different sizes share labour markets, infrastructure, and public services.

The chapter, therefore, does not close the discussion on the regional effects of smart cities. It proposes a way of observing them. The evidence presented suggests that intensive incorporation of the Smart City agenda in revisions of Master Plans may be associated with a recomposition of the municipal contribution to intra-regional inequality. The value of the exercise lies in showing that the smart city agenda, when incorporated into urban planning, can be analysed as part of a regional structure of economic, institutional, and territorial interdependencies. In this shift, the municipality ceases to be only a local unit of urban policy and is also observed through the position it occupies in the functional relations that organise the territory.

7 CONCLUSION

This work began with a shift in framing. Smart cities were observed not only as urban agendas aimed at modernising services, infrastructure and management, but as phenomena embedded in regional networks. This shift changes the type of question that can be asked. The problem is no longer simply to identify which cities are smarter, which technologies they adopt, or which indicators perform better. Rather, it concerns how urban attributes, institutional choices and planning instruments relate to the position of municipalities within interdependent territorial systems.

The findings do not point to a single economic outcome associated with the smart city agenda. Selected municipal conditions and planning content vary across the territory, while the econometric relationship is sensitive to the treatment definition and remains subject to identification concerns. Read together, the exercises situate the agenda within a heterogeneous municipal system rather than establish a uniform path from urban smartness to regional change.

This reading also qualifies the very notion of the smart city. Technology remains part of urban transformation, but it does not, by itself, define either its purpose or its outcomes. A city equipped with sensors, digital platforms and communication networks may remain socially exclusionary, institutionally fragile or unable to provide basic services. Conversely, municipalities with more limited technological resources may develop forms of planning, participation, public coordination and service provision that are consistent with broader dimensions of urban smartness. The smart city agenda acquires substance when it is related to the concrete problems of the territory and to the capacities available to address them.

In Brazil, this formulation takes on specific contours. Municipal autonomy coexists with sharp differences in economic scale, administrative capacity, fiscal resources and position within the urban network. Metropolises, intermediate centres and small municipalities share formal responsibilities for planning and service provision, but have very different conditions under which to exercise them. In addition, some of the services, jobs and facilities concentrated in particular centres are used by residents of neighbouring localities. The municipality is an institutional unit of decision-making, but it is not a self-contained functional unit. This combination of local autonomy and regional interdependence guides the interpretation of the results.

The first empirical exercise translated this multidimensional conception into comparable indicators for Brazil's 5,570 municipalities. Full territorial coverage made it possible to include thousands of localities that do not appear in the main national and international rankings, which are generally restricted to state capitals or to cities above certain population thresholds. The result was not merely an expansion of the sample. By incorporating

small municipalities and centres at different hierarchical levels, it became possible to examine urban smartness as a characteristic distributed across a system of cities, rather than as an exclusive attribute of large centres endowed with advanced infrastructure.

The structural dimensions displayed distinct empirical distributions across Brazilian municipalities. Because each dimensional score was normalised separately, their average values should not be interpreted as a common scale of substantive achievement. Rather, the scores locate municipalities relative to the observed range within each domain. The dimensional profiles also show that high values of the composite index may arise from different combinations of economic, social, environmental, institutional and technological conditions, rather than requiring uniformly high scores across all components. The composite score is therefore most informative when read alongside its underlying indicators and the territorial characteristics of each municipality. The presence of smaller jurisdictions among high-scoring municipalities broadens the descriptive coverage, but does not establish that the same conditions can be reproduced independently of productive specialisation, scale, centrality or regional integration.

The spatial distribution added another layer to this diagnosis. The indices showed positive and statistically significant spatial autocorrelation, with clusters of municipalities displaying similar levels of performance. High-value clusters were more strongly concentrated in the South and Southeast regions and in areas with greater economic and infrastructural density. Low-value clusters were more frequent in the North and Northeast. This pattern does not allow causal relationships to be identified, but it indicates that urban smartness is not randomly distributed across the territory. Technological, institutional, economic and social capacities appear to be embedded in broader regional processes of concentration, diffusion and persistent inequality.

The second empirical exercise shifted the analysis from observed conditions to the formal language of planning. In a country where smart city initiatives are fragmented, decentralised and weakly standardised, identifying a policy common to all municipalities would not be possible. The Master Plan offered an institutionally comparable alternative. Through the collection and processing of 1,236 documents, an indicator was constructed to record the thematic diversity with which content associated with smart cities appears in municipal planning.

The documentary results also revealed a heterogeneous agenda. The thematic dimensions followed distinct distributions across municipalities and over time, while Urban Brands appeared in a comparatively limited set of documents. More recent plans tended to incorporate content associated with digital transformation, participation, sustainability and quality of life more frequently, especially from the second half of the 2010s onwards. Even so, no single model of incorporation was identified. Municipalities with similar aggregate values reached these positions through different combinations of dimensions,

reflecting distinct local strategies, vocabularies and priorities.

The structural and documentary indicators answer different questions. The former describe selected municipal conditions, resources and capacities, whereas the latter record thematic presence in planning instruments. Their exploratory correspondence is clearer in the upper categories of the two sets of measures, but does not establish implementation or the direction of influence. Common determinants and different reference years further limit the interpretation of this relationship. The distinction between municipal conditions and documentary content remains part of the research design, rather than a discrepancy to be explained away.

This distinction also prevents the Master Plan from being interpreted as evidence of implementation. The presence of a theme in the document indicates its entry into the formal repertoire of planning, but does not reveal, by itself, whether regulation, financing, execution or administrative continuity followed. At the same time, the normative text should not be reduced to a statement without consequences. The plan organises guidelines, legitimises priorities, guides subsequent instruments and creates reference points for public and private decisions. Its effect depends on the capacity to transform this inscription into budgetary allocation, regulation, projects, monitoring and institutional coordination.

The final empirical exercise related documentary incorporation to the signed municipal contribution to the intra-regional component of GDP per capita inequality. This outcome combines a municipality's GDP per capita relative to its Immediate Geographic Region with its economic weight within the corresponding Intermediate Geographic Region. The resulting measure retains the municipal scale of the planning event while making its economic interpretation dependent on the wider regional distribution.

The econometric exercise does not support a general and homogeneous relationship between documentary incorporation of the Smart City agenda and regional inequality. Under the p75 rule, intensive new thematic incorporation in revised Master Plans is associated with a negative estimate for the signed municipal contribution to the intra-regional component of GDP per capita inequality in some specifications. The pattern is less stable under the median-based reference threshold, and initial adoption does not display a consistent detectable change. Because the outcome is a signed accounting term and the estimates remain sensitive to treatment definition and identification diagnostics, these results should not be interpreted as evidence of a reduction in aggregate regional inequality or as the effect of implemented smart city policies.

The distinction between initial adoption and revision remains empirically informative because the two events represent different stages of the planning trajectory. A first Master Plan establishes a formal planning framework, whereas revision modifies an existing document. The estimates differ across these events, but the design does not identify whether this contrast reflects administrative learning, pre-existing instruments,

implementation capacity, selection into revision or other correlated conditions. Likewise, the absence of a detectable pattern for initial adoption should not be interpreted as evidence that first plans are ineffective; it indicates only that no consistent change in the signed municipal contribution was detected within the observation window.

The exploratory comparisons by urban hierarchy, prior documentary content and thematic dimension do not identify a transmission mechanism. Several subgroup estimates are accompanied by unfavourable pre-treatment diagnostics, and statistical significance in one group but not another does not establish a difference between their effects. The auxiliary outcomes likewise describe relative economic position without distinguishing output, population and regional-peer adjustments as causal channels. These exercises therefore qualify where the empirical pattern appears more clearly, but do not demonstrate institutional absorption, migration, productivity growth or any other transmission mechanism. The empirical contribution remains a conditional pattern associated with a documented planning event.

The robustness checks call for caution. The direction and order of magnitude of the result for intensive revisions were maintained when the comparison group and the estimator were changed, but significance remained marginal in part of the specifications. The pattern was also not reproduced uniformly across all generalised entropy measures, and the intervals robust to violations of parallel trends included zero. The data support the existence of suggestive and conditional evidence, not the definitive identification of a structural effect. The contribution of the result lies in revealing a regularity that deserves further investigation and in showing that the regional scale produces questions and evidence that would remain invisible in an analysis restricted to individual urban performance.

The broader contribution of this work lies in this shift. The smart cities literature has often asked which cities have the best indicators, which technologies are adopted, and which effects appear in relation to innovation, productivity, population or internal inequality. The approach developed here adds another question: how do changes associated with urban smartness relate to the city's position within an interdependent territorial system? This shift brings the Smart City agenda closer to regional economics, urban networks and federalism, without abandoning its urban dimension.

The work also offers an empirical infrastructure for this dialogue. The construction of multidimensional indicators for all municipalities, the organisation of a documentary database of Master Plans, the development of a content dictionary and the decomposition of inequality into municipal contributions constitute procedures that can be combined in other applications. The combination of observed conditions, institutional incorporation and relational outcomes provides a research architecture applicable to urban systems characterised by administrative fragmentation, inequality among local governments and functional interdependencies.

The implications for public policymaking derive from this territorial reading. A national smart city agenda is likely to produce more consistent results when it starts from municipal heterogeneity, rather than from a uniform model of digital transformation. The same instruments do not carry the same meaning in a metropolis, in a regional centre, in an intermediate municipality or in a small locality that depends on services provided in its surroundings. Common guidelines may organise principles of inclusion, sustainability, data security and transparency, but their operationalisation needs to consider population scale, position within the urban network, available infrastructure, administrative capacity and local problems.

This differentiation does not diminish the role of national coordination. On the contrary, the asymmetries observed suggest room for more structured action by the federal government and the states in data production, technical assistance, financing and the promotion of territorial cooperation. Municipalities with lower capacity tend to require more basic instruments, such as the organisation of administrative records, the digitalisation of services, the training of civil servants, the expansion of connectivity and integration across municipal departments. Centres that perform regional functions, in turn, require more complex systems, capable of serving populations and flows that extend beyond their administrative boundaries.

Revision can be regarded as a potential institutional window for reassessing priorities and connecting plan content to regulation, budgeting and monitoring. The empirical exercise does not identify these implementation channels, so the estimates do not establish that revisions with these characteristics generate the observed economic pattern. From a policy-design perspective, however, verifiable targets, administrative responsibilities, monitoring indicators and correspondence with the Multi-Year Plan, budgetary guidelines and annual budget provide observable dimensions through which documentary incorporation can be followed beyond the legal text.

For municipalities adopting their first Master Plan, the estimates do not indicate a consistent short-run change in the signed municipal contribution. They do not show whether initial adoption builds technical routines, administrative learning or planning capacity. Assessing these possibilities would require direct measures of institutional development and a longer post-adoption horizon.

The regional scale needs to occupy a clearer place in these strategies. Mobility, health, sanitation, connectivity, environmental management, labour markets and specialised services are often organised beyond a single municipality. Public consortia, shared data platforms, cooperation arrangements and coordinated planning between centres and areas of influence can reduce costs, expand scale and avoid duplication. This cooperation, however, needs to recognise that flows are not symmetrical. Central municipalities concentrate benefits and burdens, while smaller localities may remain dependent or weakly integrated.

Policy monitoring should observe who accesses the gains and how they are distributed across the territory.

A national monitoring system could combine structural, documentary and implementation indicators. The municipal diagnosis developed in this work shows the usefulness of observing multiple dimensions in a comparable way, but it also shows that a cross-sectional measure does not track trajectories. Periodic series would make it possible to identify change, persistence and convergence. This set should be complemented by information on plan regulation, budget execution, contracts, investments, service coverage, social participation and territorial outcomes. The sequence linking guideline, instrument, expenditure, delivery and effect needs to become observable.

The empirical scope also defines the limits of the results. The structural indicators provide a multidimensional portrait, but depend on the availability and quality of municipal databases. Master Plans capture normative incorporation, not execution, and their documentary availability is uneven across regions and population sizes. The period covered by the econometric exercise is relatively short and ends in 2020. The economic variable observes the municipal contribution to GDP per capita inequality, not the distribution of household income, well-being or access to services. Spillover effects between municipalities, although part of the regional argument, were not directly identified.

These limits do not require municipalities to be abandoned as observational units. They require the geographical and causal claims to remain aligned with the data. This study provides a municipal diagnosis, a documentary measure and an exploratory regional evaluation. A stronger assessment of implemented policies would require observing the chain from legal content to regulation, resources and delivery, as well as a design that more convincingly addresses selection and interference. Those extensions build on the empirical infrastructure assembled here, but should not be presented as findings of the present study.

The limits point to a research agenda. A first path consists in constructing longitudinal indicators of urban smartness, capable of tracking municipalities before and after the adoption of policies, projects and institutional changes. Another line of research involves connecting the content of Master Plans to the implementation chain, identifying regulations, programmes, investments, contracts and outcomes. This connection would make it possible to distinguish plans that function as effective guidance from those whose incorporation remains predominantly declaratory.

The investigation of regional mechanisms offers equally broad possibilities. Spatial and network models can examine direct and indirect effects between municipalities, considering distance, hierarchy, mobility, commuting flows, service provision and digital connections. Exposure to policies implemented in nearby centres can be incorporated into evaluation designs, making it possible to observe whether smart initiatives generate

diffusion, drainage or functional reorganisation. Immediate Geographic Regions provide a useful reference, but other delimitations can be explored according to the mechanism under investigation.

There is also room to disaggregate the Smart City agenda. Governance, technology, environment, social inclusion, mobility and economic development may operate through distinct channels and produce different effects depending on the position of the municipality. The exploratory results obtained for society and governance suggest that institutional coordination deserves specific attention. Future studies may examine whether these dimensions affect employment, formalisation, productivity, migration, land values, access to services, emissions, digital inclusion and inequalities of opportunity.

Cross-country comparison can broaden this programme. Federal systems, unitary structures and different forms of local autonomy offer diverse institutional conditions for the diffusion of smart cities. The design proposed here does not depend on the reproduction of the Brazilian results, but on the combination of a local decision-making unit, a functional region and position within the urban network. This approach may contribute to understanding why similar policies produce different outcomes in territories with different capacities, hierarchies and governance arrangements.

The more general conclusion is that urban smartness is relational in nature. A municipality may improve its internal indicators without altering the dependencies it organises with its surroundings. Conversely, a change in planning may modify its relative position within the region without producing, in the short term, clearly identifiable economic growth. This distinction matters for both research and public policy. Evaluating smart cities requires observing not only which technologies have been installed or which positions have been reached in rankings, but which capacities have been built, which urban functions have been reorganised, who accesses their benefits and how their effects cross administrative boundaries.

This interpretation shifts the smart city agenda from a logic of isolated modernisation to one of territorial coordination. Smart city policies should not be assessed only by the presence of equipment, platforms or digital systems, but by the way they expand local capacities, improve service provision, reduce asymmetries in access and reorganise relations between municipalities. In a federal and unequal country, this point has direct implications: urban smartness cannot be conceived only as a competitive attribute of a few cities, but as part of a territorial development strategy that recognises centralities, dependencies and shared responsibilities.

This work does not close the discussion on the regional effects of smart cities. It proposes a way of formulating it. The passage from the city as an isolated container of solutions to the municipality as a node in a territorial network opens a field in which urban planning, institutions, technology and inequality can be analysed together. The

smart city, when observed from the perspective of regional economics, ceases to be defined only by what it contains and is also understood through the territorial relations in which municipalities are embedded.

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APPENDIX

A.4.1 Classification and composition of the indicators

Table A.4.1 - Total Knowledge Intensive Activities (TKI)

Codes	Description
9	Mining support service activities
19	Manufacture of coke and refined petroleum products
21	Manufacture of basic pharmaceutical products and pharmaceutical preparations
26	Manufacture of computer, electronic and optical products
51	Air transport
58	Publishing activities
59	Motion picture, video and television programme production, sound recording and music publishing activities
60	Programming and broadcasting activities
61	Telecommunications
62	Computer programming, consultancy and related activities
63	Information service activities
64	Financial service activities, except insurance and pension funding
65	Insurance, reinsurance and pension funding, except compulsory social security
66	Activities auxiliary to financial services and insurance activities
69	Legal and accounting activities
70	Activities of head offices; management consultancy activities
71	Architectural and engineering activities; technical testing and analysis
72	Scientific research and development
73	Advertising and market research
74	Other professional, scientific and technical activities
75	Veterinary activities
78	Employment activities
79	Travel agency, tour operator reservation service and related activities
84	Public administration and defence; compulsory social security
85	Education
86	Human health activities
90	Creative, arts and entertainment activities
91	Libraries, archives, museums and other cultural activities
94	Activities of membership organisations
99	Activities of extraterritorial organisations and bodies

Source: Eurostat (2009).

Note: Codes refer to the NACE Rev. 2 statistical classification of economic activities.

Table A.4.2 - List of urban planning and land regulation instruments

Legislation
1. Legislation on special social interest areas and/or zones 2. Legislation on special interest zones and/or areas 3. Urban perimeter law 4. Land subdivision legislation 5. Zoning or land use and occupation legislation 6. Legislation on additional building rights or paid grant of the right to build 7. Betterment levy (special assessment) legislation 8. Legislation on joint/consortium urban operations 9. Neighborhood impact study legislation 10. Building code 11. Environmental zoning or ecological-economic zoning legislation 12. Administrative easement legislation 13. Heritage listing/protection (tombamento) legislation 14. Protected areas / conservation units legislation 15. Legislation on special concession of use for housing purposes 16. Legislation on special adverse possession of urban property (urban usucapião) 17. Surface right legislation 18. Land tenure regularization legislation 19. Possession legitimation legislation 20. Prior environmental impact assessment legislation

Source: IBGE (2022b).

Table A.4.3 - Digital service channels provided by municipal governments

Remote service channels for citizens
1. SMS messages sent to citizens 2. SMS messages received from citizens 3. Apps developed by the city government 4. Apps developed by other organizations or citizens using information or data made available by the city government 5. Website optimized for mobile devices or designed as a mobile version 6. Issuing tax bills (boletos) or other payment slips.

Source: IBGE (2020).

Table A.4.4 - Municipal digital participation and engagement channels

City-citizen interaction channels
1. Online public consultation allowing citizens to submit contributions to laws, budgets, and plans 2. Online discussion groups such as forums or internet communities 3. Online poll on topics of interest to the city government 4. Online voting to inform decision-making on public policies, budgets, etc.

Source: IBGE (2020).

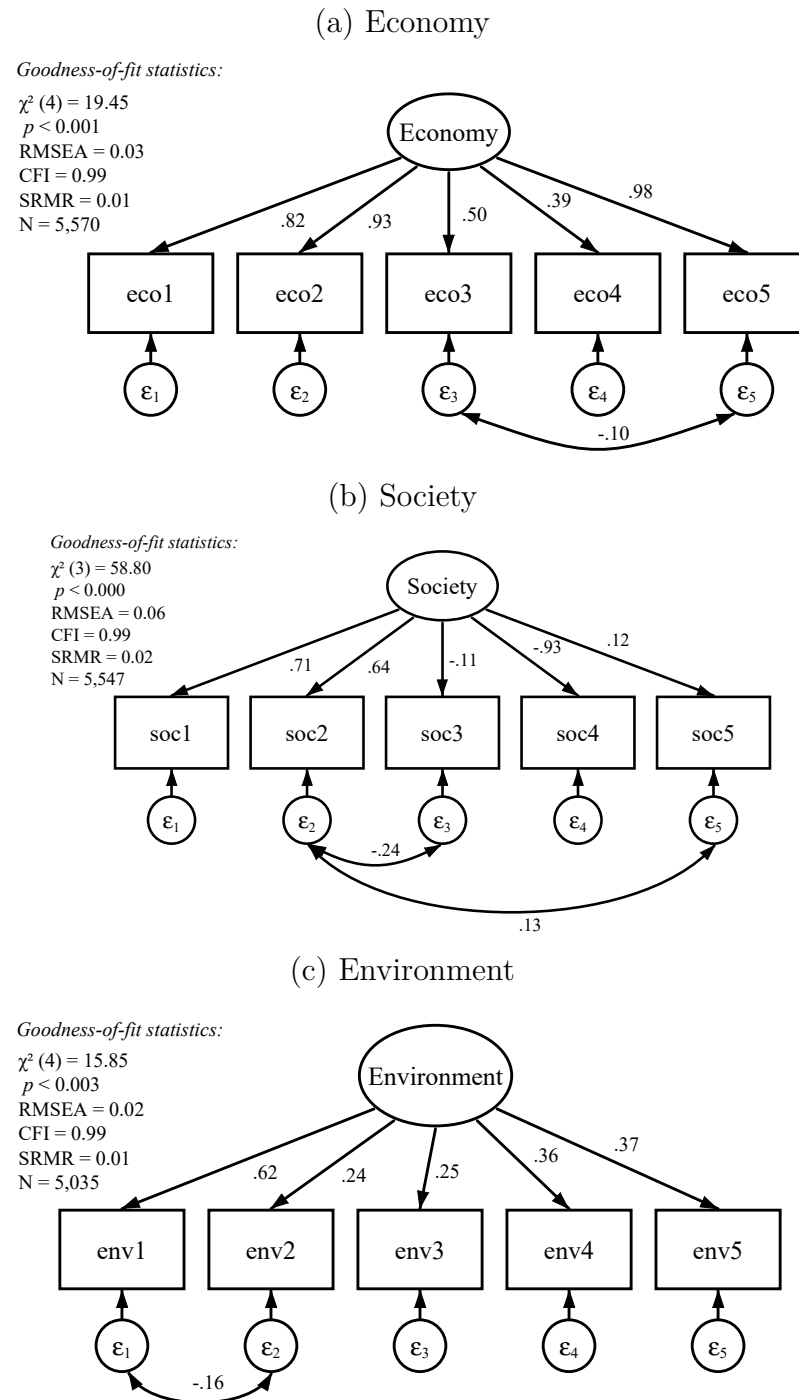
Table A.4.5 - Municipal smart infrastructure systems

Digital systems in citizens' daily life
1. Electronic public transport ticketing 2. Municipal buses equipped with GPS 3. Operations and control center 4. Smart street lighting system 5. Smart traffic signals 6. Sensors for monitoring risk-prone areas

Source: IBGE (2020).

