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Article

Spatial analysis and technological influences on smart city development in Kazakhstan

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Abstract: This study delves into the evolving landscape of smart city development in Kazakhstan, a domain gaining increasing relevance in the context of urban modernization and digital transformation. The research is anchored in the quest to understand how specific technological factors influence the formation of smart cities within the region. To this end, the study adopts a Spatial Autoregressive Model (SAR) as its core analytical tool, leveraging data on server density, cloud service usage, and electronic invoicing practices across various Kazakhstani cities. The crux of the research revolves around assessing the impact of these selected technological variables on the smart city development process. The SAR model's application facilitates a nuanced understanding of the spatial dynamics at play, offering insights into how these factors vary in influence across different urban areas. A key finding of this investigation is the significant positive correlation between the adoption of electronic invoicing and smart city development, a result that stands in contrast to the relatively insignificant impact of server density and cloud service usage. The conclusion drawn from these findings underscores the pivotal role of digital administrative processes, particularly electronic invoicing, in driving the smart city agenda in Kazakhstan. This insight not only contributes to the academic discourse on smart cities but also holds practical implications for policymakers and urban planners. It suggests a strategic shift towards prioritizing digital administrative innovations over mere infrastructural or technological upgrades. The study's outcomes are poised to guide future smart city initiatives in Kazakhstan and offer a reference point for similar emerging economies embarking on their smart city journeys.

Keywords: city; data connectivity; e-mobility; Internet of Things; Kazakhstan; smart cities; spatial analysis; spatial autoregressive model; technological factors

1. Introduction

The concept of smart cities has emerged as a pivotal solution to the challenges posed by urbanization and technological advancement. The development background of smart cities is rooted in the need to integrate technology with urban planning to create more efficient, sustainable, and livable urban environments. This integration has become increasingly relevant as cities worldwide face growing pressures from population growth, environmental concerns, and the rapid pace of digital transformation.

The 21st century has ushered in an era of urban transformation, characterized by the seamless integration of information and communication technologies (ICTs) into city infrastructures. These socalled 'smart cities' are fundamentally reshaping the urban landscape, driven by the potential to optimize resources, enhance service delivery, foster economic development, and ultimately, improve the quality of life for residents (Batty et al., 2012). Smart city formation, however, is not a random or spontaneous process. Instead, it is influenced by a confluence of factors, among which technology plays a pivotal role (Angelidou, 2015). As such, an understanding of these technological impacts is crucial to the broader study of smart cities, particularly in developing nations where the smart city concept is being increasingly adopted.

In the context of this global trend, the research background of our study focuses on Kazakhstan, a nation experiencing significant urban development and digitalization. The country's unique geographical and socio-economic landscape presents a distinctive case for examining the factors influencing smart city formation. This study is situated within the broader research domain that investigates the interplay between technology and urban development, particularly in emerging economies. Kazakhstan has recognized the potential of technological integration into urban development, and yet, comprehensive studies exploring this phenomenon remain relatively scarce (Mukhtarova and Zhidebekkyzy, 2015). To address this gap in literature, the present study provides an indepth spatial analysis of factors influencing the formation of smart cities in Kazakhstan, focusing particularly on the role of technology. We employ crosssectional data from the Bureau of National Statistics of the Agency for Strategic Planning and Reforms for 2021, offering a timely and pertinent analysis. Central to our investigation is the 'Flowchart of Technological Impacts on Smart Cities' (**Figure 1**), a visual tool that elucidates how specific technological factors—Internet of Things (IoT), electronic mobility, and data connectivity – are instrumental in the evolution of smart cities (Toppeta, 2010).