A.4.2 Measurement models, indicator coverage and sensitivity of the composite index

Figure A.4.1 - Measurement diagrams for the Smart City dimensions estimated by CFA



Source: Author's own elaboration.

Note: The figure reports the standardised measurement diagrams for the dimensions estimated by CFA/SEM. Governance and Technology are not displayed because they were estimated by GSEM to accommodate indicators with Gaussian, Poisson and Bernoulli distributions. Their response-specific GSEM coefficients are reported in Table 4.4.

Table A.4.6 - Correlation matrix of alternative Smart City composite indices

	Smart City Index (second-order CFA)	Smart City Index (PCA)	Smart City Index (mean)
Smart City Index (second-order CFA)	1		
Smart City Index (PCA)	0.97***	1	
Smart City Index (mean)	0.95***	0.99***	1

Source: Author's own elaboration.

Note: *** $p < 0.001$.

Table A.4.7 - Sensitivity diagnostics for the Smart City Index

Specification	N	Pearson	Spearman	Median $ \Delta rank $	P95	Top 20	Top 100	Same quintile (%)
Complete-information sample	5,009	0.9998	0.9999	12	44	19/20	100/100	98.48
Influential-case diagnostic	5,570	0.9928	0.9973	62	234	16/20	89/100	93.36
Upper-tail sensitivity	5,570	0.9970	0.9984	39	157	14/20	88/100	95.98
Economy-exclusion diagnostic	5,570	0.9794	0.9800	171	672	13/20	80/100	80.39

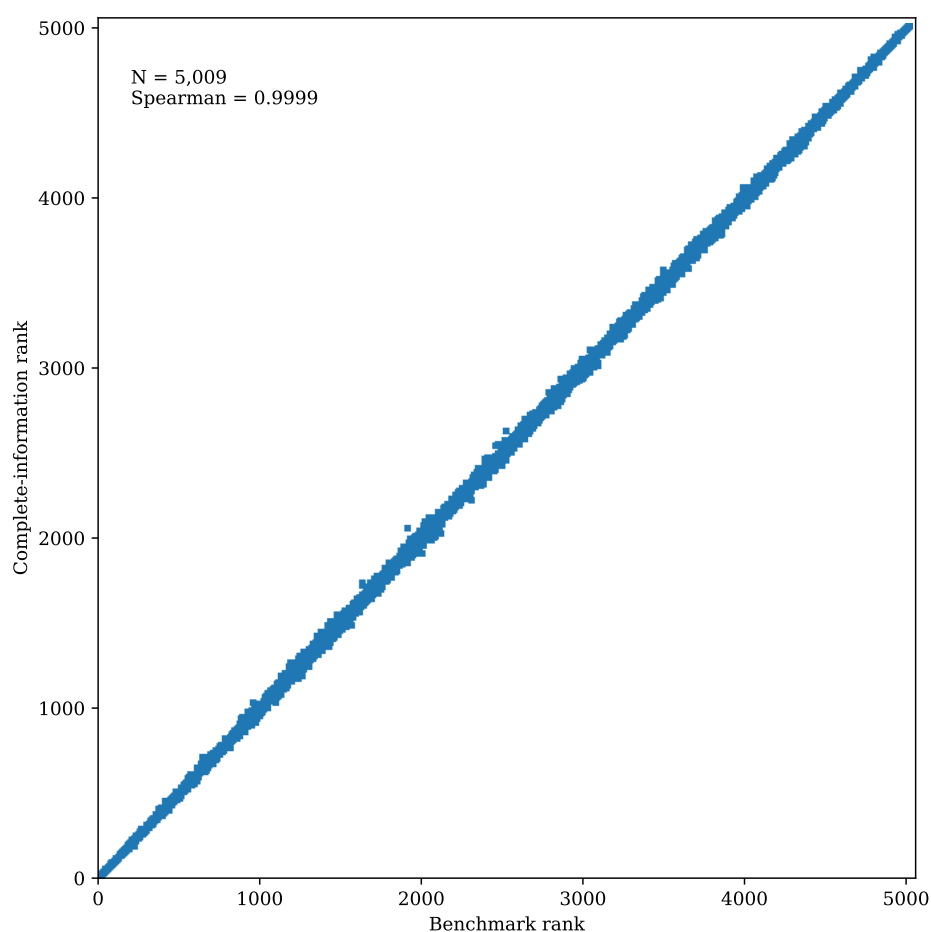
Source: Author's own elaboration.

Note: The benchmark specification contains 5,570 model-based Smart City scores. The complete-information specification re-estimates the measurement models and the PCA using the 5,009 units with all 25 manifest indicators observed; Top 20 and Top 100 overlap are computed within this common comparison sample. The influential-case diagnostic excludes Fernando de Noronha, Carmésia and Afuá only from the estimation of the Environment measurement-model parameters and subsequently predicts scores for the full benchmark universe. The upper-tail sensitivity caps only the upper 0.1% of the standardised Sustainable Commuting and Sustainable Vehicles inputs, corresponding to five observations in each variable. Rank changes are measured relative to the benchmark specification. Quintiles are recalculated within each comparison universe. The Economy-exclusion diagnostic retains the benchmark Society, Environment, Governance and Technology scores and re-estimates the PCA using only these four dimensions. It is intended to assess the sensitivity of the composite ordering to the direct inclusion of the Economy dimension and does not represent an alternative preferred definition of urban smartness.

The complete-information exercise indicates that unequal manifest-indicator coverage has little practical effect on the aggregate ordering. The diagnostics involving influential environmental observations produce larger changes in individual positions, particularly near the upper tail, while preserving a very high overall correlation with the benchmark. A distinct pattern emerges when the Economy dimension is removed altogether. The resulting four-dimensional index remains strongly rank-correlated with the benchmark ($\rho = 0.980$), and 80.4% of the units remain in the same quintile, but exact positions become more sensitive, with 13 of the benchmark Top 20 and 80 of the Top 100 remaining in the corresponding groups. This exercise changes the substantive

composition of the index and should therefore be interpreted as a dimensional sensitivity diagnostic rather than as an alternative measurement specification. Taken together, the results indicate that broad municipal ordering is not reducible to Economy alone, while showing that the economic dimension materially contributes to the relative position of some municipalities.

Figure A.4.2 - Benchmark and complete-information rankings of the Smart City Index

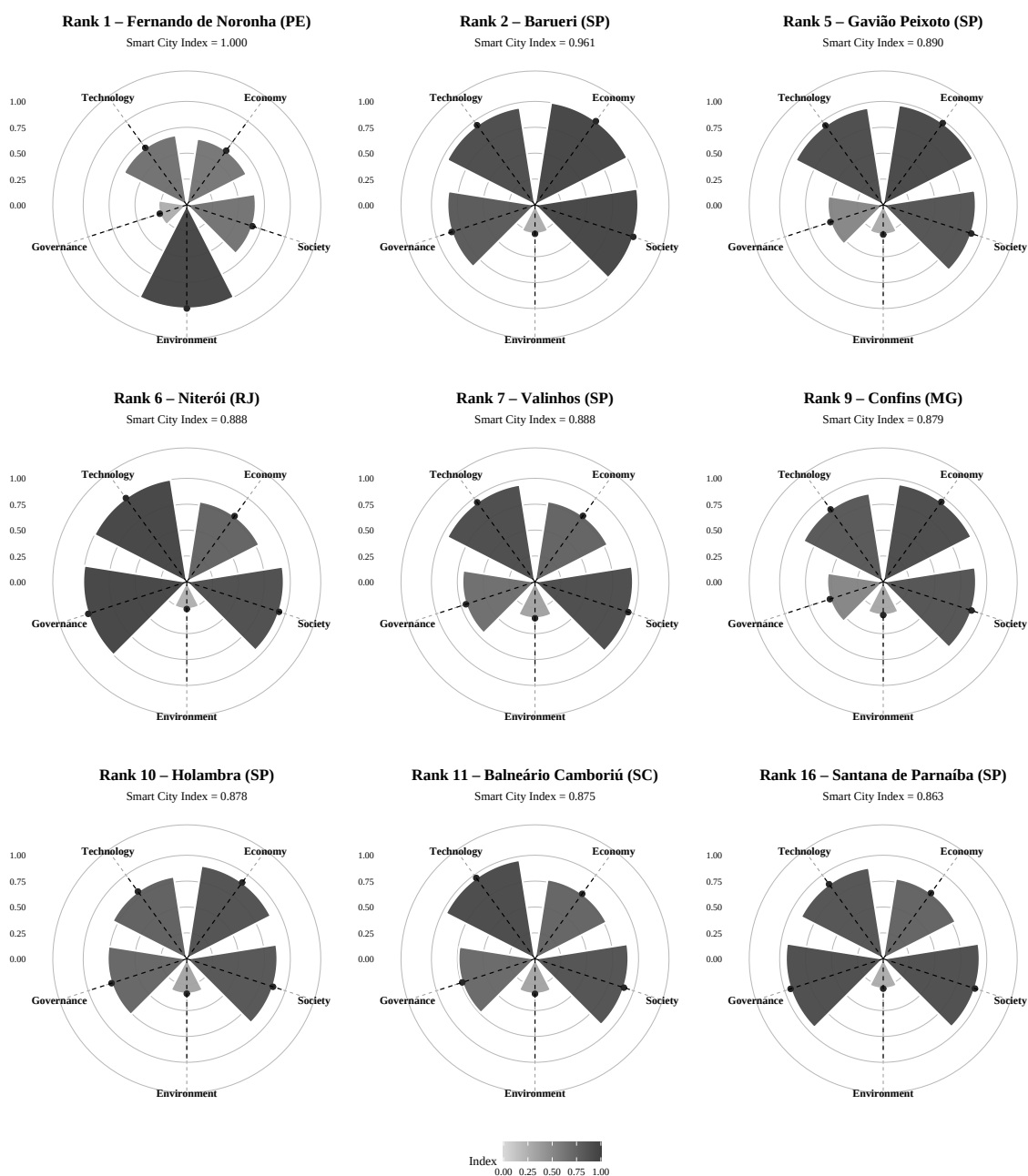


Source: Author's own elaboration.

Note: The figure compares municipal rank positions under the benchmark Smart City Index with the index obtained after re-estimating the full measurement and aggregation procedure for the 5,009 units with complete information on all 25 manifest indicators. The diagonal line represents exact rank equality. The Spearman rank correlation between the two measures is 0.9999.

A.4.3 Complementary dimensional profiles

Figure A.4.3 – Dimensional profiles of the highest-ranked non-capital units in the Smart City Index



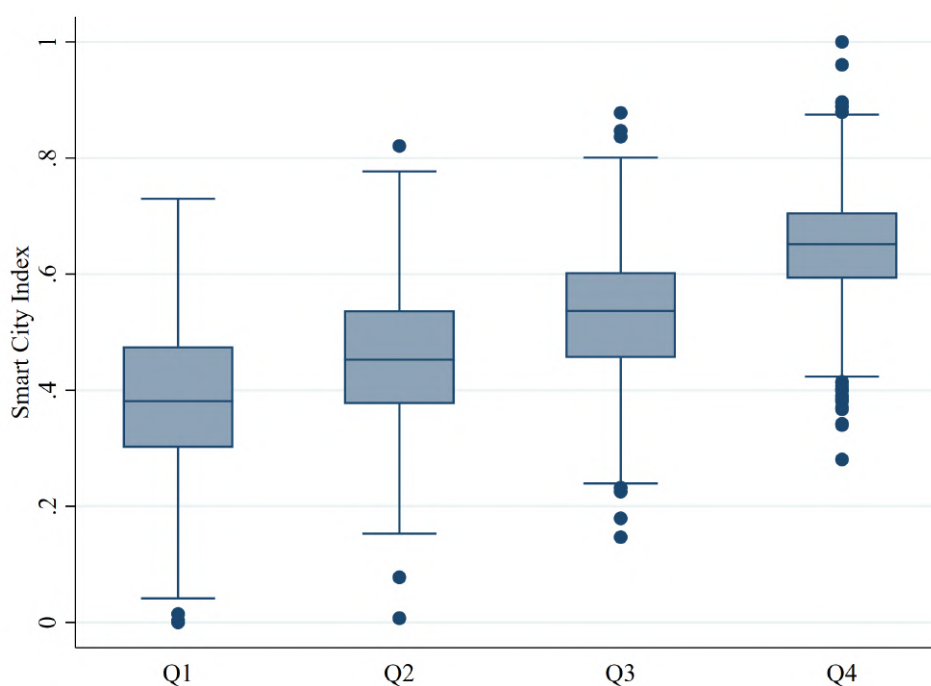
Source: Author's own elaboration.

Note: Each radial bar reports the normalised score of the unit in one Smart City dimension. Scores range from 0, lowest observed dimensional score, to 1, highest observed dimensional score. The title of each panel reports the unit's national position in the Smart City Composite Index. State capitals were excluded from the ranking shown in this figure. Scores are relative to the observed distribution of each dimension and should not be interpreted as directly comparable levels of substantive achievement across dimensions.

A.4.4 Urban population share and the Smart City Index

As a complementary descriptive exercise, the benchmark Smart City Index was compared with the share of residents classified as living in urban areas in the 2022 Demographic Census. The association is positive, with Pearson and Spearman correlations of 0.676 and 0.694, respectively. The mean Smart City Index increases monotonically across quartiles of urban population share, from 0.386 in the first quartile to 0.456, 0.529 and 0.649 in the subsequent groups. Among the individual dimensions, Society and Technology show the strongest rank associations with urban population share, while Environment and Governance present more moderate correlations. The distributions nevertheless overlap across quartiles, indicating that differences in municipal urbanisation are associated with, but do not fully account for, the observed distribution of the composite index.

Figure A.4.4 - Distribution of the Smart City Index by quartile of municipal urban population share



Source: Author's own elaboration based on the 2022 Demographic Census (IBGE, 2023a).

Note: Quartiles are defined from the distribution of the share of the municipal population classified as urban in the 2022 Demographic Census. The quartile cutoffs are 54.11%, 70.835% and 86.05%. Q1 therefore represents the units with the lowest urban population shares and Q4 those with the highest. These groups are descriptive sample strata and should not be interpreted as an official classification of urban and rural municipalities or as equivalent to the Degree of Urbanisation methodology discussed in Section 4.4.1. The Smart City Index ranges from 0, the lowest observed composite score, to 1, the highest observed composite score.

Table A.5.1 - Annual number of municipalities adopting and revising Master Plans in Brazil (1958–2009)

Year	Plans Adopted	Plans Revised	Year	Plans Adopted	Plans Revised
1958	1		1986	4	
1959	1		1987	3	
1960	1		1988	3	
1962	1		1989	2	
1964	1		1990	3	
1965	1		1991	7	
1966	1		1992	12	1
1967	1		1993	8	
1968	6		1994	10	
1969	5		1995	17	
1970	1		1996	14	
1971	5		1997	9	
1972	5	1	1998	9	
1973	2		1999	11	
1974	1		2000	26	
1975	1		2001	28	1
1976	4		2002	25	
1977	2		2003	33	
1978	1		2004	73	3
1979	2		2005	48	
1981	2		2006	692	12
1982	2		2007	280	4
1983	2	1	2008	311	16
1984	3		2009	145	11
1985	2				

Source: Author's own elaboration based on data from IBGE (2022b).

Table A.5.2 - Small municipalities with Master Plans established before the Statute of the City, Brazil

State	Municipality	Year of Adoption	Population	GDP per capita
RS	Alecrim	1969	5710	22,752.43
RS	André da Rocha	1994	1351	66,019.37
RS	Campina das Missões	1968	5325	35,008.26
RS	Cândido Godói	1975	6106	44,431.53
RS	Cerro Grande do Sul	1993	12579	13,565.23
RS	Charrua	1994	3228	27,540.86
RS	Chuí	1997	6832	44,950.40
RS	Chuveisca	1998	5518	17,769.62
RS	Colorado	1992	3088	54,318.85
RS	Coxilha	1997	2731	70,047.13
RS	Dois Lajeados	1996	3410	37,640.35
RS	Espumoso	1958	15594	40,022.51
RS	Formigueiro	1971	6569	29,181.69
RS	Getúlio Vargas	1992	16158	40,131.23
RS	Harmonia	1994	4967	41,037.87
RS	Morro Redondo	1995	6609	15,731.82
RS	Muçum	1968	4967	57,317.87
RS	Muitos Capões	1997	3184	228,409.27
RS	Novo Barreiro	1998	4185	23,752.18

Table A.5.2 - Continue

State	Municipality	Year of Adoption	Population	GDP per capita
RS	Putinga	1995	3861	27,279.02
RS	Salvador do Sul	1976	7975	38,804.44
RS	São Valentim	1984	3220	31,363.02
RS	São Valentim do Sul	1998	2248	29,273.76
RS	Selbach	1970	5114	44,837.38
RS	Sertão	1972	5220	54,705.53
RS	Tupanci do Sul	1994	1447	41,640.68
RS	Vale do Sol	2000	11873	18,632.27
RS	Vista Alegre do Prata	1992	1553	39,892.09
MG	Bom Sucesso	1999	17612	21,406.72
MG	Faria Lemos	1959	3202	19,012.97
MG	Ibertioga	1964	4999	16,437.39
MG	Imbé de Minas	1997	6976	11,359.91
MG	Santa Bárbara do Monte Verde	1997	3212	16,021.12
MG	Santa Rita de Minas	1998	7322	17,213.52
MG	Senhora dos Remédios	1968	10474	9,709.34
MG	Urucuia	1997	17470	9,001.53
SP	Bilac	2000	8197	33,082.37
SP	Lucianópolis	1973	2412	31,256.46
SP	Ocaçu	1972	4294	41,165.58
SP	Reginópolis	1968	10047	17,965.16
SP	Santa Adélia	1995	15639	22,947.05
SP	Tuiuti	1996	7058	26,354.56
GO	Pontalina	1994	17899	33,007.99
GO	Trombas	1990	3497	16,710.78
PI	Bonfim do Piauí	1999	5700	8,599.79
PI	Cabeceiras do Piauí	1993	10671	7,459.96
TO	Itapiratins	1993	3814	30,330.42
TO	São Sebastião do Tocantins	1977	4898	11,365.08

Source: Author's own elaboration based on IBGE (2022d) and IBGE (2021).

Note: The table includes municipalities with fewer than 20,000 inhabitants that are not part of metropolitan regions or urban agglomerations and that reported having a master plan established before 2001. Prior to the Statute of the City (Federal Law No. 10,257/2001), the requirement to adopt a master plan applied primarily to municipalities with more than 20,000 inhabitants, according to the 1988 Federal Constitution. Therefore, these cases suggest voluntary or context-specific adoption of master plans. Information on municipalities classified as areas of special tourist interest or subject to environmental or risk-related regulations is not available. GDP per capita is measured in current Brazilian reais (BRL).

A.5.1 Documentary verification and inconsistencies between MUNIC (2021) and municipal Master Plans

This appendix presents selected examples of inconsistencies identified between the information reported by municipalities in the 2021 Pesquisa de Informações Básicas Municipais (Survey of Basic Municipal Information, MUNIC) (IBGE, 2022b) and the documentary evidence obtained from the institutional repositories of municipal governments and Municipal Councils.

The aim is to illustrate the manual verification procedure adopted in the construction of the empirical database, as well as to show the nature of the divergences observed, which involve inconsistencies in revision dates, references to different instruments, and the absence or inadequacy of the documents available.

A.5.1.1 Types of inconsistencies identified

Documentary verification made it possible to identify different types of inconsistencies, which can be grouped into the following categories:

- (i) divergence between the date reported in MUNIC and the date of enactment of the Master Plan legislation;
- (ii) a record of revision that corresponded only to legislative proceedings, without approval of the plan in the period reported;
- (iii) reference to instruments other than the Master Plan, such as sectoral plans or municipal organic laws;
- (iv) absence of documentary evidence of the Master Plan in institutional repositories.

A.5.1.2 Examples of documentary inconsistencies

This section presents illustrative examples of inconsistencies between the information reported in the 2021 MUNIC survey and the documentary evidence available in municipal institutional repositories. The selected cases cover different federative units, with the aim of highlighting recurring patterns of divergence and the heterogeneity observed in the availability of documents.

- Saudades (SC): The municipality reported having established its Master Plan in 2005 and updated it in 2014. However, consultation of the institutional repository revealed that the revision occurred only in 2025, through Complementary Law No. 157.
- Catiguá (SP): The municipality reported the establishment of a Master Plan in 2017. The analysis revealed that the instrument approved that year corresponded to the Basic Sanitation Master Plan, and no Urban Development Master Plan was located.

- Santa Quitéria (CE): The municipality declared the establishment of a Master Plan in 2010. The verification indicated that the available document refers to the revision of the Municipal Organic Law, and it was not possible to locate the Master Plan in the institutional repositories.
- Viçosa (MG): There is no documentary evidence that the Master Plan was revised in 2018, as reported to IBGE. In 2018, there was a revision of the law concerning the Career Plan for Education Workers in the Municipal Public Network. The most recent revision of the Viçosa Master Plan was enacted through Law No. 3,018/2023.
- Teófilo Otoni (MG): The municipality, with more than 100,000 inhabitants, reported having established its Master Plan in 2008 and revised it in 2015. However, the institutional repository provides only the 2008 document. Recent records indicate that a revision process was opened only in 2025.
- Massapê do Piauí (PI): The municipality – with a population of 6,456 inhabitants, according to the 2021 MUNIC survey – reported having implemented its Master Plan in 2010, but no documentary evidence of the instrument was found in institutional repositories. By contrast, other municipal planning documents, such as the Multi-Year Plan and the Budget Guidelines Law, are available.
- Patos (PB): The municipality reported the establishment of a Master Plan in 2016. Documentary verification revealed that the instrument currently in force was established in 2006, with no evidence of revision up to the reference period of the 2021 MUNIC survey.
- Garrafão do Norte (PA): With a population of 26,155 inhabitants, according to the 2021 MUNIC survey, the municipality reported the establishment of a Master Plan in 2010. However, documentary analysis indicated that the plan was established in 2006, with no revision up to the time of the survey.

Overall, the inconsistencies observed suggest limitations in the accuracy of the information reported by municipalities, possibly associated with difficulties in institutional monitoring of urban planning instruments or with the interpretation of the MUNIC questionnaire. In particular, the requirement for periodic revision of Master Plans, established by § 3 of Article 40 of the City Statute, may contribute to the occurrence of imprecise records, especially in municipalities that did not carry out revisions within the prescribed period.

Despite the identification of inconsistencies in the information reported by municipalities in the 2021 MUNIC survey, the use of this database as an initial filtering stage proved operationally necessary, given the high cost of comprehensive documentary verification for the full set of Brazilian municipalities. In this sense, the strategy adopted

rests on the assumption that, in aggregate terms, the declaratory database constitutes an adequate approximation of the population of interest, although it is subject to specific errors.

In addition, the institutional framework established by the City Statute is considered to create asymmetric incentives in the reporting process. Municipalities required to prepare and periodically revise a Master Plan tend to report its existence and revision, even if with possible inaccuracies regarding the date or the specific instrument. By contrast, the probability of underreporting the existence of the Master Plan is considered to be reduced, since such an omission would imply acknowledging non-compliance with a legal requirement.

These elements suggest that the inconsistencies observed are more closely associated with errors in classification, interpretation or revision of information than with the systematic absence of the instrument among the municipalities that reported it.

Table A.5.3 - Examples of inconsistencies between MUNIC (2021) declarations and institutional records for municipalities with more than 100,000 inhabitants excluded from the sample

State	Municipality	Population	Type of inconsistency
BA	Santo Antônio de Jesus	103,204	Declared revision in 2015; only the 2004 document available (Law nº 18/2004).
GO	Rio Verde	247,259	Declared revision in 2018; only the 2007 document available (Law nº 5218/2007).
MA	Codó	123,368	Declared revision in 2020; only the 2007 document available (Law nº 1449/2007).
MA	São José de Ribamar	180,345	No evidence of master plan document found in the institutional repository.
MG	Teófilo Otoni	141,269	Declared revision in 2015; only the 2008 document available (Law nº 5892/2008).
PA	Ananindeua	540,410	Declared revision in 2020; only the 2006 master plan law available in the institutional repository (Law nº 2237/2006).
PA	Bragança	130,122	Declared revision in 2015; only the 2006 document available; no response to request for revised version (Law nº 06/2015).
PA	Breves	104,280	Declared adoption in 2011; only a 2001 master plan document available (Law nº 02/2001).
PB	Patos	108,766	Declared adoption in 2016; actual plan enacted in 2006 with no subsequent revision (Law nº 3503/2006).
PE	Recife	1,661,017	Declared revision in 2020; revision legally enacted in 2021 (Law nº 02/2021).
PE	Camaragibe	159,945	Declared adoption in 2017; plan enacted in 2004 and last revised in 2007 (Law nº 341/2007).

Table A.5.3 - Continue

State	Municipality	Population	Type of inconsistency
PI	Parnaíba	153,863	Declared revision in 2016; only the 2007 document available (Law nº 2296/2007).
PR	Londrina	580,870	Declared revision in 2020; revision effectively implemented in 2022 (Law nº 13339/2022).
PR	Fazenda Rio Grande	103,750	Declared revision in 2014; no revision in the period; latest revision in 2025 (Law nº 265/2025).
PR	Ponta Grossa	358,838	Declared revision in 2018; no revision in the period; latest revision in 2025 (Law nº 14305/2025).
RJ	Teresópolis	185,820	Declared revision in 2019; most recent available version from 2006 (Law nº 079/2006).
SP	Pindamonhangaba	171,885	Declared revision in 2020; no revision between 2010 and 2020; revisions only after 2022 (Law nº 66/2022 and Law nº 82/2024).

Source: Author's own elaboration based on IBGE (2022b) and municipal institutional repositories.

Note: This table presents selected cases of municipalities with more than 100,000 inhabitants excluded from the final sample due to inconsistencies between declared information in MUNIC (2021) and documentary evidence. The inconsistencies include discrepancies in revision dates, absence of revised documents, and lack of verifiable master plan records in institutional repositories.

Figure A.5.1 - Examples of heterogeneity in municipal master plan document

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Leis

Atualizadas

187

LEI Nº 14.771, DE 17 DE DEZEMBRO DE 2015 - PUBLICADA NO DOMÍNIO PÚBLICO

17/12/2015

DISPÕE SOBRE A REVISÃO DO PLANO DIRETOR DE CURITIBA DE ACORDO COM O DISPOSTO NO ART. 40, § 3º, DO ESTATUTO DA CIDADE, PARA ORIENTAÇÃO E CONTROLE DO DESENVOLVIMENTO INTEGRADO DO MUNICÍPIO.

A CÂMARA MUNICIPAL DE CURITIBA, CAPITAL DO ESTADO DO PARANÁ, aprovou e eu, Prefeito Municipal, sanciono a seguinte lei:

Art. 1º

Esta lei dispõe sobre a revisão do Plano Diretor de Curitiba, instituído pela Lei nº 2.828, de 10 de agosto de 1986 e adequado ao Estatuto da Cidade pela Lei nº 11.286, de 16 de dezembro de 2004.

TÍTULO I

DA REVISÃO DO PLANO DIRETOR DE CURITIBA

Art. 2º

Esta lei promove a revisão do Plano Diretor de Curitiba de acordo com o disposto no art. 40, § 3º, do Estatuto da Cidade, consolidada as políticas públicas, princípios, diretrizes e objetivos sucessivamente implantados no Município, incorpora novos princípios, diretrizes e objetivos alinhados às demais disposições legais e as dinâmicas demográfica, social, econômica, ambiental, orientando as ações futuras de adequação da estrutura urbana.

Art. 3º

O Plano Diretor de Curitiba abrange a totalidade do território do Município, completamente urbano, e estabelece princípios, diretrizes e objetivos para:

I - a política de desenvolvimento urbano;

II - a política urbana ambiental;

III - a política social e econômica;

IV - a gestão democrática da cidade.

Art. 4º

O Plano Diretor visa propiciar melhores condições para o desenvolvimento integrado, harmônico e sustentável de Curitiba com a Região Metropolitana, sendo o instrumento básico,

LeisMunicipais.com.br - Lei Ordinária 1477/2015 (<http://municipal.leis.mpb.br>) - Gerado em: 13/11/2024 11:08

Source: Own compilation based on municipal institutional repositories.

Note: The figure presents selected examples of initial pages from municipal master plans in Brazil, illustrating variation in formatting, digitisation quality, and textual structure. The documents include both digitally generated files and scanned copies, often containing handwritten annotations, stamps, and visual noise, which affect the performance of automated text extraction procedures.

A.5.2 Text extraction and optical character recognition procedures

This appendix describes the technical procedures adopted for the textual extraction of municipal Master Plans in digital format, with emphasis on the challenges associated with the heterogeneity of the documents and on the strategies used to ensure the integrity of the information employed in the empirical analysis.

A.5.2.1 Heterogeneity of documents and implications for text extraction

The Master Plans collected display a high degree of heterogeneity in terms of structure, formatting and digitisation quality. The documents range from native digital files, with structured and directly processable text, to files resulting from low-quality scans, often containing visual noise, handwritten annotations, institutional stamps and image distortions.

This heterogeneity imposes relevant limitations on the application of automated text extraction methods, since a significant share of the documents does not contain embedded text, requiring the use of optical character recognition (OCR) techniques. In several cases, the quality of the scan compromises the accuracy of the recognition process, generating losses or distortions in the textual information.

Illustrative examples of these variations are presented in Figure A.5.1, which shows the diversity of formatting patterns, using as examples the Master Plans of the municipalities of Irituia (PA), Lagoa da Confusão (TO), Pedro Afonso (TO), Novo Oriente (CE), Igarassu (PE), Orobó (PE), União de Minas (MG) and Curitiba (PR).

A.5.2.2 Text extraction strategy

Given these limitations, a sequential text extraction strategy was adopted, combining different computational methods with the aim of maximising the recovery of textual content from the documents.

Initially, an attempt was made to extract text directly using specialised libraries for reading PDF files, such as PyMuPDF and pypdf, which are suitable for documents with natively embedded digital text. In cases where this approach did not produce satisfactory results, OCR routines were applied, using tools based on automatic character recognition.

Different OCR configurations were tested, including standard approaches and more intensive image pre-processing procedures, involving contrast adjustment, binarisation and filtering. These stages sought to improve the legibility of scanned documents and, consequently, the accuracy of text extraction.

A.5.2.3 Complementary manual recovery procedures

Despite the application of these automated strategies, a subset of documents continued to display low-quality text extraction, owing to severe limitations in the legibility of the scanned images.

In these cases, a complementary manual recovery procedure was adopted. The documents were processed on devices equipped with advanced optical recognition capabilities, allowing the text to be selected and extracted directly from the images. The textual content obtained was then consolidated into standardised digital files, subsequently converted into PDF format and reinserted into the automated processing workflow.

This procedure was applied to a specific set of municipalities whose documents presented significant limitations for automatic reading, including Perobal (PR), São João do Ivaí (PR), Porto Grande (AP), Fortim (CE), Aguiar (PB), Paulista (PB), Brumado (BA), Saubara (BA), Eugenópolis (MG), Santa Cruz do Escalvado (MG) and Jambreiro (SP).

A.5.2.4 File standardisation and consistency of the textual database

After the text extraction stage, the documents were submitted to a standardisation process, with the aim of ensuring consistency in the database used for keyword identification.

This process included the consolidation of texts into a uniform format, the removal of invalid characters and the verification of the integrity of the extracted content. Although no substantive intervention was made in the original text, the procedure sought to ensure that the differences observed between documents reflected the content of the Master Plans, rather than artefacts of the extraction process.

A.5.2.5 Methodological considerations

The procedures adopted reflect the need for methodological adaptation to the specific empirical conditions of the data used. The lack of standardisation in the documents and the variability in the quality of the scans impose constraints on the direct application of automated techniques, requiring the combination of different processing strategies.

By making these stages explicit, this appendix seeks to ensure methodological transparency and enable the replicability of the procedures, while also highlighting the challenges associated with constructing textual databases from institutional documents in contexts of high heterogeneity.

Table A.5.4 - Random sample of 90 Brazilian municipalities for exploratory analysis of Master Plans

State	Municipality	MP Law (No./Year)	State	Municipality	MP Law (No./Year)	State	Municipality	MP Law (No./Year)
RO	Rolim de Moura	0266/2018	SP	Elias Fausto	0060/2013	PR	Umuarama	0445/2018
RO	Chupinguaia	2011/2017	SP	Gavião Peixoto	0087/2015	PR	União da Vitória	0003/2012
AC	Capixaba	0424/2013	SP	Guarujá	0156/2013	PR	Wenceslau Braz	2613/2013
PA	Portel	0007/2018	SP	Igarapava	0056/2018	SC	Agrolândia	0161/2016
PA	Prainha	0084/2017	SP	Itaberá	2692/2015	SC	Água Doce	0122/2017
PI	Corrente	0706/2019	SP	Itararé	3773/2017	SC	Balneário Barra do Sul	0086/2020
PI	São José do Piauí	0003/2010	SP	Jaguariúna	0204/2012	SC	Bandeirante	1000/2013
CE	Granja	0882/2010	SP	Jambeiro	0060/2015	SC	Botuverá	0049/2019
CE	Quixeré	0034/2018	SP	Lorena	0244/2016	SC	Guaraciaba	0085/2018
RN	Currais Novos	0009/2012	SP	Monte Alegre do Sul	1896/2020	SC	Lages	0523/2018
RN	Itajá	0266/2014	SP	Pedranópolis	0102/2014	SC	Ouro	0036/2016
RN	Nova Cruz	1273/2017	SP	Piracicaba	0405/2019	SC	Princesa	0074/2019
PB	Bananeiras	0473/2010	SP	Piraju	0173/2018	SC	Sangão	0023/2011
PB	Bom Jesus	0599/2018	PR	Barra do Jacaré	0426/2011	SC	Serra Alta	0934/2012
PE	Olinda	0054/2020	PR	Bom Jesus do Sul	0795/2017	SC	Xavantina	0071/2017
PE	Orobó	0934/2010	PR	Campina Grande do Sul	0018/2015	RS	Balneário Pinhal	0027/2012
BA	Castro Alves	0001/2018	PR	Campo Magro	0717/2012	RS	Caçapava do Sul	3449/2014
BA	Poções	0950/2011	PR	Coronel Vivida	2952/2019	RS	Cambará do Sul	3313/2016
MG	Aimorés	2268/2011	PR	Entre Rios do Oeste	0065/2020	RS	Dois Irmãos das Missões	0991/2010
MG	Araxá	5998/2011	PR	Foz do Iguaçu	0271/2017	RS	Entre Rios do Sul	0021/2020
MG	Lavras	0419/2020	PR	Iguatu	0776/2018	RS	Frederico Westphalen	4214/2015
MG	Machado	0062/2010	PR	Iretama	0099/2013	RS	Ivorá	0884/2010
MG	Ouro Branco	2188/2017	PR	Leópolis	0001/2010	RS	Nova Palma	1350/2010
MG	Paracatu	0118/2016	PR	Maripá	0043/2013	RS	Salvador do Sul	3274/2016
MG	Patos de Minas	0433/2013	PR	Paulo Frontin	0912/2013	RS	Tapejara	4518/2020
MG	Santa Cruz do Escalvado	0008/2016	PR	Porto Barreiro	0446/2014	MT	Campos de Júlio	0788/2017
ES	Baixo Guandu	2722/2012	PR	Renascença	0026/2020	MT	Guaranã do Norte	0258/2017
ES	Brejetuba	0847/2020	PR	Roncador	1190/2017	GO	Flores de Goiás	0057/2016
RJ	Campos dos Goytacazes	0015/2020	PR	Siqueira Campos	0486/2010	GO	Nerópolis	1777/2015
RJ	Petrópolis	7167/2014	PR	Teixeira Soares	1826/2019	GO	Orizona	1239/2020

Source: Author's own elaboration based on municipal legislation and institutional repositories.

Note: The table presents a random sample of 90 municipalities selected for exploratory reading of Master Plan documents. The “MP Law (No./Year)” refers to the number and year of the municipal legislation establishing or revising the Master Plan (MP).

Table A.5.5 - Selected Brazilian municipalities and their Master Plans: legal identification and access links

State	Municipality	Type of Plan	MP Law (No./Year)	Document Link
DF	Brasília	Urban Master Plan	00854/2012	< https://planosdiretoresmunicipisbrasil.neocities.org/Links%20do%20Cap5/5300108_DF_Bras%C3%ADlia.pdf >
RJ	Niterói	Urban Master Plan	03385/2019	< https://planosdiretoresmunicipisbrasil.neocities.org/Links%20do%20Cap5/3303302_RJ_Niter%C3%B3i.pdf >
PR	Curitiba	Urban Master Plan	14771/2015	< https://planosdiretoresmunicipisbrasil.neocities.org/Links%20do%20Cap5/4106902_PR_Curitiba.pdf >
SP	Holambra	Urban Master Plan	00300/2019	< https://planosdiretoresmunicipisbrasil.neocities.org/Links%20do%20Cap5/3519055_SP_Holambra.pdf >
RJ	Rio de Janeiro	Urban Master Plan	00111/2011	< https://planosdiretoresmunicipisbrasil.neocities.org/Links%20do%20Cap5/3304557_RJ_Rio%20de%20Janeiro.pdf >
ES	Vitória	Urban Master Plan	09271/2018	< https://planosdiretoresmunicipisbrasil.neocities.org/Links%20do%20Cap5/3205309_ES_Vit%C3%B3ria.pdf >
MG	Belo Horizonte	Urban Master Plan	11181/2019	< https://planosdiretoresmunicipisbrasil.neocities.org/Links%20do%20Cap5/3106200_MG_Belo%20Horizonte.pdf >
GO	Goiânia	Urban Master Plan	00246/2013	< https://planosdiretoresmunicipisbrasil.neocities.org/Links%20do%20Cap5/5208707_GO_Goi%C3%A2nia.pdf >
RS	Porto Alegre	Urban Master Plan	00663/2010	< https://planosdiretoresmunicipisbrasil.neocities.org/Links%20do%20Cap5/4314902_RS_Porto%20Alegre.pdf >
SP	São Paulo	Urban Master Plan	16050/2014	< https://planosdiretoresmunicipisbrasil.neocities.org/Links%20do%20Cap5/3550308_SP_S%C3%A3o%20Paulo.pdf >
SP	Campinas	Urban Master Plan	00189/2018	< https://planosdiretoresmunicipisbrasil.neocities.org/Links%20do%20Cap5/3509502_SP_Campinas.pdf >
SP	São Caetano do Sul	Urban Master Plan	00374/2015	< https://planosdiretoresmunicipisbrasil.neocities.org/Links%20do%20Cap5/3548807_SP_S%C3%A3o%20Caetano%20do%20Sul.pdf >
CE	Juazeiro do Norte	Smart City Technology Master Plan	00117/2018	< https://planosdiretoresmunicipisbrasil.neocities.org/Links%20do%20Cap5/PDTCI_CE_Juazeiro%20do%20Norte.pdf >
SP	Campinas	Smart City Strategic Plan		< https://planosdiretoresmunicipisbrasil.neocities.org/Links%20do%20Cap5/PECCi_SP_Campinas.pdf >

Source: Author's own elaboration based on municipal legislation and institutional repositories.

Note: The table includes different types of planning instruments, namely Urban Master Plans, Smart City Technology Master Plans, and Smart City Strategic Plans. The “MP Law (No./Year)” refers to the number and year of the municipal legislation establishing or revising the Master Plan (MP). In cases where no specific law number is available, the field is left blank.