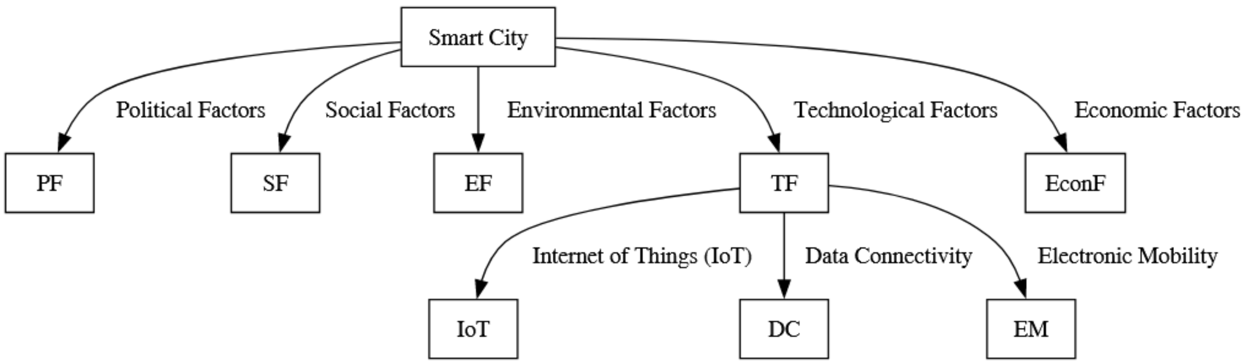

Figure 1. Flowchart of technological impacts on smart cities.

This flowchart underscores the transformative power of technology in an urban context, providing a blueprint for how technological advancements can foster smart city development (Nam and Pardo, 2011a). In tandem with our examination of technological influences, this research also utilizes the Spatial Autoregressive Model to scrutinize the spatial dependence and locational differences in industrial production within Kazakhstan. This model is instrumental in identifying and interpreting patterns of spatial autocorrelation and providing insights into the geographic dynamics of smart city development (Anselin, 1988; LeSage and Pace, 2009). This study aims to make several contributions. Primarily, it seeks to offer valuable insights into the factors shaping smart city formation in Kazakhstan, thereby providing policymakers and urban planners with empirically based guidance for future urban development strategies. Furthermore, by emphasizing the role of technology, it aligns with global urban development trends and contributes to the emerging body of literature on smart cities in developing nations (Caragliu et al., 2011; Neirotti et al., 2014).

The development of smart cities is profoundly influenced by technological advancements and trends. According to TechnologyHQ (2023), one of the primary concerns is the heightened risk of cyberattacks due to the interconnected nature of smart city infrastructure. The increased dependence on technology in managing critical city functions makes them vulnerable to cyber threats, as evidenced by incidents in US cities. Another significant trend is the utilization of digital twins, which serve as comprehensive digital representations of physical assets, aiding in the efficient management of city systems such as traffic and construction impacts. Additionally, the adoption of artificial intelligence (AI) and machine learning (ML) presents both opportunities and risks for smart cities, especially concerning societal impacts, which many cities are not fully prepared to handle.

The introduction and expansion of 5G technology are expected to further accelerate smart city development. However, legal disputes and regulatory challenges have led to uneven adoption rates across different regions. Furthermore, the success of smart cities is contingent on the interoperability of IoT devices and systems. Cities face the challenge of integrating diverse networks and data protocols to manage various services efficiently, all while operating under budget constraints. Complementing these technological trends, Darabseh and Martins (2023) highlight the potential of Blockchain technology in the architecture, engineering, construction, and operation (AECO) sector within smart cities. Blockchain can address issues like data protection and ownership, but its implementation requires careful orchestration to avoid creating redundant and inefficient digital systems. The research presents a novel framework for Blockchain application in construction, which is crucial for the infrastructure development of smart cities.

To contextualize our research, we conducted a comprehensive review of existing literature. This review encompasses studies on smart city definitions, frameworks, and key components, with a focus on technological factors such as digital infrastructure, cloud computing, and electronic governance. The literature reveals a gap in understanding how these technological factors specifically influence smart city development in the context of Kazakhstan, a rapidly evolving but under-researched region. Building on this foundation, the aim of our research is to explore and identify the key technological factors that drive the formation of smart cities in Kazakhstan. We seek to understand how variables such as server density, cloud service adoption, and electronic invoicing practices contribute to or hinder this process. This exploration is crucial for developing targeted strategies and policies to foster smart city development in similar emerging economies.