Table A.5.6 - English translations of Portuguese keyword expressions used in the dictionary

Source table	Subgroup	Portuguese search expression	English translation / gloss
5.6	SE1	crescimento sustentável	sustainable growth
5.6	SE1	desenvolvimento sustentável	sustainable development
5.6	SE1	economia sustentável	sustainable economy
5.6	SE1	economia verde	green economy
5.6	SE1	ecopolo*	eco-pole(s)
5.6	SE1	economicamente sustentável	economically sustainable
5.6	SE1	produção sustentável	sustainable production
5.6	SE1	sustentabilidade econômica	economic sustainability
5.6	SE2	indústria* não poluente*	non-polluting industry/industries
5.6	SE2	indústria* sustentável*	sustainable industry/industries
5.6	SE3	sustentabilidade da* atividade*	sustainability of activity/activities
5.6	SE3	turismo sustentável	sustainable tourism
5.6	SE4	inteligência da economia	smart economy
5.6	P1	arranjo* produtivo* local*	local productive arrangement(s)
5.6	P1	associativismo	associativism / collective organisation
5.6	P1	economia solidária	solidarity economy
5.6	P1	economia colaborativa	collaborative economy
5.6	P1	cooperativa* de produção	production cooperative(s)
5.6	P2	parque* tecnológico*	technology park(s)
5.6	P2	polo* tecnológico*	technology hub(s)
5.6	P3	cidade industrial	industrial city
5.6	P3	condomínio* industrial*	industrial condominium(s) / industrial estate(s)
5.6	P3	distrito* industrial*	industrial district(s)
5.6	P3	parque* industrial*	industrial park(s)
5.6	P3	polo* de atividade*	activity hub(s)
5.6	P3	polo* de crescimento*	growth pole(s)
5.6	P3	polo* de desenvolvimento*	development pole(s)
5.6	P3	polo* de emprego*	employment hub(s)
5.6	P3	polo* de indústria*	industrial hub(s)
5.6	P3	polo* estratégico* de desenvolvimento	strategic development hub(s)
5.6	P3	zona* industrial*	industrial zone(s)
5.6	P4	diversificação da* atividade* industrial*	diversification of industrial activity/activities
5.6	P4	diversificação da base produtiva	diversification of the productive base
5.6	P4	diversificação da economia	diversification of the economy
5.6	P4	diversificação da matriz econômica	diversification of the economic matrix
5.6	P4	diversificação da produção	diversification of production
5.6	P4	diversificação econômica	economic diversification
5.6	P4	modernização da estrutura produtiva	modernisation of the productive structure
5.6	P5	atividade* produtiva*	productive activity/activities
5.6	P5	atividade* competitiva*	competitive activity/activities
5.6	P5	cadeia* produtiva*	production chain(s)
5.6	P5	setor* produtivo*	productive sector(s)
5.6	P6	economia* criativa*	creative economy/economies
5.6	P7	capacitação técnica	technical training
5.6	P7	geração de emprego*	job creation
5.6	P7	oportunidade* de trabalho	work opportunity/opportunities

Table A.5.6 - Continue

Source table	Subgroup	Portuguese search expression	English translation / gloss
5.6	P7	qualificação da mão-de-obra	workforce qualification
5.6	P7	trabalho e renda	work and income
5.6	E1	instalação de empresa*	establishment of company/companies
5.6	E1	atração de empresa*	attraction of company/companies
5.6	E1	incubadora* de empresa*	business incubator(s)
5.6	E1	nova* empresa*	new company/companies
5.6	E1	novο* negócio*	new business(es)
5.6	E1	startup*	startup(s)
5.6	E2	empreendedor(a)*	entrepreneur(s)
5.6	E2	empreendedorismo*	entrepreneurship
5.6	E2	empreendimento*	enterprise(s) / venture(s)
5.6	E2	microempreendedor*	micro-entrepreneur(s)
5.6	E3	atração de investimento* privado*	attraction of private investment(s)
5.6	E3	oportunidade* de negócio*	business opportunity/opportunities
5.6	E3	fortalecimento da* empresa*	strengthening of company/companies
5.6	E3	parceria* público-privada*	public-private partnership(s)
5.7	WB1	cidade mais justa	fairer city
5.7	WB1	direito à igualdade	right to equality
5.7	WB1	direito* social*	social right(s)
5.7	WB1	equidade econômica	economic equity
5.7	WB1	equidade social	social equity
5.7	WB1	igualdade de gênero	gender equality
5.7	WB1	igualdade racial	racial equality
5.7	WB1	justiça social	social justice
5.7	WB1	responsabilidade* social*	social responsibility/responsibilities
5.7	WB1	responsabilidade solidária	solidarity responsibility
5.7	WB1	socialmente justa*	socially just
5.7	WB2	reduzir a* desigualdade*	reduce inequality/inequalities
5.7	WB3	bem-estar	well-being
5.7	WB3	qualidade de vida	quality of life
5.7	WB4	convívio	social coexistence
5.7	WB4	convivência comunitária	community coexistence
5.7	WB5	cultura de paz	culture of peace
5.7	WB5	prevenção da violência	violence prevention
5.7	WB5	proteção social	social protection
5.7	WB5	cidade saudável	healthy city
5.7	WB5	saúde	health
5.7	WB5	segurança	security / safety
5.7	WB5	segurança alimentar	food security
5.7	WB6	ação* educacional*	educational action(s)
5.7	WB6	cidade educadora	educating city
5.7	WB6	educação de excelência	education of excellence
5.7	WB6	educação profissional	vocational education
5.7	WB6	ensino de tempo integral	full-time education
5.7	WB6	formação educacional	educational training
5.7	WB6	qualidade da educação	quality of education
5.7	WB6	qualidade de ensino	quality of teaching
5.7	WB7	inclusão social	social inclusion
5.7	WB7	inclusão sócio-territorial	socio-territorial inclusion

Table A.5.6 - Continue

Source table	Subgroup	Portuguese search expression	English translation / gloss
5.7	WB7	inclusiva*	inclusive
5.7	WB7	integração* social*	social integration(s)
5.7	WB8	direito à moradia	right to housing
5.7	WB8	programa* habitacional*	housing programme(s)
5.7	WB8	redução do* déficit* habitacional*	reduction of the housing deficit(s)
5.7	WB8	reduzir o* déficit* habitacional*	reduce the housing deficit(s)
5.7	WB9	direito à cidade	right to the city
5.7	WB9	direito universal à cidade	universal right to the city
5.7	L1	arborização urbana	urban tree planting
5.7	L1	arborização viária	street tree planting
5.7	L2	ecoparque*	eco-park(s)
5.7	L2	ecoponto*	eco-point(s) / waste drop-off point(s)
5.7	L2	espaço* verde*	green space(s)
5.7	L3	área* de lazer	leisure area(s)
5.7	L3	estabelecimento de praça*	establishment of square(s)
5.7	L3	parque* linear*	linear park(s)
5.7	L3	parque* municipal*	municipal park(s)
5.7	L3	parque* urbano*	urban park(s)
5.7	L3	recreação	recreation
5.7	L4	habitabilidade	habitability
5.7	L4	habitação de interesse social	social-interest housing
5.7	L4	habitação digna	decent housing
5.7	L4	habitação social	social housing
5.7	L4	habitação popular	popular housing / low-income housing
5.7	L4	moradia* adequada*	adequate dwelling(s)
5.7	L4	moradia* digna*	decent dwelling(s)
5.7	L5	investir em infraestrutura	invest in infrastructure
5.7	L5	investimento* em infraestrutura	infrastructure investment(s)
5.7	L6	enterramento da* fiação*	undergrounding of wiring/cables
5.7	L6	iluminação pública	public lighting
5.7	L7	lixeira* inteligente*	smart bin(s)
5.7	L7	iluminação inteligente	smart lighting
5.7	L7	bueiro* inteligente*	smart storm drain(s)
5.7	L7	hidrômetro* inteligente*	smart water meter(s)
5.7	L8	banheiro* público*	public toilet(s)
5.7	L8	equipamento* comunitário*	community facility/facilities
5.7	L8	equipamento* público*	public facility/facilities
5.7	L8	equipamento* social*	social facility/facilities
5.7	L8	equipamento* para terceira idade	facility/facilities for older people
5.7	L9	requalificação de bairro*	neighbourhood regeneration
5.7	L9	requalificação urbana	urban regeneration
5.7	L9	requalificação de praça*	regeneration of square(s)
5.7	L10	edifício* inteligente*	smart building(s)
5.7	L10	edifício* verde*	green building(s)
5.7	L10	telhado* verde*	green roof(s)
5.7	L11	feira* de artesanato	craft fair(s)
5.7	L11	horta* comunitária*	community garden(s)
5.8	ES1	melhoria do meio ambiente	improvement of the environment
5.8	ES1	qualificação ambiental	environmental enhancement

Table A.5.6 - Continue

Source table	Subgroup	Portuguese search expression	English translation / gloss
5.8	ES2	preservação ambiental	environmental preservation
5.8	ES2	preservação do meio ambiente	preservation of the environment
5.8	ES2	preservação dos mananciais	preservation of water sources
5.8	ES2	preservação dos recursos naturais	preservation of natural resources
5.8	ES2	proteção ambiental	environmental protection
5.8	ES2	proteção dos recursos naturais	protection of natural resources
5.8	ES2	conservação ambiental	environmental conservation
5.8	ES3	educação ambiental	environmental education
5.8	ES4	recuperação ambiental	environmental recovery
5.8	ES4	recuperação de áreas degradadas	recovery of degraded areas
5.8	ES4	resiliência	resilience
5.8	ES4	reflorestamento	reforestation
5.8	ES4	tratamento de efluentes	effluent treatment
5.8	ES5	reciclagem	recycling
5.8	ES5	reciclável*	recyclable
5.8	ES5	renovável*	renewable
5.8	ES5	reutilizável*	reusable
5.8	ES5	separação do lixo	waste separation
5.8	ES5	separação absoluta dos resíduos	absolute separation of waste
5.8	ES5	separação dos resíduos	waste separation
5.8	ES5	coleta seletiva	selective waste collection
5.8	ES6	reuso da(e) água	water reuse
5.8	ES6	drenagem urbana	urban drainage
5.8	ES7	desenho urbano sustentável	sustainable urban design
5.8	ES8	área* protegida*	protected area(s)
5.8	ES8	biodiversidade	biodiversity
5.8	ES8	corredor* de integração ecológica	ecological integration corridor(s)
5.8	ES8	corredor* ecológico*	ecological corridor(s)
5.8	ES8	corredor* verde*	green corridor(s)
5.8	ES9	ecologicamente equilibrado	ecologically balanced
5.8	ES9	ecossistema*	ecosystem(s)
5.8	ES9	equilíbrio ecológico	ecological balance
5.8	ES10	área* verde*	green area(s)
5.8	ES10	parede* verde*	green wall(s)
5.8	ES11	eficiência energética	energy efficiency
5.8	ES12	energia* alternativa*	alternative energy/energies
5.8	ES12	energia* limpa*	clean energy/energies
5.8	ES12	energia* renovável*	renewable energy/energies
5.8	ES12	fonte* limpa*	clean source(s)
5.8	ES12	fonte* renovável*	renewable source(s)
5.8	ES13	eólica*	wind energy / wind
5.8	ES13	solar*	solar energy / solar
5.8	ES14	ambientalmente sustentável*	environmentally sustainable
5.8	ES14	sustentabilidade ambiental	environmental sustainability
5.8	ES14	sustentabilidade urbano-ambiental	urban-environmental sustainability
5.8	ES14	sustentável* ambientalmente	environmentally sustainable
5.8	ES15	sustentabilidade da cidade	sustainability of the city
5.8	ES15	sustentabilidade urbana	urban sustainability
5.8	ES15	construção* sustentável*	sustainable construction(s)
5.8	ES16	conforto climático	climatic comfort

Table A.5.6 - Continue

Source table	Subgroup	Portuguese search expression	English translation / gloss
5.8	ES16	redução de(as) emissão*	reduction of emission(s)
5.8	ES16	redução* de poluentes	reduction of pollutants
5.8	ES16	reduzir* as emissões	reduce emissions
5.8	UM1	transporte* sustentável*	sustainable transport
5.8	UM2	transporte* coletivo*	collective transport
5.8	UM2	transporte* público*	public transport
5.8	UM2	transporte* integrado*	integrated transport
5.8	UM3	ferroviário*	railway / rail
5.8	UM3	monotrilhos	monorails
5.8	UM3	metrô*	metro(s)
5.8	UM3	BRT*	BRT system(s)
5.8	UM3	trem*	train(s)
5.8	UM3	VLP*	VLP system(s)
5.8	UM3	VLT*	VLT system(s) / light rail
5.8	UM4	mobilidade da população	population mobility
5.8	UM4	mobilidade e transporte	mobility and transport
5.8	UM4	mobilidade urbana	urban mobility
5.8	UM5	plano de mobilidade	mobility plan
5.8	UM5	política* de mobilidade	mobility policy/policies
5.8	UM6	mobilidade inclusiva	inclusive mobility
5.8	UM6	transporte* solidário*	solidarity transport
5.8	UM7	sistema* integrado* de mobilidade	integrated mobility system(s)
5.8	UM7	corredor* de ônibus	bus corridor(s)
5.8	UM7	sistema* subterrâneo*	underground system(s)
5.8	UM7	sistema* de mobilidade	mobility system(s)
5.8	UM7	terminal* de integração	integration terminal(s)
5.8	UM8	bicicletário*	bicycle parking facility/facilities
5.8	UM8	ciclofaixa*	cycle lane(s)
5.8	UM8	ciclomobilidade	cycle mobility
5.8	UM8	ciclopista*	cycle track(s)
5.8	UM8	ciclorrota*	cycle route(s)
5.8	UM8	ciclovário(a)*	cycling-related
5.8	UM8	ciclovía*	cycleway(s) / bicycle lane(s)
5.8	UM9	controle de semáforo*	traffic light control
5.8	UM9	controle de tráfego	traffic control
5.8	UM9	semafórico(a)*	traffic-light-related
5.8	UM9	sinalização visual	visual signage
5.8	UM9	controle* inteligente*	smart control(s)
5.8	UM10	parada* de ônibus inteligente*	smart bus stop(s)
5.8	UM10	semáforo* inteligente*	smart traffic light(s)
5.8	A1	acessibilidade de(para) pedestres	accessibility for pedestrians
5.8	A1	acessibilidade de(para) pessoas	accessibility for people
5.8	A1	acessibilidade universal	universal accessibility
5.8	A1	acessibilidade urbana	urban accessibility
5.8	A2	aterro* sanitário*	sanitary landfill(s)
5.8	A2	projeto* de esgotamento	sewerage project(s)
5.8	A2	saneamento ambiental	environmental sanitation
5.8	A2	saneamento básico	basic sanitation
5.9	G1	audiência* pública*	public hearing(s)

Table A.5.6 - Continue

Source table	Subgroup	Portuguese search expression	English translation / gloss
5.9	G1	consulta* pública*	public consultation(s)
5.9	G1	controle social	social control
5.9	G1	debate*	debate(s)
5.9	G1	plebiscito*	plebiscite(s)
5.9	G1	referendo*	referendum(s)
5.9	G2	conselho da cidade	city council / council of the city
5.9	G2	conselho* municipal*	municipal council(s)
5.9	G2	conselho* regional*	regional council(s)
5.9	G3	iniciativa popular	popular initiative
5.9	G3	mobilização* comunitária*	community mobilisation(s)
5.9	G3	participação da população	participation of the population
5.9	G3	participação da sociedade	participation of society
5.9	G3	participação direta dos cidadãos	direct citizen participation
5.9	G3	participação efetiva da sociedade	effective participation of society
5.9	G3	participativa	participatory
5.9	G3	participação popular	popular participation
5.9	G3	participação social	social participation
5.9	G3	engajados(as)	engaged
5.9	G4	democracia comunitária	community democracy
5.9	G4	democracia participativa	participatory democracy
5.9	G4	descentralizada*	decentralised
5.9	G4	gestão democrática	democratic management
5.9	G4	sistema democrático e participativo	democratic and participatory system
5.9	G5	acesso à informação	access to information
5.9	G5	sistema* municipal* de informações	municipal information system(s)
5.9	G5	transparência	transparency
5.9	G6	governança	governance
5.9	PL1	gestão de processos	process management
5.9	PL1	gestão pública de qualidade	quality public management
5.9	PL1	gestão inovadora	innovative management
5.9	PL1	gestão plena compartilhada	fully shared management
5.9	PL2	planejamento e gestão	planning and management
5.9	PL2	planejamento integrado	integrated planning
5.9	PL2	planejamento municipal	municipal planning
5.9	PL2	planejamento urbano	urban planning
5.9	PL3	plano plurianual	multi-year plan
5.9	PL3	plano* setorial*	sectoral plan(s)
5.9	PL3	plano* especial* de urbanização	special urbanisation plan(s)
5.10	T1	científico-tecnológico	scientific-technological
5.10	T1	técnico-científico(a)	technical-scientific
5.10	T1	tecnologia*	technology/technologies
5.10	T1	tecnológico(a)*	technological
5.10	T2	aplicativo*	application(s) / app(s)
5.10	T2	informatização	computerisation
5.10	T2	processamento* digital*	digital processing
5.10	T2	processo* tecnológico*	technological process(es)
5.10	T2	digitalizar	to digitise
5.10	T2	digitalização*	digitisation
5.10	T2	sistema de registros online	online records system

Table A.5.6 - Continue

Source table	Subgroup	Portuguese search expression	English translation / gloss
5.10	T2	informatizado(a)*	computerised
5.10	T2	telemática	telematics
5.10	T3	hardware	hardware
5.10	T3	software*	software
5.10	T3	robótica	robotics
5.10	T3	inteligência artificial	artificial intelligence
5.10	T3	realidade aumentada	augmented reality
5.10	T3	telemedicina	telemedicine
5.10	T4	bicicleta* elétrica*	electric bicycle(s)
5.10	T4	carro* conectado*	connected car(s)
5.10	T4	carro* elétrico*	electric car(s)
5.10	T4	drone*	drone(s)
5.10	T4	bilhetagem eletrônica	electronic ticketing
5.10	T4	sensoriamento eletrônico	electronic sensing
5.10	T5	sistema* inteligente*	smart system(s)
5.10	RD1	centro* de pesquisa	research centre(s)
5.10	RD1	ciência e tecnologia	science and technology
5.10	RD1	científico(a)*	scientific
5.10	RD2	banco* de dados	database(s)
5.10	RD2	big data	big data
5.10	RD2	sistema* de informação*	information system(s)
5.10	RD2	sistema integrado de informação*	integrated information system(s)
5.10	C1	conectividade	connectivity
5.10	C1	internet	internet
5.10	C1	inclusão digital	digital inclusion
5.10	C1	wi-fi	Wi-Fi
5.10	I1	inovação*	innovation(s)
5.10	I1	inovador(a)*	innovative
5.10	I1	inovativo(a)*	innovative
5.11	UB1	cidade* sustentável*	sustainable city/cities
5.11	UB1	município* sustentável*	sustainable municipality/municipalities
5.11	UB2	cidade* inteligente*	smart city/cities
5.11	UB2	zona* urbana* inteligente*	smart urban zone(s)
5.11	UB2	smart city*	smart city/cities
5.11	UB3	cidade* resiliente*	resilient city/cities
5.11	UB4	cidade* conectada*	connected city/cities
5.11	UB5	cidade* criativa*	creative city/cities
5.11	UB6	cidade da ciência	city of science
5.11	UB7	cidade* tecnológica*	technological city/cities
5.11	UB8	cidade* digital*	digital city/cities
5.11	UB9	cidade* verde*	green city/cities
5.11	UB10	cidade* do futuro	city/cities of the future

5.11 UB11 metrópole* inovadora* innovative metropolis/metropolises

Source: Author's own elaboration based on the keyword dictionary presented in Tables 5.6–5.11. Note: This table provides English translations or glosses of the Portuguese search expressions used in the keyword dictionary. The terms were searched in Portuguese, since the municipal Master Plans analysed in this study were written in Portuguese. The English translations are provided only to facilitate interpretation by non-Portuguese-speaking readers and were not used as search terms. The “Source Table” and “Subgroup” columns identify the corresponding classification in Tables 5.6–5.11. The asterisk (*) indicates that singular and plural forms were considered. The element “(a)” indicates that gender variations were considered.

Table A.5.7 - Frequency and proportion of municipalities citing Urban Brands subgroups in master plans, by year (2010–2020)

Year	Total	UB1		UB2		UB3		UB4		UB5	
		Num.	Prop. (%)	Num.	Prop. (%)	Num.	Prop. (%)	Num.	Prop. (%)	Num.	Prop. (%)
2010	97	20	20.62	0	0.00	0	0.00	0	0.00	0	0.00
2011	101	31	30.69	0	0.00	0	0.00	0	0.00	1	0.99
2012	114	40	35.09	0	0.00	0	0.00	1	0.88	0	0.00
2013	87	26	29.89	0	0.00	0	0.00	0	0.00	0	0.00
2014	93	22	23.66	0	0.00	0	0.00	0	0.00	0	0.00
2015	78	35	44.87	1	1.28	0	0.00	0	0.00	0	0.00
2016	133	47	35.34	0	0.00	2	1.50	0	0.00	1	0.75
2017	108	31	28.70	2	1.85	1	0.93	0	0.00	0	0.00
2018	134	65	48.51	4	2.99	1	0.75	0	0.00	2	1.49
2019	166	71	42.77	4	2.41	2	1.20	1	0.60	0	0.00
2020	125	59	47.20	4	3.20	1	0.80	0	0.00	0	0.00
Total	1,236	447		15		7		2		4	

Year	Total	UB6		UB7		UB8		UB9		UB10		UB11	
		Num.	Prop. (%)	Num.	Prop. (%)	Num.	Prop. (%)	Num.	Prop. (%)	Num.	Prop. (%)	Num.	Prop. (%)
2010	97	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
2011	101	0	0.00	1	0.99	1	0.99	0	0.00	0	0.00	0	0.00
2012	114	0	0.00	0	0.00	1	0.88	0	0.00	0	0.00	0	0.00
2013	87	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
2014	93	0	0.00	0	0.00	1	1.08	2	2.15	0	0.00	0	0.00
2015	78	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
2016	133	0	0.00	1	0.75	0	0.00	0	0.00	0	0.00	0	0.00
2017	108	0	0.00	1	0.93	2	1.85	0	0.00	0	0.00	0	0.00
2018	134	2	1.49	0	0.00	2	1.49	0	0.00	1	0.75	1	0.75
2019	166	0	0.00	1	0.60	0	0.00	1	0.60	0	0.00	0	0.00
2020	125	0	0.00	0	0.00	1	0.80	0	0.00	0	0.00	0	0.00
Total	1,236	2		4		8		3		1		1	

Source: Author's own elaboration based on municipal Master Plans.