As we venture further into the 21st century, the need for sustainable, efficient, and technologically advanced cities will continue to grow. Through our investigation, we hope to shed light on how Kazakhstan, and potentially other similar developing nations, can harness the power of technology to facilitate their urban evolution and transition towards becoming truly ‘smart’ cities. The remainder of this paper is organized as follows: Section 2 provides a literature review, discussing previous studies on smart cities, technological factors, and spatial analysis as shown in **Figure**

2. Section 3 describes the data and methodology used in this study, including the Spatial Autoregressive Model and the specific variables examined. Section 4 presents the results and analysis of the model, offering insights into the impact of server density, cloud service usage, and electronic invoicing on smart city transformation in Kazakhstan. The discussion was held in Section 5, comparing results with existing papers in the smart city development. Finally, Section 6 concludes the paper, summarizing the findings and their implications for policymakers and future research.

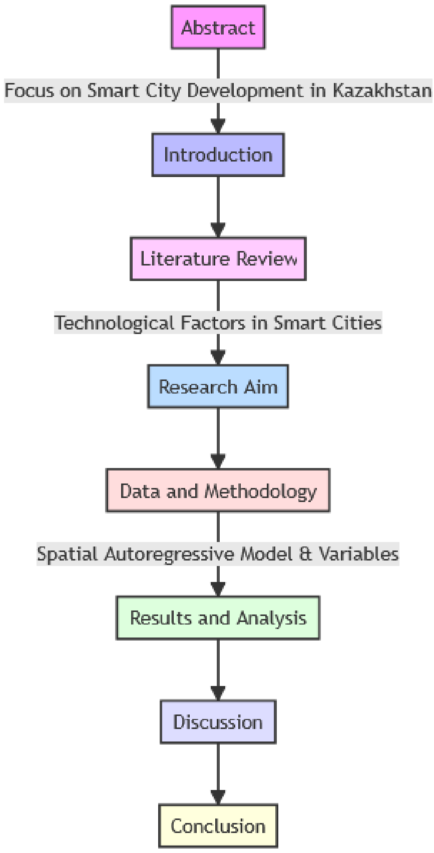

Figure 2. Research path of smart city development study.

2. Review of literature

"Smart city" is a term that has gained prominence in discussions around urban planning and development. Such a city is characterized by its use of electronic methods and sensors to gather data, which is then utilized to manage assets, resources, and services efficiently. This data driven approach enhances operations across various city sectors, including transportation, utilities, waste management, crime detection, and public services such as schools and hospitals (Harrison and Donnelly, 2011).

Smart cities leverage information and communication technology (ICT) and various physical devices connected to the IoT network to optimize the efficiency of city operations and services and connect to citizens (Chourabi et al., 2012). The goal of building a smart city is to improve the quality of life by using technology to improve the efficiency of services and meet residents' needs. The concept of smart cities is not just about integrating technology into urban services. At its core, it's about using technology and data purposefully to make better decisions and deliver better outcomes

(Nam and Pardo, 2011b). Thus, it involves a lot more than just technology. It involves a strategic approach to urban planning and development that considers the needs of all stakeholders in the city.

The concept of a "smart city" has become a focal point in urban development and planning discourse. A smart city is often defined as an urban area that uses different types of electronic methods and sensors to collect data, with insights gained from that data used to manage assets, resources, and services efficiently. This data collection is used to improve the operations across the city, including traffic and transportation systems, power plants, utilities, water supply networks, waste management, crime detection, information systems, schools, libraries, hospitals, and other community services (Harrison and Donnelly, 2011).

It has emerged as a significant area of academic inquiry and practical application, fuelled by the advent of the digital age and the growing complexity of urban environments (Townsend, 2013). Extensive scholarship has been dedicated to understanding the factors influencing smart city formation and the methodologies employed to analyze this phenomenon, such as spatial autoregressive analysis. One of the critical dimensions of smart city research is understanding the influencing factors driving their formation. Komninos (2002) underscored the centrality of innovation, human capital, and ICT infrastructure, while Hollands (2008) highlighted the role of political and economic factors. Caragliu et al. (2011) and Neirotti et al. (2014) extended this line of thought, pointing to technological advances, urbanization pressures, and sustainability considerations as pivotal determinants.

The research by Kuzior et al. (2023) delves into the role of egovernance as a critical facilitator in the integration of smart city elements. They utilized various methods, including cluster analysis and vector autoregression/vector error correction (VAR/VEC) modeling, to study the impact of economic, social, political, and technological indicators on governance across 68 smart cities. The Human Development Index was found to have the most significant impact. At the same time, the role of information technologies was identified as the primary direct influence on the Smart City Governance Index. The work by Kollárová et al. (2023) provides an indepth overview of the security and privacy aspects crucial for smart city development in Slovakia. The authors used a systematic review method to outline the opportunities and challenges in conceptualizing a smart city model, emphasizing the importance of norms, policies, and standards in ensuring security and privacy. The study concludes that a secure smart city is a cross disciplinary challenge, requiring context based policies, standards, and procedures.

Asavanirandorn et al. (2023) examine the factors that affect the acceptance of online job searches among the older urban poor in Thailand, a critical consideration in developing smart cities. They applied a logit regression model on data collected from preretirement and retirement individuals, finding that gender, religion, family arrangement, and income significantly impact online job search activities. The paper recommends that urban planners consider these factors in formulating smart city development plans. The paper by Nugroho et al. (2022) discusses the use of local government websites for the application and socialization of environmental policy in the context of smart cities. The authors conducted an observational analysis of the websites of Surakarta, Indonesia, and Pingtung, Taiwan, two cities with contrasting environmental policy awareness and application. The results highlight the differences in how both cities implement their environmental policies through websites and the factors that may contribute to these differences.

Various factors influence the development of smart cities. According to Nevado Gil et al. (2020), the geographical location of cities and the gender of their governance significantly impact the smart city rankings. Their study on European cities revealed that cities located in the west of Europe and governed by women presented higher levels in the smart city rankings. This suggests that the sociopolitical context plays a crucial role in the development of smart cities (Collins et al., 2021). Smart cities have gained significant attention globally, including South Korea, where the government has invested in largescale smart city projects to enhance urban living and promote economic growth (Choi, 2020). South Korea's success in smart city development can be attributed to direct state support, public trust, and an integrated approach. The country's smart city projects provide enhanced comfort and opportunities for personal growth. They are divided into stages, representing different levels of technological integration and sophistication. The process of planning and constructing a customized smart city in South Korea involves analyzing the urban situation, finding solutions, system design, and business promotion (Choi, 2020).

The integration of the Internet of Things (IoT) with cloud computing represents a crucial development in the technological landscape. Manzoor et al. (2023) highlight the pivotal role of cloud computing in enhancing IoT capabilities, particularly in connecting a diverse range of devices and managing data. This integration, as they point out, is not without challenges, yet it offers significant benefits and advancements. Their analysis, employing the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method and a bibliometric network, explores the depth of this integration, assessing the quality of service (QoS) in various IoT cloud applications. Echoing this sentiment, Karumanchi et al. (2022) emphasize the importance of cloud computing in maintaining data integrity within IoT frameworks, especially in supply chain management. They propose a hybrid integrity verification-based encoding and decoding technique to optimize data integrity in cloud-based IoT applications, demonstrating improved performance over traditional methods. Chamandeep (2020) discusses the growing interdependence between cloud computing and IoT. The proliferation of IoT devices generates vast amounts of data, necessitating robust cloud services for effective management and communication. This relationship indicates that the extent of cloud service usage by companies can serve as a measure of IoT integration and deployment in various sectors. These studies collectively suggest that the adoption of IT cloud services by companies is indicative of the extent to which IoT technologies have permeated different industries. The increasing reliance on cloud platforms for IoT applications underscores the potential of using cloud service adoption as a metric for measuring IoT growth and integration.

The integration of electronic mobility-as-a-service (eMaaS) in smart cities has led to a notable shift in urban transportation and financial transactions, as highlighted in the research by Anthony (2023). This study emphasizes the increasing adoption of electronic invoices by eMaaS providers as a key indicator of the digitalization and efficiency of e-mobility solutions in urban areas (Anthony, 2023). Such a trend not only transforms mobility but also offers a measurable parameter for the success and acceptance of eMaaS in the context of smart city development (Anthony, 2023).