Notes: (i) “Num.” refers to the number of municipalities whose master plans include at least one keyword associated with each Urban Brands subgroup (UB1–UB11). (ii) “Prop.” corresponds to the share of municipalities citing each subgroup relative to the total number of master plans enacted or revised in the respective year (“Total”). (iii) Each subgroup is coded as 1 when at least one keyword is identified in the document, and 0 otherwise. (iv) The classification of keywords into subgroups follows the taxonomy defined in Table 5.11.

A.6.1 Documentation of Master Plans and manual checks

Table A.6.1 - Document access requests for previous Master Plan versions

Municipality	State	Updated law identified	Previous law requested	Access request	Response	Final decision
Ibicoara	Bahia	Law n°. 191/2013	Law n°. 096/2008	E-mail sent to municipal administration	No response	Excluded
Tapiraí	São Paulo	Complementary Law n°. 087/2016	Complementary Law n°. 049/2011	E-mail sent to municipal administration	No response	Excluded
Nioaque	Mato Grosso do Sul	Updated Master Plan identified	Previous version requested	E-mail sent to municipal administration	Document received	Included

Source: Author's own elaboration based on municipal institutional repositories and formal document access requests.

Note: The table reports cases in which the immediately previous Master Plan version was not available in municipal institutional repositories. Formal requests were sent to the corresponding municipal administrations. Personal names, e-mail addresses and signatures are omitted for privacy reasons.

Table A.6.2 - Master Plan documents manually checked for high textual similarity

Municipality	State	Event	Year	Document Link
Lindóia do Sul	Santa Catarina	Adoption	2013	< https://planosdiretoresmunicbrasil.neocities.org/4209854_SC_Lind%C3%B3ia%20do%20Sul.pdf >
Arabutã	Santa Catarina	Adoption	2013	< https://planosdiretoresmunicbrasil.neocities.org/4201273_SC_Arabut%C3%A3.pdf >
Ipira	Santa Catarina	Adoption	2013	< https://planosdiretoresmunicbrasil.neocities.org/4207601_SC_Ipira.pdf >
Pedro Gomes	Mato Grosso do Sul	Adoption	2016	< https://planosdiretoresmunicbrasil.neocities.org/5006408_MS_Pedro%20Gomes.pdf >
Figueirão	Mato Grosso do Sul	Adoption	2017	< https://planosdiretoresmunicbrasil.neocities.org/5003900_MS_Figueir%C3%A3o.pdf >
Santos	São Paulo	Revision	2018	< https://planosdiretoresmunicbrasil.neocities.org/3548500_SP_Santos.pdf >
São Vicente	São Paulo	Revision	2018	< https://planosdiretoresmunicbrasil.neocities.org/3551009_SP_S%C3%A3o%20Vicente.pdf >
São Manoel do Paraná	Paraná	Revision	2020	< https://planosdiretoresmunicbrasil.neocities.org/4125555_PR_S%C3%A3o%20Manoel%20do%20Paran%C3%A1.pdf >
Tapejara	Paraná	Revision	2020	< https://planosdiretoresmunicbrasil.neocities.org/4126801_PR_Tapejara.pdf >
Vitor Meireles	Santa Catarina	Revision	2020	< https://planosdiretoresmunicbrasil.neocities.org/4219358_SC_Vitor%20Meireles.pdf >
Ibirama	Santa Catarina	Revision	2019	< https://planosdiretoresmunicbrasil.neocities.org/4206900_SC_Ibirama.pdf >
Chapadão do Lageado	Santa Catarina	Revision	2020	< https://planosdiretoresmunicbrasil.neocities.org/4204194_SC_Chapad%C3%A3o%20do%20Lageado.pdf >

Table A.6.2 - Continued

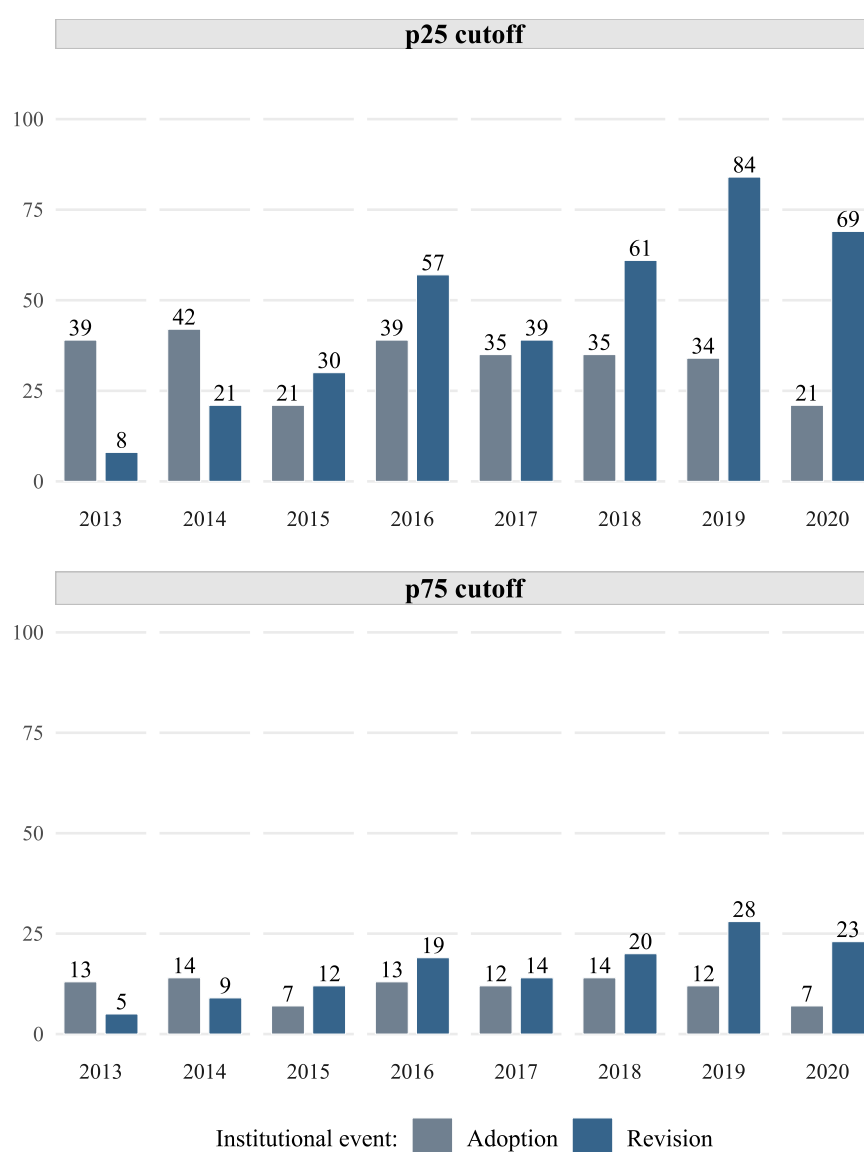
Municipality	State	Event	Year	Document Link
Petrolândia	Santa Catarina	Revision	2019	< https://planosdiretoresmunicbrasil.neocities.org/4212700_SC_Petrol%C3%A2ndia.pdf >

Source: Author's own elaboration based on municipal Master Plan documents collected from municipal institutional repositories and the database constructed for this study.

Note: The table reports Master Plan documents used in the manual verification of cases with high textual similarity between municipalities located in the same Immediate Geographic Region. Adoption refers to the first legal establishment of a municipal Master Plan, while Revision refers to the approval of a new or amended Master Plan when a previous plan was already in force. Document links correspond to the versions consulted during the manual checking procedure.

A.6.2 Distribution of treatments and average trajectories by cohort

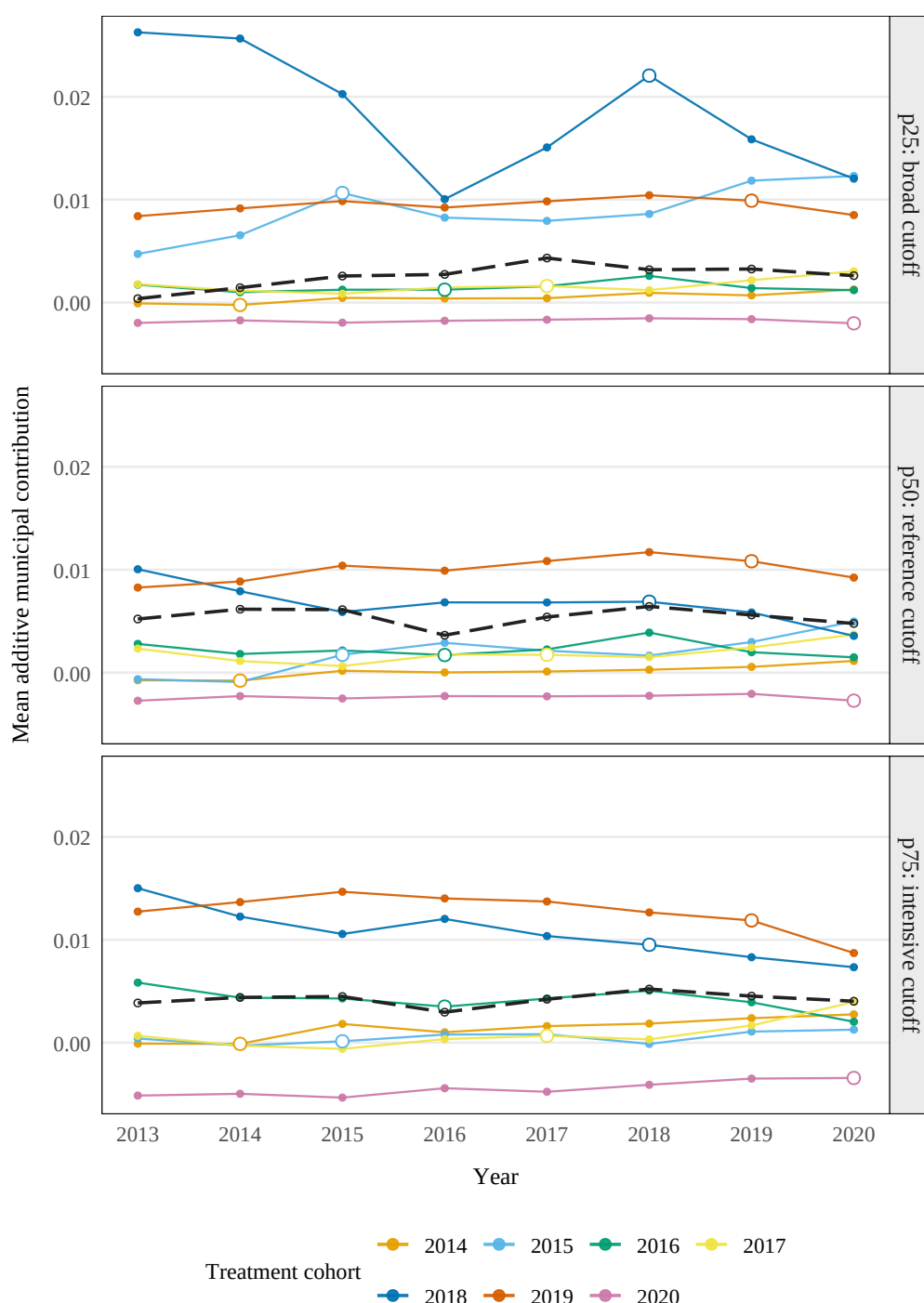
Figure A.6.1 - Smart City treated cohorts under alternative treatment cutoffs, 2013-2020



Source: Author's own elaboration based on IBGE (2021, 2022b) and the municipal Master Plan database constructed for this study.

Note: The figure reports the number of eligible municipalities classified as treated under the *p25* and *p75* Smart City treatment rules by institutional event and year. Adoption refers to municipalities that initially adopted a Master Plan, while Revision refers to municipalities that revised a previously existing Master Plan. The *p25* cutoff represents a broader treatment definition, and the *p75* cutoff identifies intensive Smart City incorporation. Under each cutoff, treated municipalities are those whose Smart City citation index is positive and equal to or above the corresponding percentile cutoff defined by event type and year. The 2013 treated cohorts are shown for descriptive purposes but excluded from the main DiD estimations because no pre-treatment observation is available within the 2013–2020 outcome panel. The never-treated comparison groups contain 82 municipalities in Adoption and 147 in Revision under *p25*, and 256 municipalities in Adoption and 386 in Revision under *p75*. The same vertical scale is used in both panels to facilitate comparison.

Figure A.6.2 - Annual mean of the additive municipal contribution by treatment cohort and Smart City cutoff, Adoption

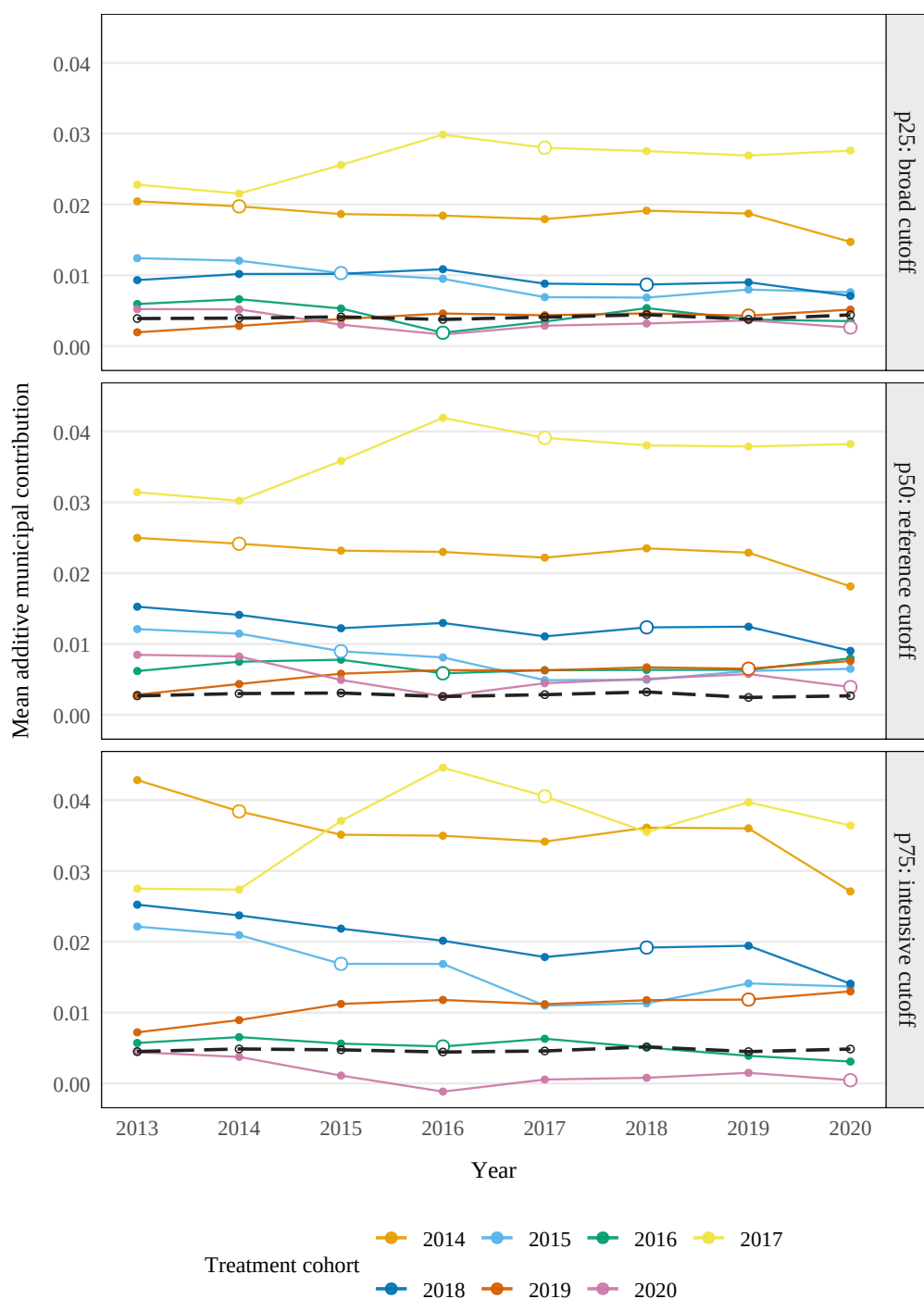


Lines report annual means by treatment cohort. The dashed black line reports the never-treated group. Hollow markers indicate the treatment year for each treated cohort.

Source: Author's own elaboration.

Note: The figure reports annual means of the municipal additive contribution to the intra-regional component of GDP per capita inequality, computed using GE(1), by treatment cohort and Smart City cutoff. The dashed black line reports the mean for eligible never-treated municipalities. Hollow markers indicate the treatment year for each treated cohort. Municipalities in first-year treated cohorts are excluded because no pre-treatment observation is available within the 2013–2020 outcome panel. The figure is descriptive and does not report treatment effects.

Figure A.6.3 - Annual mean of the additive municipal contribution by treatment cohort and Smart City cutoff, Revision

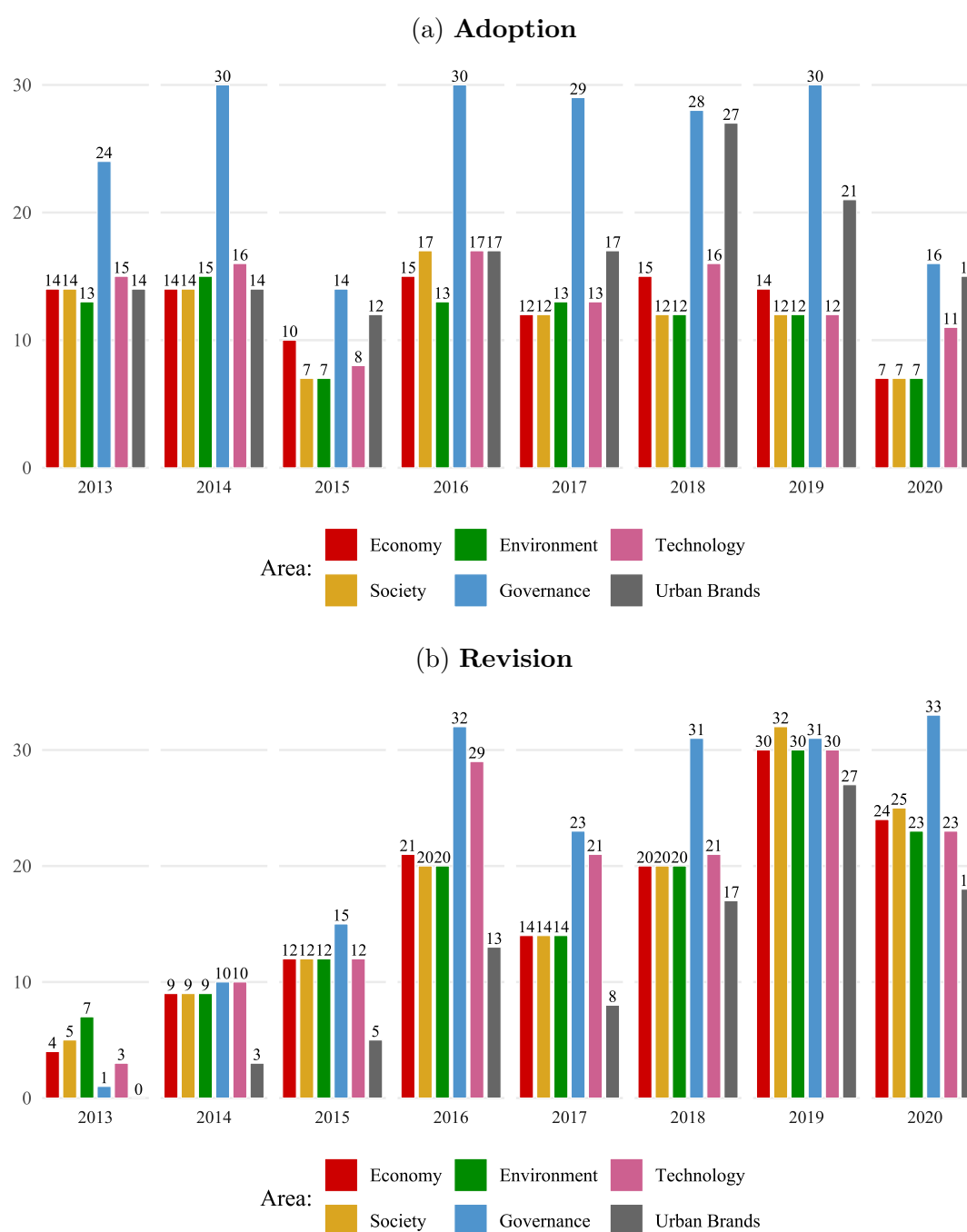


Lines report annual means by treatment cohort. The dashed black line reports the never-treated group. Hollow markers indicate the treatment year for each treated cohort.