Recent advancements in data center infrastructures and communication networks underscore the importance of server management as a critical factor in data connectivity. Tso et al. (2016) highlight the significance of resource utilization efficiency in Cloud Data Centres, emphasizing that server and network equipment significantly contribute to operational costs, thus making efficient server management crucial for improving Return-on-Investment. Similarly, Li and Yang's (2000) study on queueing systems with a variable number of servers in modern communication networks reveals how server allocation directly impacts bandwidth management and service rates, further establishing the number of servers as a pivotal measure of data connectivity. Both studies collectively illustrate how server management strategies, from resource provisioning in data centers to dynamic server allocation in communication networks, play an integral role in maintaining and enhancing data connectivity (Tso et al. 2016; Li and Yang, 2000).

The evolution of urban economies and the integration of smart manufacturing practices are becoming increasingly pivotal in defining the development of smart cities. Kumar and Dahiya (2016) discuss the transformation from traditional urban economies to smart city economies, emphasizing the need to reconsider economic theories and practices in the context of smart cities. This transition is marked by the rise of information and communication technology (ICT), leading to diverse challenges and opportunities in smart city economic development, including the significant contribution of urban economies to national GDPs. Complementing this perspective, Suvarna et al. (2020) delve into how smart manufacturing, characterized by data-oriented automation and cyber-physical production systems, contributes to the smart city framework. They highlight the role of smart manufacturing in enhancing ergonomics and sustainability, two critical indices of smart cities. Collectively, these studies suggest that the volume of production in industries, reflecting advancements in smart manufacturing and economic shifts in urban settings, serves as a crucial measure of smart city development (Kumar and Dahiya, 2016; Suvarna et al., 2020).

The role of governance in smart cities is also highlighted by Berrone and Ricart (2017), who argue that smart governance is about promoting smart city initiatives. They emphasize the importance of good governance and effective policies in fostering strong interactions at the urban level. This perspective aligns with the findings of Nevado et al. (2020), reinforcing the idea that the political landscape significantly influences the development of smart cities. In addition to governance, the concept of smart cities is closely tied to sustainability. A study by Zhao et al. (2022) emphasizes the importance of renewable energy sources in smart cities, highlighting the role of solar energy in particular. The integration of renewable energy sources is seen as a critical factor in transforming urban landscapes into sustainable smart cities. The literature also points to the importance of technological infrastructure in the development of smart cities. A study by Huseynova et al. (2022) highlights the role of ICT infrastructure, particularly broadband connectivity, in the development of smart cities in Azerbaijan. The research argues that broadband connectivity is a crucial component of the digital infrastructure of smart cities, enabling the delivery of various digital services and applications.

In the Kazakhstani context, prior studies have mainly focused on the role of government policies, infrastructure development, and economic factors in smart city formation (Mukhtarova and Zhidebekkyzy, 2015; Kassen, 2013). These studies, however, have tended to neglect the role of technology and spatial characteristics in shaping the smart city landscape in the country. In the context of smart city development, the role of Information and Communication Technology (ICT) cannot be overstated. A study conducted in Kazakhstan provides a compelling case for the influence of ICT on regional economic growth, thereby indirectly contributing to the formation of smart cities (Kireyeva, et al. 2021). Technological advancements, particularly IoT, electronic mobility, and data connectivity, are recognized as core components of smart cities (Toppeta, 2010; Nam and Pardo, 2011b; Zanella et al., 2014). They contribute significantly to the development of urban services, cost reduction, resource optimization, and enhanced citizen engagement (Albino et al., 2015). In this regard, Anthopoulos and Fitsilis (2010) suggest that the interplay of these factors contributes significantly to shaping smart cities, setting the stage for a more holistic and integrated approach to urban development.

Complementing the analysis of these influencing factors, spatial autoregressive analysis emerges as a prominent tool in studying smart cities, particularly in terms of industrial production and urban development (Anselin, 1988; LeSage and Pace, 2009). This approach enables a nuanced understanding of locational differences and spatial dependencies, providing valuable insights into geographic dynamics that traditional models might overlook (LeSage and Pace, 2009). Elhorst (2014) and ArribasBel (2014) further stressed the value of spatial autoregressive analysis, noting its ability to reveal hidden patterns and complex relationships between variables. It has also been employed to illuminate issues of spatial autocorrelation, allowing for a more refined understanding of the geographical diffusion of smart city characteristics (Paelinck and Klaassen, 1979).