Source: Author's own elaboration.

Note: The figure reports annual means of the municipal additive contribution to the intra-regional component of GDP per capita inequality, computed using GE(1), by treatment cohort and Smart City cutoff. The dashed black line reports the mean for eligible never-treated municipalities. Hollow markers indicate the treatment year for each treated cohort. Municipalities in first-year treated cohorts are excluded because no pre-treatment observation is available within the 2013–2020 outcome panel. The figure is descriptive and does not report treatment effects.

Figure A.6.4 - Treated cohorts by Smart City dimension and institutional event under intensive cutoffs, 2013–2020



Source: Author's own elaboration based on IBGE (2021, 2022b) and the municipal Master Plan database constructed for this study.

Note: The figure reports the number of eligible municipalities classified as treated by Smart City dimension, institutional event, and year. Panel (a) refers to Adoption, and Panel (b) refers to Revision. The $p75$ cutoff is used for Economy, Society, Environment, Governance, and Technology. For Urban Brands, the $p80$ cutoff is used because the $p75$ threshold still includes zero citation values. Treated municipalities are those whose citation index in the corresponding dimension is positive and equal to or above the cutoff defined by event type and year. The 2013 treated cohorts are shown for descriptive purposes but excluded from the main DiD estimations because no pre-treatment observation is available within the 2013–2020 outcome panel.

A.6.3 Complementary estimates, sensitivity analyses and diagnostics

Table A.6.3 - Average treatment effects under the broad $p25$ Smart City cutoff

Event	Specification	Estimate	SE	P-value	95% CI	Pre-test p-value	N obs.	Munics
Adoption	Baseline	-0.0002	0.001	0.899	[-0.0027; 0.0024]	0.392	2472	309
Adoption	Log(Pop)	-0.0002	0.002	0.873	[-0.0031; 0.0027]	0.321	2472	309
Adoption	Metropolitan Region	-0.0002	0.001	0.867	[-0.0029; 0.0025]	0.390	2472	309
Adoption	REGIC	-0.0002	0.001	0.855	[-0.0029; 0.0024]	0.546	2472	309
Revision	Baseline	-0.0018**	0.001	0.049	[-0.0036; -0.0000]	0.005	4064	508
Revision	Log(Pop)	-0.0010	0.001	0.324	[-0.0031; 0.0010]	0.026	4064	508
Revision	Metropolitan Region	-0.0017*	0.001	0.088	[-0.0036; 0.0003]	0.007	4064	508
Revision	REGIC	-0.0016	0.001	0.126	[-0.0037; 0.0005]	0.012	4064	508

Source: Author's own elaboration.

Note: The table reports average treatment effects for the composite Smart City index under the broad $p25$ cutoff. Event refers to the institutional event. Munics refers to the number of municipalities. The outcome is the municipal additive contribution to the intra-regional component of GDP per capita inequality, computed using GE(1), the Theil T index. Estimates are obtained separately by institutional event using eligible never-treated municipalities as the comparison group. Baseline refers to the model without covariates; Log(Pop) controls for the logarithm of municipal population; Metropolitan Region controls for municipal membership in a Metropolitan Region; REGIC controls for urban hierarchy categories. Municipalities in first-year treated cohorts are excluded because no pre-treatment observation is available within the 2013–2020 outcome panel. The number of observations may vary across cutoffs because treatment status and first-year cohort exclusions depend on the corresponding treatment rule. The pre-test p-value refers to the joint Wald test for the null hypothesis that all pre-treatment group-time effects are equal to zero. SE denotes standard error. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table A.6.4 - Event-study estimates underlying the main dynamic specification

Institutional event	Event time	Period	Estimate	SE	p-value	95% CI
Adoption	-5	Pre	-0.0004	0.001	0.755	[-0.0028; 0.0020]
Adoption	-4	Pre	-0.0005	0.002	0.722	[-0.0036; 0.0025]
Adoption	-3	Pre	-0.0010	0.001	0.226	[-0.0027; 0.0006]
Adoption	-2	Pre	-0.0002	0.001	0.698	[-0.0015; 0.0010]
Adoption	-1	Pre	-0.0005	0.001	0.400	[-0.0018; 0.0007]
Adoption	0	Post	-0.0007*	0.000	0.088	[-0.0016; 0.0001]
Adoption	1	Post	-0.0007	0.001	0.388	[-0.0025; 0.0010]
Adoption	2	Post	-0.0001	0.001	0.913	[-0.0024; 0.0022]
Adoption	3	Post	0.0006	0.001	0.693	[-0.0022; 0.0034]
Adoption	4	Post	-0.0000	0.002	0.996	[-0.0041; 0.0041]
Adoption	5	Post	0.0017	0.003	0.597	[-0.0047; 0.0082]
Adoption	6	Post	0.0027	0.005	0.595	[-0.0072; 0.0125]
Revision	-5	Pre	-0.0004	0.002	0.809	[-0.0036; 0.0028]

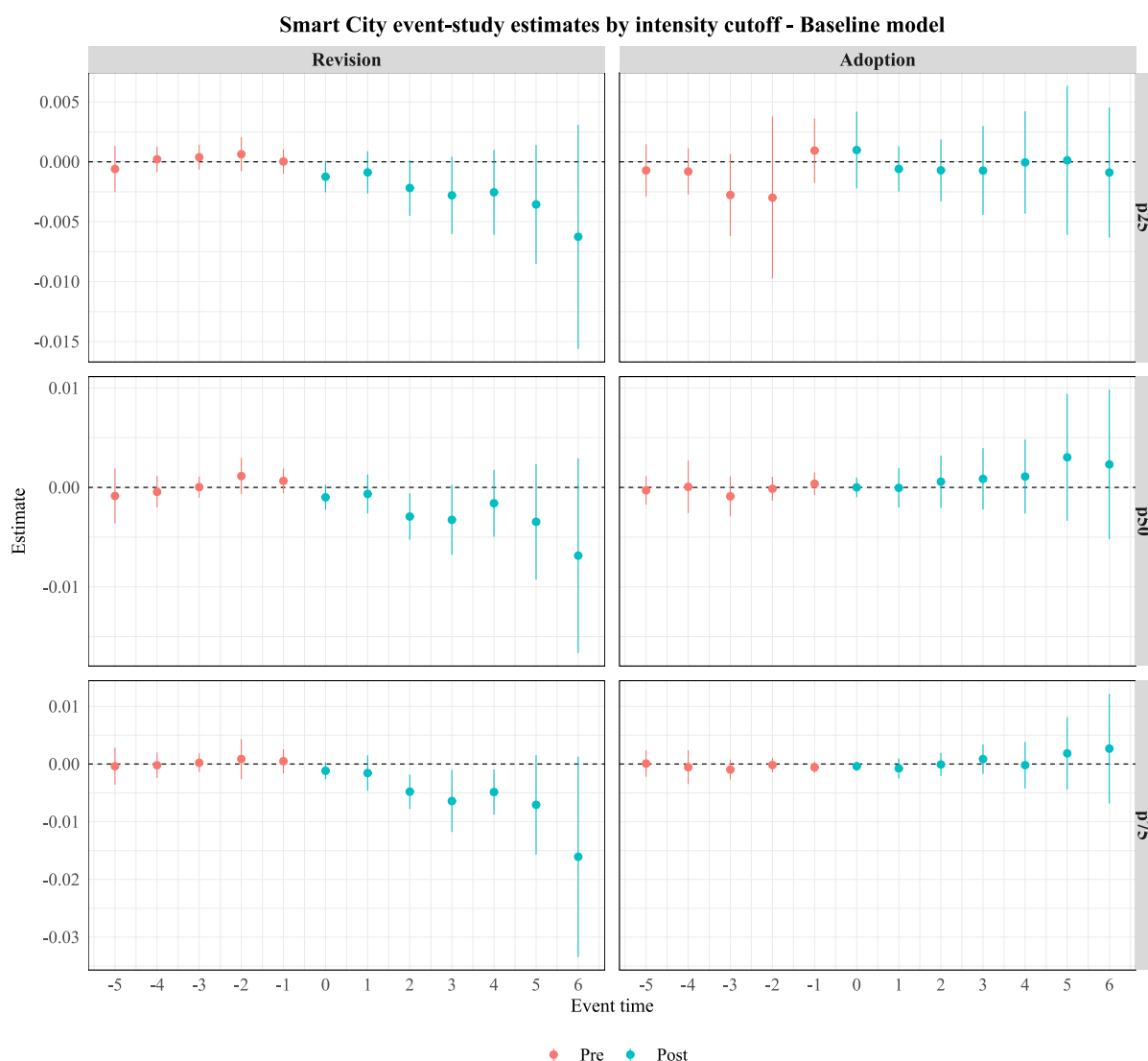
Table A.6.4 - Continued

Institutional event	Event time	Period	Estimate	SE	p-value	95% CI
Revision	-4	Pre	0.0000	0.001	0.998	[-0.0025; 0.0025]
Revision	-3	Pre	0.0006	0.001	0.499	[-0.0011; 0.0023]
Revision	-2	Pre	0.0011	0.002	0.558	[-0.0025; 0.0046]
Revision	-1	Pre	0.0006	0.001	0.515	[-0.0013; 0.0026]
Revision	0	Post	-0.0010	0.001	0.212	[-0.0026; 0.0006]
Revision	1	Post	-0.0011	0.002	0.483	[-0.0043; 0.0020]
Revision	2	Post	-0.0038**	0.002	0.014	[-0.0069; -0.0008]
Revision	3	Post	-0.0055*	0.003	0.083	[-0.0117; 0.0007]
Revision	4	Post	-0.0036*	0.002	0.092	[-0.0077; 0.0006]
Revision	5	Post	-0.0053	0.005	0.231	[-0.0141; 0.0034]
Revision	6	Post	-0.0111	0.009	0.217	[-0.0288; 0.0065]

Source: Author's own elaboration.

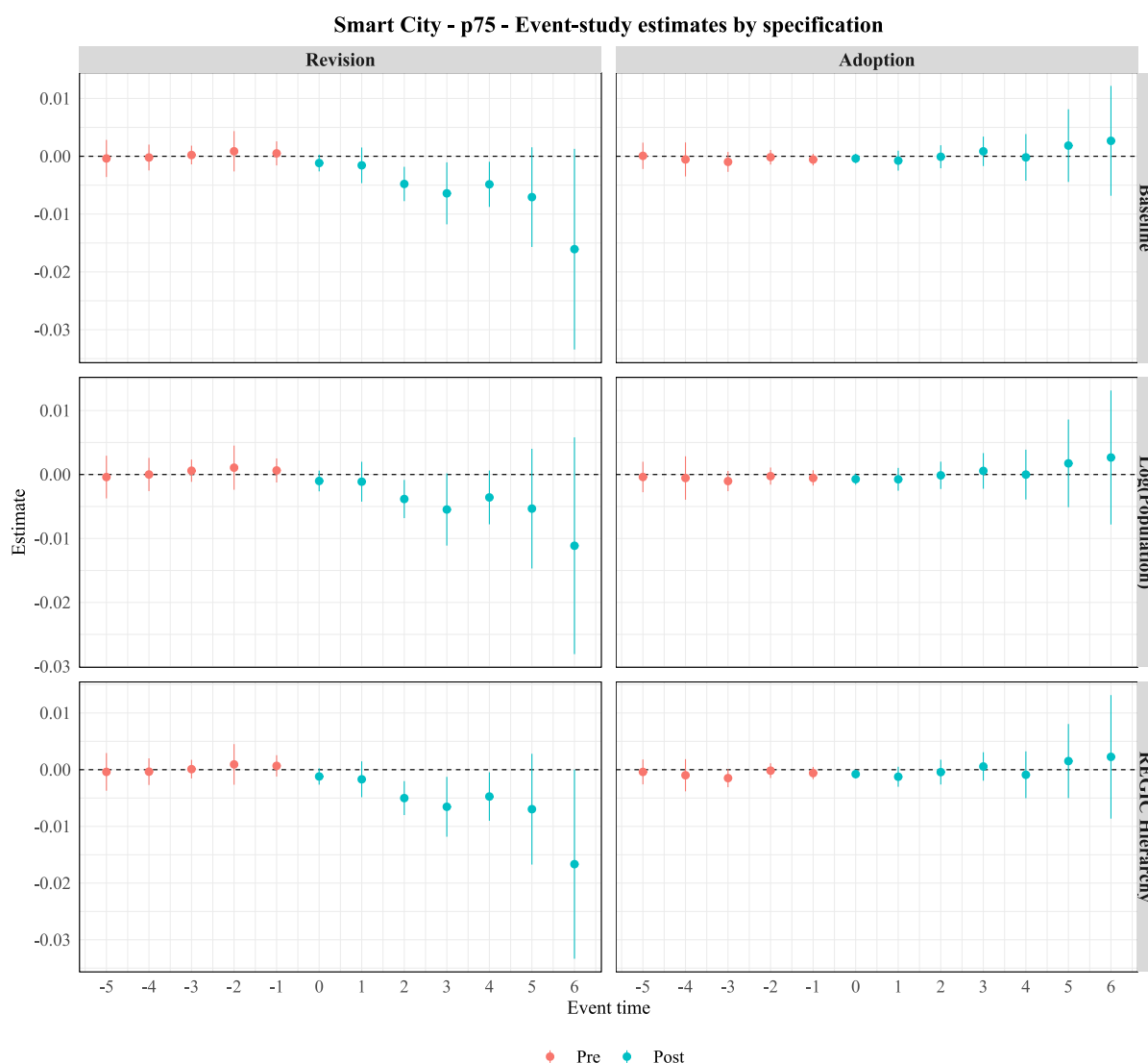
Note: The table reports the event-study coefficients underlying Figure 6.6. Estimates refer to the composite Smart City index under the $p75$ intensive cutoff, controlling for the logarithm of municipal population. The outcome is the municipal additive contribution to the intra-regional component of GDP per capita inequality, computed using GE(1), the Theil T index. Event time is defined relative to the year of treatment. The control group consists of eligible never-treated municipalities. Municipalities in first-year treated cohorts are excluded because no pre-treatment observation is available within the 2013–2020 outcome panel. SE denotes standard error, and 95% CI denotes the 95% confidence interval. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Figure A.6.5 - Event-study estimates by Smart City intensity cutoff, baseline model



Source: Author's own elaboration.

Note: The figure reports event-study estimates for the composite Smart City index under the *p25*, *p50*, and *p75* treatment cutoffs using the baseline specification. The outcome is the municipal additive contribution to the intra-regional component of GDP per capita inequality, computed using GE(1), the Theil T index. Rows identify the treatment cutoff, and columns identify the institutional event. The *p25* cutoff represents a broader treatment definition, *p50* is the reference cutoff, and *p75* identifies intensive incorporation. The control group consists of eligible never-treated municipalities. Municipalities in first-year treated cohorts are excluded because no pre-treatment observation is available within the 2013–2020 outcome panel. Dots report estimated effects, and vertical bars report 95% confidence intervals. Vertical scales are allowed to vary across panels to improve readability.

Figure A.6.6 - Event-study estimates under the $p75$ Smart City cutoff by specification

Source: Author's own elaboration.

Note: The figure reports event-study estimates for the composite Smart City index under the $p75$ intensive cutoff across alternative specifications. The outcome is the municipal additive contribution to the intra-regional component of GDP per capita inequality, computed using GE(1), the Theil T index. Rows identify the specification, and columns identify the institutional event. The baseline model includes no additional covariates; the conditional specifications control separately for the logarithm of municipal population and REGIC urban hierarchy. The control group consists of eligible never-treated municipalities. Municipalities in first-year treated cohorts are excluded because no pre-treatment observation is available within the 2013–2020 outcome panel. Dots report estimated effects, and vertical bars report 95% confidence intervals. Vertical scales are allowed to vary across panels to improve readability.

Table A.6.5 - Joint pre-treatment tests by Smart City cutoff and specification

Institutional event	Cutoff	Specification	Wald statistic	Degrees of freedom	p-value	N obs.	Munics
Adoption	$p25$	Baseline	22.138	21	0.392	2472	309
Adoption	$p25$	Log(Pop)	23.437	21	0.321	2472	309

Table A.6.5 - Continued

Institutional event	Cutoff	Specification	Wald statistic	Degrees of freedom	p-value	N obs.	Munics
Adoption	<i>p25</i>	Metropolitan Region	22.165	21	0.390	2472	309
Adoption	<i>p25</i>	REGIC	19.604	21	0.546	2472	309
Adoption	<i>p50</i>	Baseline	28.376	21	0.130	2576	322
Adoption	<i>p50</i>	Log(Pop)	29.447	21	0.104	2576	322
Adoption	<i>p50</i>	Metropolitan Region	24.689	21	0.261	2576	322
Adoption	<i>p50</i>	REGIC	23.304	21	0.328	2576	322
Adoption	<i>p75</i>	Baseline	31.880	21	0.060	2680	335
Adoption	<i>p75</i>	Log(Pop)	24.874	21	0.253	2680	335
Adoption	<i>p75</i>	Metropolitan Region	32.396	21	0.053	2680	335
Adoption	<i>p75</i>	REGIC	24.577	21	0.266	2680	335
Revision	<i>p25</i>	Baseline	41.119	21	0.005	4064	508
Revision	<i>p25</i>	Log(Pop)	35.260	21	0.026	4064	508
Revision	<i>p25</i>	Metropolitan Region	40.189	21	0.007	4064	508
Revision	<i>p25</i>	REGIC	38.304	21	0.012	4064	508
Revision	<i>p50</i>	Baseline	38.327	21	0.012	4064	508
Revision	<i>p50</i>	Log(Pop)	34.731	21	0.030	4064	508
Revision	<i>p50</i>	Metropolitan Region	35.579	21	0.024	4064	508
Revision	<i>p50</i>	REGIC	36.699	21	0.018	4064	508
Revision	<i>p75</i>	Baseline	33.198	21	0.044	4088	511
Revision	<i>p75</i>	Log(Pop)	28.237	21	0.134	4088	511
Revision	<i>p75</i>	Metropolitan Region	33.607	21	0.040	4088	511
Revision	<i>p75</i>	REGIC	30.449	21	0.083	4088	511

Source: Author's own elaboration.

Note: The table reports joint Wald tests for the null hypothesis that all pre-treatment group-time average treatment effects are equal to zero. Estimates refer to the composite Smart City index under the *p25*, *p50*, and *p75* treatment cutoffs. The outcome is the municipal additive contribution to the intra-regional component of GDP per capita inequality, computed using GE(1), the Theil T index. Baseline refers to the model without covariates; *Log(Pop)* controls for the logarithm of municipal population; Metropolitan Region controls for municipality membership in a Metropolitan Region; REGIC controls for urban hierarchy categories. Estimates are obtained separately by institutional event using eligible never-treated municipalities as the comparison group. Municipalities in first-year treated cohorts are excluded because no pre-treatment observation is available within the 2013–2020 outcome panel. The *p25* cutoff represents a broader treatment definition, *p50* is the reference cutoff, and *p75* identifies intensive incorporation. Munics refers to the number of municipalities.