Despite the growing body of literature in this area, there remains a need for more comprehensive, context specific studies. Specifically, in the context of developing countries like Kazakhstan, there needs to be more research that melds analysis of the technological impacts with spatial autoregressive models to elucidate the formation of smart cities. The present study aims to bridge this gap, providing an indepth analysis of these facets in the specific context of Kazakhstan.

3. Methodology

To ensure a comprehensive understanding of our research approach, we employed the Spatial Autoregressive Model (SAR) to analyze the spatial dependencies and relationships among various factors influencing smart city development in Kazakhstan. The SAR model was chosen for its efficacy in handling spatial autocorrelation, a common feature in geographical data, which traditional regression models often overlook. Our data collection process involved a meticulous aggregation of city-level data from various sources, including government databases, industry reports, and digital infrastructure surveys. The primary variables selected for analysis were the number of servers, the prevalence of companies using IT cloud services, and the adoption of electronic invoicing systems. These variables were specifically chosen to represent diverse aspects of technological advancement relevant to smart city infrastructure. This methodological approach allowed us to systematically explore and quantify the spatial relationships between technological factors and smart city development in Kazakhstan. The choice of SAR model, coupled with our rigorous data collection and analysis process, provided a robust framework for understanding the complex dynamics at play in smart city transformation.

The exploration of spatial differences and their influence on the formation of smart cities, particularly in the context of the Republic of Kazakhstan, necessitates the use of a robust analytical methodology. This study employs a Spatial Autoregressive Model (SAR), an effective approach that takes into account spatial dependencies and locational variations in a given dataset (Anselin, 1988; LeSage and Pace, 2009). The dataset used in this study was retrieved from the Bureau of National Statistics of the Agency for Strategic Planning and Reforms for 2021. **Figure 3**, "Smart City Development Analysis Methodology," provides a structured approach to understanding and analyzing the factors influencing smart city development in Kazakhstan, ensuring a systematic and comprehensive analysis of available data and technological variables.

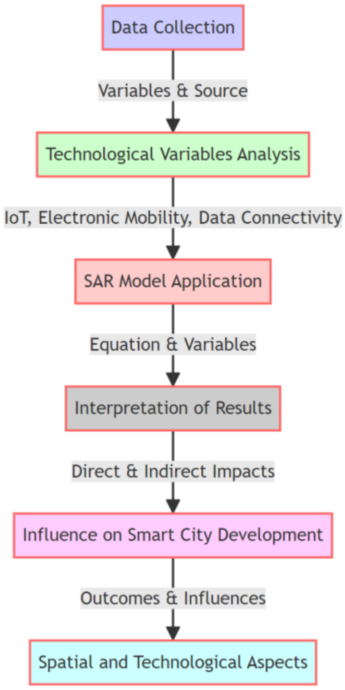

Figure 3. Smart city development analysis methodology.

3.1. Number of servers

The variable "Number of Servers" represents the number of servers businesses maintain in a given city. Servers are foundational in computing infrastructure as they host, store, and process data, facilitate digital connectivity, and support various services and applications. As a core element in the Internet of Things (IoT), servers enable the interconnectivity of multiple devices and systems (Whitmore et al., 2015). In the context of smart cities, the quantity of servers serves as an indicator of the city's digital infrastructure capacity and robustness. An analysis of the data reveals a wide range of server quantities across different cities, from a minimum of 8 in Baikonur to a maximum of 14,104 in Almaty as shown in **Figure 4**. The discrepancy in these figures indicates heterogeneous digital infrastructure capabilities, suggesting differences in the digitalization levels of the various cities. Such variations could potentially influence the cities' ability to harness technology for industrial production, thereby affecting their transition towards becoming smart cities (Hollands, 2008).

Understanding the distribution of servers across cities could aid in identifying infrastructural gaps and potential areas of investment for bolstering technological capacities. This is particularly important, as the proliferation of servers signifies an enhanced capacity to manage big data, a crucial aspect of smart city functioning. Therefore, a higher number of servers could lead to more efficient and sophisticated data management, potentially driving industrial growth and smart city development (Batty et al., 2012).