Table A.6.6 - Cohort-specific average treatment effects under the *p75* Smart City cutoff

Institutional event	Specification	Cohort	Treated municipalities	Estimate	SE	p-value	95% CI
Adoption	Baseline	2014	14	0.0013	0.0031	0.6787	[-0.0049; 0.0075]
Adoption	Baseline	2015	7	0.0011	0.002	0.5886	[-0.0029; 0.0051]
Adoption	Baseline	2016	13	-0.0002	0.0019	0.898	[-0.0039; 0.0034]
Adoption	Baseline	2017	12	-0.0002	0.0014	0.8733	[-0.0030; 0.0026]
Adoption	Baseline	2018	14	-0.0023*	0.0013	0.0816	[-0.0050; 0.0003]
Adoption	Baseline	2019	12	-0.0014	0.0016	0.3761	[-0.0046; 0.0017]
Adoption	Baseline	2020	7	0.0006	0.0009	0.5281	[-0.0012; 0.0023]
Adoption	Log(Pop)	2014	14	0.0012	0.0032	0.6943	[-0.0050; 0.0075]
Adoption	Log(Pop)	2015	7	0.0011	0.0021	0.6053	[-0.0030; 0.0051]
Adoption	Log(Pop)	2016	13	-0.0004	0.002	0.841	[-0.0044; 0.0036]
Adoption	Log(Pop)	2017	12	-0.0002	0.0014	0.8799	[-0.0029; 0.0025]
Adoption	Log(Pop)	2018	14	-0.0026*	0.0014	0.0649	[-0.0054; 0.0002]
Adoption	Log(Pop)	2019	12	-0.0019	0.002	0.3235	[-0.0058; 0.0019]
Adoption	Log(Pop)	2020	7	0.0010	0.0011	0.3878	[-0.0012; 0.0031]
Adoption	REGIC	2014	14	0.0013	0.0032	0.6798	[-0.0049; 0.0075]
Adoption	REGIC	2015	7	0.0000	0.0024	0.9928	[-0.0047; 0.0047]
Adoption	REGIC	2016	13	-0.0009	0.0019	0.65	[-0.0047; 0.0029]
Adoption	REGIC	2017	12	0.0001	0.0014	0.9492	[-0.0027; 0.0029]
Adoption	REGIC	2018	14	-0.0031*	0.0017	0.0667	[-0.0064; 0.0002]
Adoption	REGIC	2019	12	-0.0028*	0.0016	0.0769	[-0.0059; 0.0003]
Adoption	REGIC	2020	7	0.0005	0.0013	0.7283	[-0.0021; 0.0031]
Revision	Baseline	2014	9	-0.0085	0.0061	0.1604	[-0.0204; 0.0034]
Revision	Baseline	2015	12	-0.0068	0.0053	0.1967	[-0.0172; 0.0035]
Revision	Baseline	2016	19	-0.0009	0.0015	0.5552	[-0.0037; 0.0020]
Revision	Baseline	2017	14	-0.0069	0.005	0.1699	[-0.0167; 0.0029]
Revision	Baseline	2018	20	-0.0005	0.001	0.5965	[-0.0025; 0.0014]
Revision	Baseline	2019	28	0.0012	0.0009	0.2194	[-0.0007; 0.0030]
Revision	Baseline	2020	23	-0.0014	0.0009	0.1161	[-0.0032; 0.0003]
Revision	Log(Pop)	2014	9	-0.0056	0.006	0.3445	[-0.0174; 0.0061]
Revision	Log(Pop)	2015	12	-0.0065	0.0048	0.1789	[-0.0160; 0.0030]
Revision	Log(Pop)	2016	19	-0.0004	0.0013	0.7455	[-0.0030; 0.0021]
Revision	Log(Pop)	2017	14	-0.0065	0.0049	0.188	[-0.0161; 0.0032]
Revision	Log(Pop)	2018	20	0.0002	0.0011	0.8652	[-0.0019; 0.0023]
Revision	Log(Pop)	2019	28	0.0012	0.001	0.2147	[-0.0007; 0.0032]
Revision	Log(Pop)	2020	23	-0.0012	0.0008	0.1385	[-0.0029; 0.0004]
Revision	REGIC	2014	9	-0.0094	0.0062	0.1334	[-0.0216; 0.0029]
Revision	REGIC	2015	12	-0.0066	0.0047	0.1621	[-0.0159; 0.0027]
Revision	REGIC	2016	19	-0.0009	0.0013	0.4987	[-0.0034; 0.0017]
Revision	REGIC	2017	14	-0.0071	0.0048	0.1378	[-0.0165; 0.0023]
Revision	REGIC	2018	20	-0.0001	0.001	0.9063	[-0.0020; 0.0018]
Revision	REGIC	2019	28	0.0010	0.001	0.3198	[-0.0010; 0.0030]
Revision	REGIC	2020	23	-0.0014	0.001	0.1573	[-0.0034; 0.0005]

Source: Author's own elaboration.

Note: The table reports cohort-specific average treatment effects for the composite Smart City index under the $p75$ intensive cutoff. Cohorts are defined by the year in which eligible municipalities meet the Smart City treatment rule. Baseline refers to the model without covariates; $\text{Log}(\text{Pop})$ controls for the logarithm of municipal population; REGIC controls for urban hierarchy categories. The outcome is the municipal additive contribution to the intra-regional component of GDP per capita inequality, computed using GE(1), the Theil T index. Estimates are obtained separately by institutional event using eligible never-treated municipalities as the comparison group.

Table A.6.7 - Heterogeneous average treatment effects by urban hierarchy and Smart City cutoff

Event	Cutoff	Model	Hierarchy	ATT	SE	p	95% CI	Pre-test p-value	Treated	Never
Adoption	$p25$	Base	High	0.0058	0.006	0.303	[-0.0052; 0.0168]	0.000	29	10
Adoption	$p25$	Base	Intermed.	-0.0013	0.002	0.535	[-0.0053; 0.0027]	0.038	48	15
Adoption	$p25$	Base	Local	-0.0009	0.002	0.640	[-0.0046; 0.0029]	0.705	150	57
Adoption	$p25$	Pop	High	0.0056	0.006	0.321	[-0.0054; 0.0166]	0.000	29	10
Adoption	$p25$	Pop	Intermed.	-0.0012	0.002	0.535	[-0.0050; 0.0026]	0.000	48	15
Adoption	$p25$	Pop	Local	-0.0010	0.002	0.637	[-0.0051; 0.0031]	0.601	150	57
Adoption	$p50$	Base	High	0.0003	0.005	0.946	[-0.0092; 0.0098]	0.000	22	17
Adoption	$p50$	Base	Intermed.	-0.0015	0.001	0.289	[-0.0043; 0.0013]	0.000	35	28
Adoption	$p50$	Base	Local	0.0013	0.002	0.462	[-0.0021; 0.0046]	0.030	94	126
Adoption	$p50$	Pop	High	0.0008	0.005	0.877	[-0.0094; 0.0111]	0.000	22	17
Adoption	$p50$	Pop	Intermed.	-0.0017	0.002	0.286	[-0.0048; 0.0014]	0.008	35	28
Adoption	$p50$	Pop	Local	0.0012	0.002	0.431	[-0.0018; 0.0042]	0.187	94	126
Adoption	$p75$	Base	High	-0.0043	0.003	0.163	[-0.0103; 0.0017]		14	25
Adoption	$p75$	Base	Intermed.	-0.0022	0.002	0.142	[-0.0051; 0.0007]		25	42
Adoption	$p75$	Base	Local	0.0018	0.002	0.302	[-0.0016; 0.0052]	0.000	40	189
Adoption	$p75$	Pop	High	-0.0031	0.002	0.204	[-0.0079; 0.0017]	0.000	14	25
Adoption	$p75$	Pop	Intermed.	-0.0044	0.003	0.189	[-0.0110; 0.0022]	0.000	25	42
Adoption	$p75$	Pop	Local	0.0018	0.002	0.325	[-0.0017; 0.0052]	0.000	40	189
Revision	$p25$	Base	High	-0.0021	0.002	0.241	[-0.0056; 0.0014]	0.020	118	33
Revision	$p25$	Base	Intermed.	-0.0018	0.002	0.462	[-0.0066; 0.0030]	0.020	125	48
Revision	$p25$	Base	Local	-0.0007	0.001	0.585	[-0.0030; 0.0017]	0.525	118	66
Revision	$p25$	Pop	High	-0.0006	0.002	0.764	[-0.0047; 0.0034]	0.059	118	33
Revision	$p25$	Pop	Intermed.	-0.0012	0.002	0.555	[-0.0050; 0.0027]	0.028	125	48
Revision	$p25$	Pop	Local	-0.0008	0.001	0.534	[-0.0033; 0.0017]	0.530	118	66
Revision	$p50$	Base	High	-0.0031	0.002	0.153	[-0.0073; 0.0011]	0.007	90	61
Revision	$p50$	Base	Intermed.	-0.0021	0.002	0.227	[-0.0055; 0.0013]	0.115	87	86
Revision	$p50$	Base	Local	0.0005	0.001	0.665	[-0.0017; 0.0027]	0.004	72	112
Revision	$p50$	Pop	High	-0.0012	0.002	0.603	[-0.0059; 0.0034]	0.048	90	61
Revision	$p50$	Pop	Intermed.	-0.0019	0.002	0.291	[-0.0053; 0.0016]	0.108	87	86

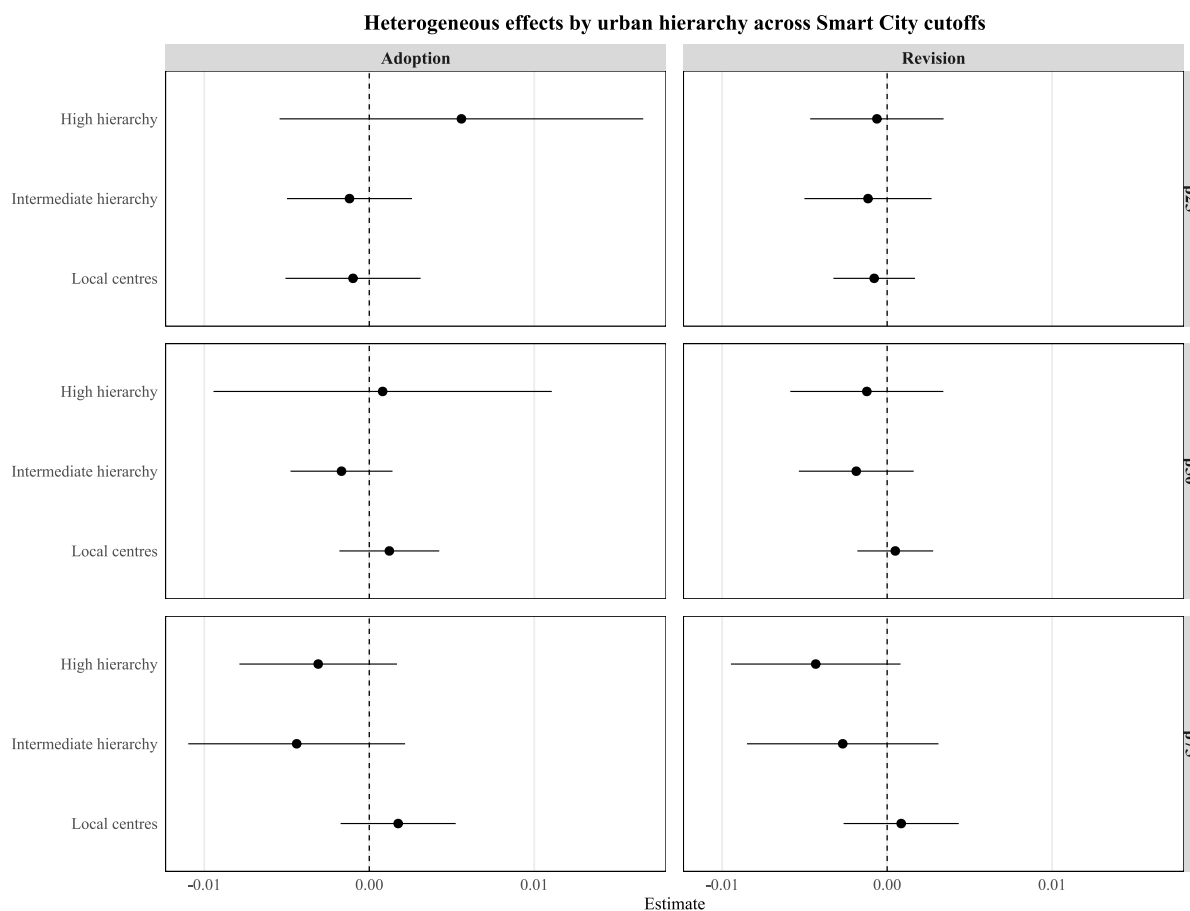
Table A.6.7 - Continued

Event	Cutoff	Model	Hierarchy	ATT	SE	p	95% CI	Pre-test p-value	Treated	Never
Revision	<i>p50</i>	Pop	Local	0.0005	0.001	0.674	[-0.0018; 0.0028]	0.304	72	112
Revision	<i>p75</i>	Base	High	-0.006***	0.002	0.009	[-0.0106; -0.0015]	0.000	56	97
Revision	<i>p75</i>	Base	Intermed.	-0.0029	0.003	0.334	[-0.0086; 0.0029]	0.061	39	135
Revision	<i>p75</i>	Base	Local	0.0009	0.002	0.614	[-0.0025; 0.0043]		30	154
Revision	<i>p75</i>	Pop	High	-0.0043*	0.003	0.099	[-0.0095; 0.0008]	0.031	56	97
Revision	<i>p75</i>	Pop	Intermed.	-0.0027	0.003	0.363	[-0.0085; 0.0031]	0.175	39	135
Revision	<i>p75</i>	Pop	Local	0.0009	0.002	0.633	[-0.0026; 0.0043]	0.000	30	154

Source: Author's own elaboration.

Note: The table reports heterogeneous average treatment effects for the composite Smart City index by REGIC urban hierarchy under the *p25*, *p50*, and *p75* treatment cutoffs. The *p25* cutoff represents a broader treatment definition, *p50* is the reference cutoff, and *p75* identifies intensive incorporation. The outcome is the municipal additive contribution to the intra-regional component of GDP per capita inequality, computed using GE(1), the Theil T index. Event refers to the institutional event, with Adoption corresponding to the initial adoption of the Master Plan and Revision to the revision of a previously existing plan. Base refers to the model without covariates, and Pop controls for the logarithm of municipal population. High, Intermed., and Local refer to the three urban hierarchy groups defined from REGIC categories (i.e., High, Intermediate, and Local centres). Estimates are obtained separately by institutional event and subgroup using eligible never-treated municipalities within each subgroup as the comparison group. Municipalities in first-year treated cohorts are excluded because no pre-treatment observation is available within the 2013–2020 outcome panel. Treated and Never report the number of treated and eligible never-treated municipalities in each subgroup. ATT denotes average treatment effect on the treated, SE denotes standard error, and 95% CI denotes the 95% confidence interval. The pre-test p-value refers to the joint Wald test for the null hypothesis that all pre-treatment group-time effects are equal to zero. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Figure A.6.7 - Heterogeneous effects by urban hierarchy across Smart City cutoffs



Source: Author's own elaboration.

Note: The figure reports heterogeneous average treatment effects for the composite Smart City index by urban hierarchy category under the $p25$, $p50$, and $p75$ treatment cutoffs. The specification controls for the logarithm of municipal population. Estimates are reported for initial adoption and revision. The outcome is the municipal additive contribution to the intra-regional component of GDP per capita inequality, computed using GE(1), the Theil T index. Eligible never-treated municipalities within each urban-hierarchy group are used as the comparison group. Municipalities in first-year treated cohorts are excluded because no pre-treatment observation is available within the 2013–2020 outcome panel. Dots report estimated effects, and horizontal bars report 95% confidence intervals.

Table A.6.8 - Heterogeneous average treatment effects by previous documentary maturity and Smart City cutoff

Cutoff	Model	Quantile	ATT	SE	p-value	95% CI	Pre-test p-value	Treated	Never
$p25$	Baseline	Q1	0.0010	0.002	0.542	[-0.0022; 0.0042]	0.073	92	33
$p25$	Baseline	Q2	-0.0042	0.004	0.228	[-0.0111; 0.0026]	0.065	98	31
$p25$	Baseline	Q3	-0.0024**	0.001	0.033	[-0.0046; -0.0002]	0.008	90	43
$p25$	Baseline	Q4	-0.0019	0.002	0.410	[-0.0064; 0.0026]	0.093	81	40
$p25$	Log(Pop)	Q1	0.0025	0.003	0.387	[-0.0032; 0.0082]	0.562	92	33
$p25$	Log(Pop)	Q2	-0.0044	0.003	0.182	[-0.0108; 0.0020]	0.070	98	31
$p25$	Log(Pop)	Q3	-0.0016	0.001	0.180	[-0.0039; 0.0007]	0.013	90	43
$p25$	Log(Pop)	Q4	-0.0006	0.002	0.800	[-0.0052; 0.0040]	0.288	81	40

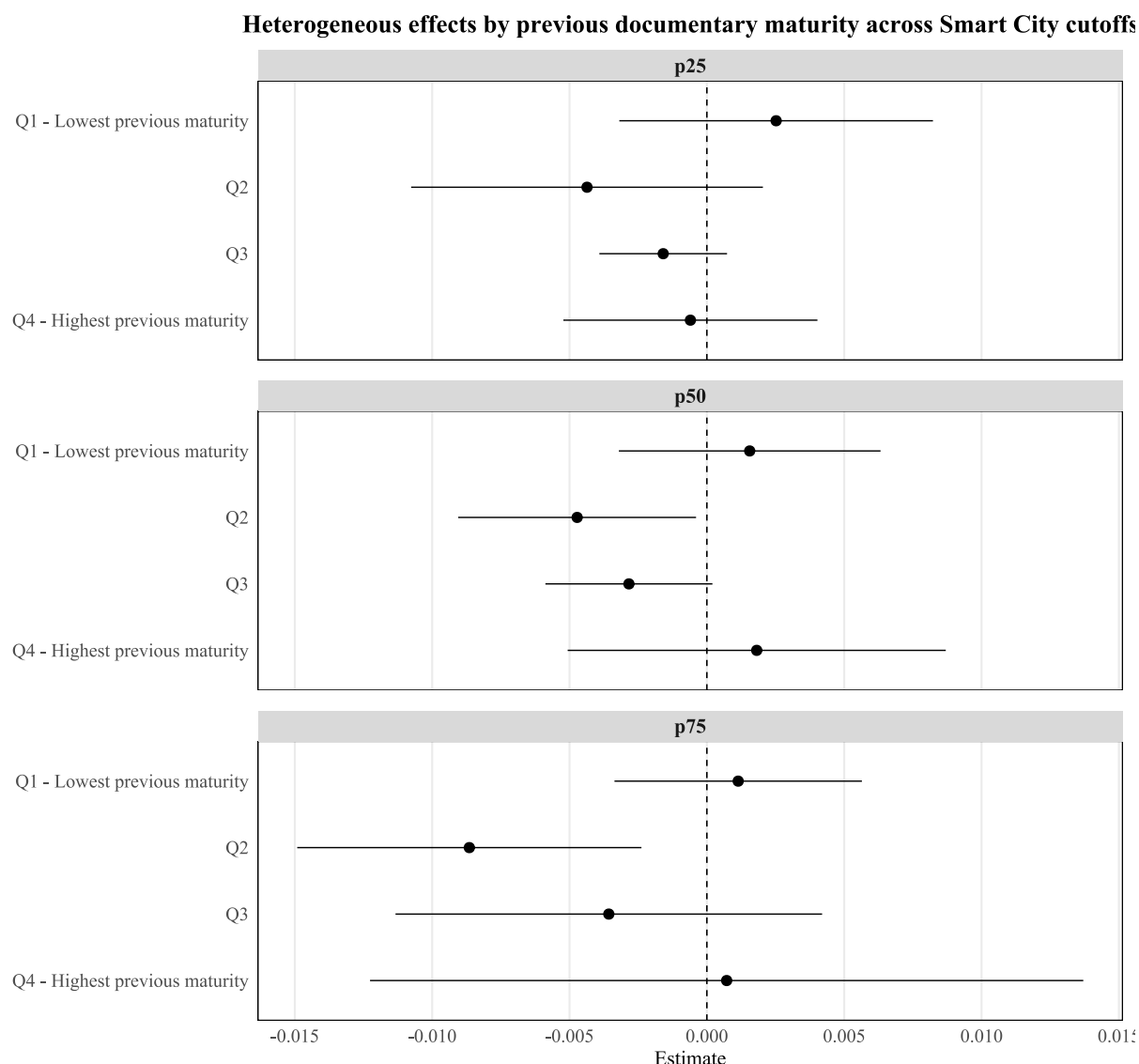
Table A.6.8 - Continued

Cutoff	Model	Quantile	ATT	SE	P-value	95% CI	Pre-test p-value	Treated	Never
<i>p25</i>	REGIC	Q1	0.0006	0.002	0.707	[-0.0025; 0.0037]	0.654	92	33
<i>p25</i>	REGIC	Q2	-0.0042	0.003	0.198	[-0.0106; 0.0022]	0.011	98	31
<i>p25</i>	REGIC	Q3	-0.0024**	0.001	0.042	[-0.0046; -0.0001]	0.083	90	43
<i>p25</i>	REGIC	Q4	-0.0008	0.002	0.720	[-0.0051; 0.0035]	0.254	81	40
<i>p50</i>	Baseline	Q1	0.0002	0.002	0.875	[-0.0028; 0.0033]	0.007	78	47
<i>p50</i>	Baseline	Q2	-0.0044**	0.002	0.041	[-0.0086; -0.0002]	0.027	73	56
<i>p50</i>	Baseline	Q3	-0.0032**	0.002	0.049	[-0.0064; -0.0000]	0.004	55	78
<i>p50</i>	Baseline	Q4	-0.0003	0.003	0.921	[-0.0069; 0.0062]	0.007	43	78
<i>p50</i>	Log(Pop)	Q1	0.0016	0.002	0.521	[-0.0032; 0.0063]	0.236	78	47
<i>p50</i>	Log(Pop)	Q2	-0.0047**	0.002	0.033	[-0.0091; -0.0004]	0.110	73	56
<i>p50</i>	Log(Pop)	Q3	-0.0028*	0.002	0.067	[-0.0059; 0.0002]	0.004	55	78
<i>p50</i>	Log(Pop)	Q4	0.0018	0.004	0.605	[-0.0051; 0.0087]	0.000	43	78
<i>p50</i>	REGIC	Q1	0.0002	0.002	0.882	[-0.0028; 0.0033]	0.610	78	47
<i>p50</i>	REGIC	Q2	-0.0037*	0.002	0.081	[-0.0080; 0.0005]	0.013	73	56
<i>p50</i>	REGIC	Q3	-0.0033**	0.002	0.031	[-0.0062; -0.0003]	0.027	55	78
<i>p50</i>	REGIC	Q4	-0.0021	0.004	0.599	[-0.0099; 0.0057]	0.012	43	78
<i>p75</i>	Baseline	Q1	-0.0004	0.002	0.854	[-0.0041; 0.0034]	0.001	61	65
<i>p75</i>	Baseline	Q2	-0.008**	0.003	0.013	[-0.0152; -0.0018]	0.000	31	99
<i>p75</i>	Baseline	Q3	-0.0038	0.004	0.339	[-0.0116; 0.0040]		17	116
<i>p75</i>	Baseline	Q4	-0.0048	0.007	0.482	[-0.0182; 0.0086]		16	106
<i>p75</i>	Log(Pop)	Q1	0.0011	0.002	0.620	[-0.0034; 0.0056]	0.007	61	65
<i>p75</i>	Log(Pop)	Q2	-0.0086***	0.003	0.007	[-0.0149; -0.0024]	0.000	31	99
<i>p75</i>	Log(Pop)	Q3	-0.0036	0.004	0.368	[-0.0113; 0.0042]	0.000	17	116
<i>p75</i>	Log(Pop)	Q4	0.0007	0.007	0.913	[-0.0123; 0.0137]	0.000	16	106
<i>p75</i>	REGIC	Q1	-0.0001	0.002	0.945	[-0.0039; 0.0036]	0.067	61	65
<i>p75</i>	REGIC	Q2	-0.009***	0.003	0.006	[-0.0149; -0.0024]	0.000	31	99
<i>p75</i>	REGIC	Q3	-0.0040	0.004	0.316	[-0.0119; 0.0038]	0.000	17	116
<i>p75</i>	REGIC	Q4	-0.0060	0.007	0.4125	[-0.0204; 0.0084]		16	106

Source: Author's own elaboration.

Note: The table reports heterogeneous average treatment effects for Revision by previous documentary maturity quartile under the *p25*, *p50*, and *p75* Smart City cutoffs. Previous documentary maturity is measured from the Smart City content observed before the Master Plan revision. Q1 denotes the lowest maturity quartile, and Q4 denotes the highest maturity quartile. The *p25* cutoff represents a broader treatment definition, *p50* is the reference cutoff, and *p75* identifies intensive incorporation. The outcome is the municipal additive contribution to the intra-regional component of GDP per capita inequality, computed using GE(1), the Theil T index. Eligible never-treated municipalities within each maturity quartile are used as the comparison group. Municipalities in first-year treated cohorts are excluded because no pre-treatment observation is available within the 2013–2020 outcome panel. ATT denotes average treatment effect on the treated. “Log(Pop)” controls for the logarithm of municipal population, and “REGIC” controls for urban hierarchy. Treated and Never report the number of municipalities in each group. The pre-test p-value refers to the joint Wald test for the null hypothesis that all pre-treatment group-time effects are equal to zero. SE denotes standard error, and 95% CI denotes the 95% confidence interval. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

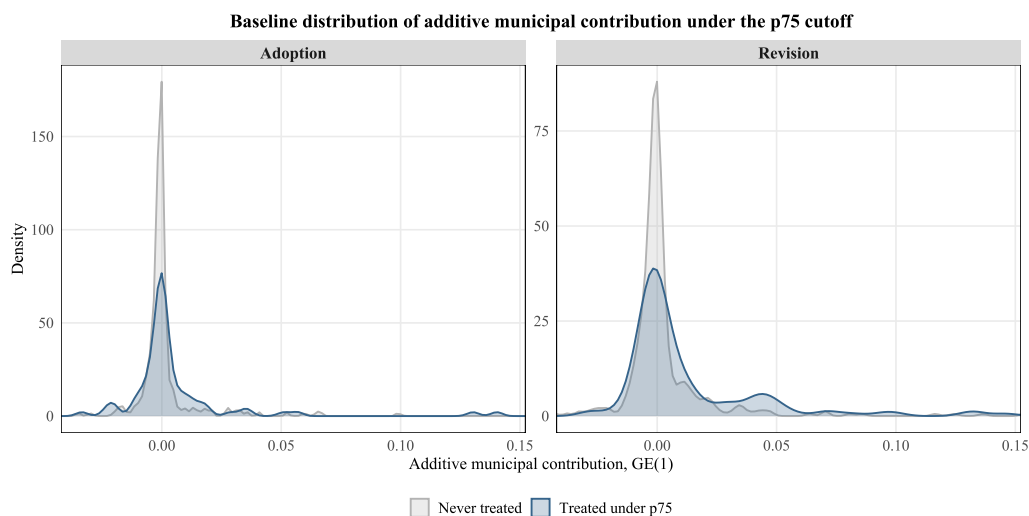
Figure A.6.8 - Heterogeneous effects by previous documentary maturity across Smart City cutoffs



Source: Author's own elaboration.

Note: The figure reports heterogeneous average treatment effects for the composite Smart City index by previous documentary maturity quartile under the *p25*, *p50*, and *p75* treatment cutoffs. The specification controls for the logarithm of municipal population. Estimates are reported for Revision because previous documentary maturity is defined from the Smart City content observed before the Master Plan revision. The outcome is the municipal additive contribution to the intra-regional component of GDP per capita inequality, computed using GE(1), the Theil T index. Eligible never-treated municipalities within each maturity group are used as the comparison group. Municipalities in first-year treated cohorts are excluded because no pre-treatment observation is available within the 2013–2020 outcome panel. Dots report estimated effects, and horizontal bars report 95% confidence intervals.

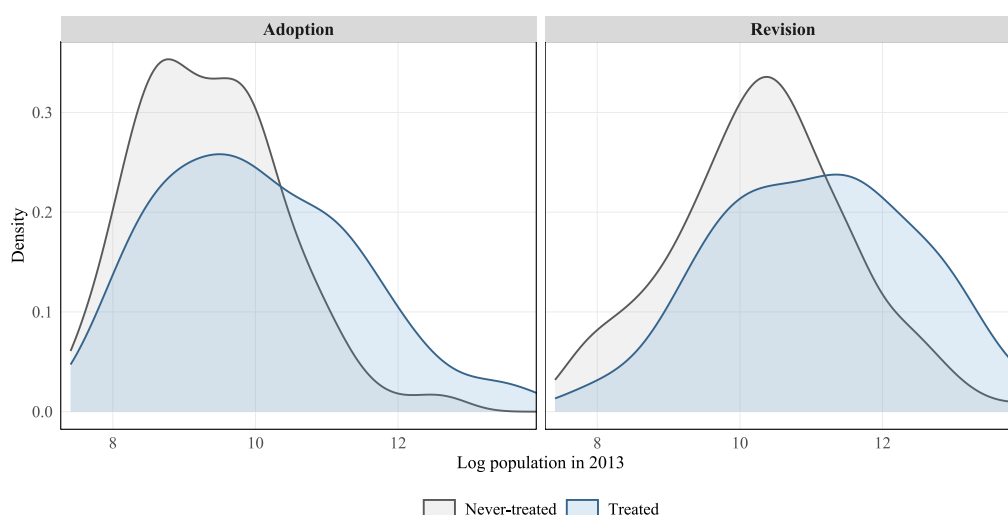
Figure A.6.9 - Baseline distribution of the additive municipal contribution under the $p75$ Smart City cutoff



Source: Author's own elaboration.

Note: The figure reports the baseline distribution of the municipal additive contribution to the intra-regional component of GDP per capita inequality, computed using GE(1), the Theil T index. Distributions are shown for municipalities classified as treated under the $p75$ Smart City cutoff and for eligible never-treated municipalities, separately for Adoption and Revision. The baseline year is 2013. Treated municipalities correspond to cohorts entering treatment after 2013, since first-year treated cohorts are excluded from the main DiD estimations due to the absence of a pre-treatment observation within the 2013–2020 outcome panel. The figure is intended as a descriptive diagnostic of the initial distribution and should not be interpreted as evidence of treatment effects.

Figure A.6.10 - Distribution of log population by treatment status under the $p75$ Smart City cutoff



Source: Author's own elaboration.

Note: The figure reports kernel density estimates for the logarithm of municipal population in 2013 among eligible never-treated municipalities and municipalities classified as treated under the $p75$ Smart City cutoff. Panels report Adoption and Revision separately. The $p75$ cutoff refers to the composite Smart City index. The x-axis is trimmed at the 1st and 99th percentiles of the pooled distribution to improve readability. Municipalities in first-year treated cohorts are excluded because no pre-treatment observation is available within the 2013–2020 outcome panel. The figure is descriptive and is used as a covariate-overlap diagnostic..

Table A.6.9 - HonestDiD sensitivity analysis for Revision under the $p75$ Smart City cutoff

$\bar{M}$	Lower 95% CI	Upper 95% CI
0.0	-0.009	0.000
0.5	-0.025	0.015
1.0	-0.042	0.032
1.5	-0.060	0.049
2.0	-0.077	0.067
2.5	-0.095	0.085
3.0	-0.113	0.103
4.0	-0.149	0.139

Source: Author's own elaboration.

Note: The table reports robust 95% confidence intervals from the HonestDiD relative-magnitude sensitivity analysis. The exercise refers to the composite Smart City index under the $p75$ intensive cutoff for Revision, controlling for the logarithm of municipal population. The outcome is the municipal additive contribution to the intra-regional component of GDP per capita inequality, computed using GE(1), the Theil T index. Dynamic coefficients are obtained from a universal-base event-study specification using eligible never-treated municipalities as the comparison group. The covariance matrix is recovered from the event-study influence functions and rescaled to match the reported event-study standard errors. The target parameter is the average of the available post-treatment dynamic effects. $\bar{M}$ indexes the maximum allowed post-treatment violation of parallel trends relative to the maximum pre-treatment violation. The intervals are computed using the C-LF method and the DeltaRM relative-magnitude restriction. Municipalities in first-year treated cohorts are excluded because no pre-treatment observation is available within the 2013–2020 outcome panel.

A.6.4 Thematic composition and auxiliary outcomes

Table A.6.10 - Exploratory treatment effects by Smart City dimension and institutional event

Event	Dimension	Cutoff	ATT	SE	p	95% CI	Pre-test p-value	Treated	Never
Adoption	Economy	$p75$	0.0006	0.0012	0.5910	[-0.0017; 0.0030]	0.51668	87	247
Adoption	Society	$p75$	0.0004	0.0012	0.7253	[-0.0020; 0.0029]	0.64877	81	254
Adoption	Environment	$p75$	-0.0002	0.0011	0.8806	[-0.0022; 0.0019]	0.51480	79	254
Adoption	Governance	$p75$	-0.0001	0.0015	0.9638	[-0.0030; 0.0028]	0.51467	177	149
Adoption	Technology	$p75$	-0.0008	0.0009	0.3533	[-0.0026; 0.0009]	0.11372	93	238
Adoption	Urban Brands	$p80$	-0.0001	0.0014	0.9366	[-0.0028; 0.0025]	0.48617	123	210
Adoption	Smart City	$p75$	-0.0001	0.0011	0.9580	[-0.0023; 0.0022]	0.25268	79	256
Revision	Economy	$p75$	0.0003	0.0014	0.8184	[-0.0025; 0.0031]	0.12697	130	381
Revision	Society	$p75$	-0.0029**	0.0014	0.0441	[-0.0056; -0.0001]	0.20658	132	379
Revision	Environment	$p75$	-0.0017	0.0013	0.1942	[-0.0043; 0.0009]	0.06384	128	380
Revision	Governance	$p75$	-0.0022**	0.0011	0.0430	[-0.0044; -0.0001]	0.08296	175	339
Revision	Technology	$p75$	-0.0003	0.0015	0.8420	[-0.0032; 0.0026]	0.13537	146	357
Revision	Urban Brands	$p80$	-0.0019	0.0015	0.1862	[-0.0048; 0.0009]	0.07156	91	373
Revision	Smart City	$p75$	-0.0028*	0.0014	0.0515	[-0.0055; 0.0000]	0.13357	125	386

Source: Author's own elaboration.

Note: The table reports exploratory average treatment effects by thematic dimension and institutional event. Event identifies the institutional event. Each row uses the intensive cutoff available for the corresponding dimension in the policy construction. The *p*75 cutoff is used for Economy, Society, Environment, Governance, Technology, and the composite Smart City index. For Urban Brands, the *p*80 cutoff is used because the *p*75 cutoff still includes zero citation values in the treatment threshold. ATT denotes average treatment effect on the treated. All specifications control for the logarithm of municipal population. The outcome is the municipal additive contribution to the intra-regional component of GDP per capita inequality, computed using GE(1), the Theil T index. Estimates are obtained using eligible never-treated municipalities as the comparison group. Municipalities in first-year treated cohorts are excluded because no pre-treatment observation is available within the 2013–2020 outcome panel. These estimates document the dimensional exercises underlying Table 6.9 and should not be interpreted as isolated causal channels. Treated and Never report the number of municipalities in each group. The pre-test p-value refers to the joint Wald test for the null hypothesis that all pre-treatment group-time effects are equal to zero. SE denotes standard error, and 95% CI denotes the 95% confidence interval. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table A.6.11 - Exploratory effects on municipal economic position by Smart City cutoff

Event	Cutoff	Outcome	Estimate	SE	p	95% CI	Pre-test p-value	Treated	Never
Adoption	<i>p</i> 25	Log GDPpc	-0.0245	0.0248	0.3224	[-0.0731; 0.0241]	0.62033	227	82
Adoption	<i>p</i> 25	Relative GDPpc gap	-0.0196	0.0254	0.4398	[-0.0693; 0.0301]	0.93428	227	82
Adoption	<i>p</i> 25	Absolute GDPpc gap	0.0232	0.0202	0.2501	[-0.0163; 0.0627]	0.72652	227	82
Adoption	<i>p</i> 50	Log GDPpc	0.0218	0.0289	0.4520	[-0.0349; 0.0785]	0.02845	151	171
Adoption	<i>p</i> 50	Relative GDPpc gap	0.0229	0.0292	0.4314	[-0.0342; 0.0801]	0.33996	151	171
Adoption	<i>p</i> 50	Absolute GDPpc gap	0.0172	0.0255	0.4993	[-0.0328; 0.0673]	0.22692	151	171
Adoption	<i>p</i> 75	Log GDPpc	-0.0071	0.0336	0.8319	[-0.0729; 0.0587]	< 0.0001	79	256
Adoption	<i>p</i> 75	Relative GDPpc gap	-0.0105	0.0339	0.7565	[-0.0769; 0.0559]	0.00678	79	256
Adoption	<i>p</i> 75	Absolute GDPpc gap	0.0284	0.0324	0.3812	[-0.0352; 0.0920]	< 0.0001	79	256
Revision	<i>p</i> 25	Log GDPpc	-0.0149	0.0111	0.1813	[-0.0367; 0.0069]	0.21963	361	147
Revision	<i>p</i> 25	Relative GDPpc gap	0.0067	0.0111	0.5460	[-0.0151; 0.0286]	0.51880	361	147
Revision	<i>p</i> 25	Absolute GDPpc gap	-0.0029	0.0112	0.7951	[-0.0248; 0.0190]	0.19183	361	147
Revision	<i>p</i> 50	Log GDPpc	-0.0145	0.0124	0.2448	[-0.0389; 0.0099]	0.01781	249	259
Revision	<i>p</i> 50	Relative GDPpc gap	-0.0076	0.0132	0.5655	[-0.0334; 0.0183]	0.02285	249	259
Revision	<i>p</i> 50	Absolute GDPpc gap	-0.0080	0.0126	0.5233	[-0.0327; 0.0166]	0.22027	249	259
Revision	<i>p</i> 75	Log GDPpc	-0.0106	0.0147	0.4700	[-0.0394; 0.0182]	0.09521	125	386
Revision	<i>p</i> 75	Relative GDPpc gap	-0.0091	0.0162	0.5722	[-0.0409; 0.0226]	0.13933	125	386
Revision	<i>p</i> 75	Absolute GDPpc gap	-0.0333**	0.0152	0.0285	[-0.0630; -0.0035]	0.05040	125	386

Source: Author's own elaboration.

Note: The table reports exploratory average treatment effects for the composite Smart City index under the *p*25, *p*50, and *p*75 treatment cutoffs on auxiliary outcomes related to municipal

economic position. All specifications control for the logarithm of municipal population. Event refers to the institutional event. Log GDPpc refers to municipal GDP per capita at 2020 prices. The relative GDPpc gap is defined as the difference between municipal log GDP per capita and the log leave-one-out GDP per capita mean of the Immediate Geographic Region. The absolute GDPpc gap measures the distance from the leave-one-out regional mean, regardless of direction. Estimates are obtained separately by institutional event using eligible never-treated municipalities as the comparison group. Municipalities in first-year treated cohorts are excluded because no pre-treatment observation is available within the 2013–2020 outcome panel. The *p*25 cutoff represents a broader treatment definition, *p*50 is the reference cutoff, and *p*75 identifies intensive incorporation. These estimates should be interpreted as exploratory evidence and not as formal mediation tests. Treated and Never report the number of municipalities in each group. The pre-test p-value refers to the joint Wald test for the null hypothesis that all pre-treatment group-time effects are equal to zero. SE denotes standard error, and 95% CI denotes the 95% confidence interval. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table A.6.12 - Exploratory effects by initial relative economic position under the *p*75 Smart City cutoff

Initial relative position	Outcome	Estimate	SE	p-value	95% CI	Pre-test p-value	Treated	Never
At/below ImGR mean	Log GDPpc	0.0036	0.018	0.839	[-0.0314; 0.0386]	0.006	60	231
At/below ImGR mean	Log peer ImGR GDPpc	-0.0194*	0.010	0.057	[-0.0395; 0.0006]	0.013	60	231
At/below ImGR mean	Relative GDPpc gap	0.0231	0.019	0.221	[-0.0139; 0.0600]	0.017	60	231
At/below ImGR mean	Absolute GDPpc gap	-0.0199	0.020	0.311	[-0.0583; 0.0185]	0.162	60	231
Above ImGR mean	Log GDPpc	-0.0196	0.024	0.404	[-0.0657; 0.0264]	< 0.001	65	155
Above ImGR mean	Log peer ImGR GDPpc	0.0113	0.012	0.359	[-0.0129; 0.0355]	0.252	65	155
Above ImGR mean	Relative GDPpc gap	-0.0309	0.024	0.192	[-0.0773; 0.0155]	0.003	65	155
Above ImGR mean	Absolute GDPpc gap	-0.0305	0.024	0.205	[-0.0777; 0.0167]	0.000	65	155

Source: Author's own elaboration.

Note: The table reports exploratory average treatment effects for Revision under the *p*75 intensive cutoff by the municipality's initial relative position in 2013. Initial relative position is defined using the sign of the log GDPpc gap relative to the leave-one-out GDP per capita mean of the Immediate Geographic Region in 2013. All specifications control for the logarithm of municipal population. Log GDPpc refers to municipal GDP per capita at 2020 prices. Log peer ImGR GDPpc captures the average GDP per capita of the other municipalities in the same Immediate Geographic Region, excluding municipality *i*. The relative GDPpc gap is defined as the difference

between municipal log GDP per capita and the log leave-one-out GDP per capita mean of the Immediate Geographic Region. The absolute GDPpc gap measures the distance from the leave-one-out regional mean, regardless of direction. Eligible never-treated municipalities within each initial-position group are used as the comparison group. Municipalities in first-year treated cohorts are excluded because no pre-treatment observation is available within the 2013–2020 outcome panel. These estimates are intended to qualify the interpretation of the auxiliary outcomes and should not be interpreted as formal mediation tests. Treated and Never report the number of municipalities in each group. The pre-test p-value refers to the joint Wald test for the null hypothesis that all pre-treatment group-time effects are equal to zero. SE denotes standard error, and 95% CI denotes the 95% confidence interval. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.