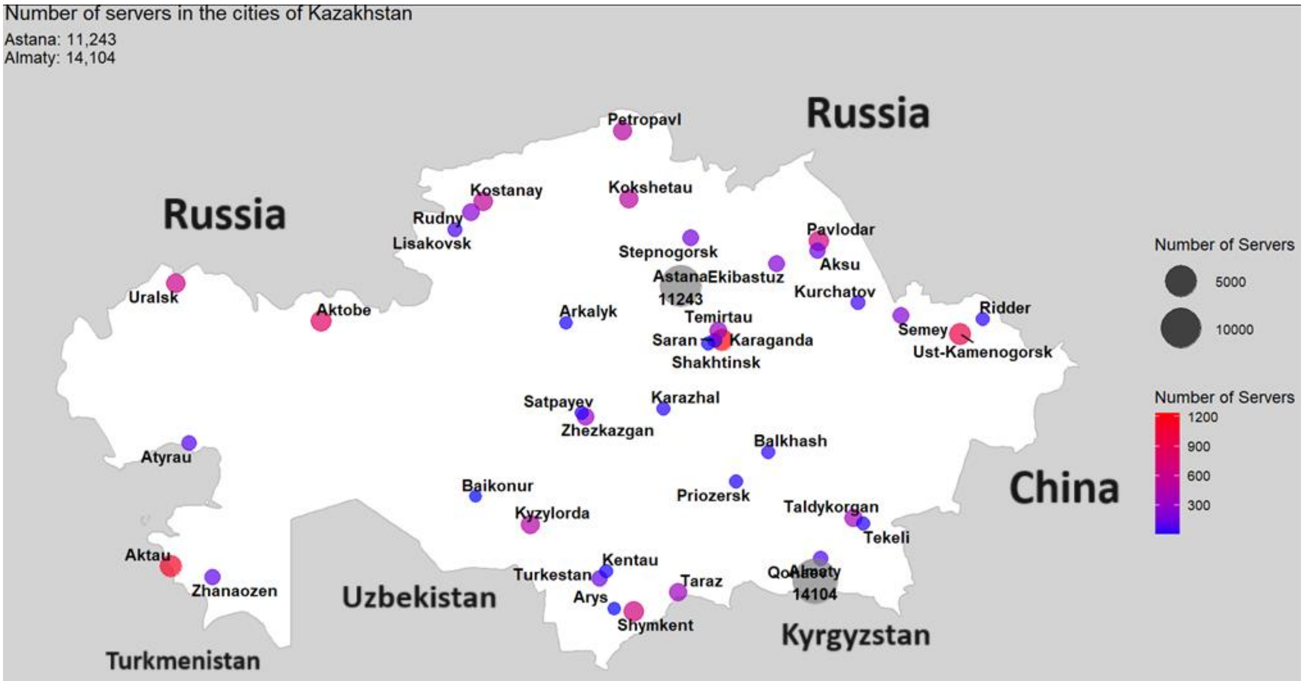

Figure 4. Number of servers in the cities of Kazakhstan. Source: Bureau of National Statistics (2021).

3.2. Companies using IT cloud services

The variable "Companies Using IT Cloud Services" signifies the number of businesses in each city that leverage cloud-based solutions in their operations. Cloud services represent an advanced IT model where data and applications are stored and managed on remote servers accessible via the Internet. This technology promotes scalability, flexibility, and cost-effectiveness in business operations, providing a competitive edge in the modern digital economy (Mell and Grance, 2011). The data indicates a substantial range in the number of companies utilizing cloud services, from a mere 2 in Baikonur to a significant 7211 in Almaty, as shown in **Figure 5**. This variation reflects differing levels of cloud technology adoption across the cities, potentially influencing their industrial efficiency, innovation capabilities, and smart city evolution (Albino et al., 2015).

Notably, the adoption of cloud services may be linked to the industrial production volume and smart city formation. Cloud technologies enable businesses to optimize operations, enhance collaboration, streamline data management, and foster innovation—all critical for driving industrial productivity and promoting smart city characteristics (Islam, 2023). Thus, examining the number of companies using IT cloud services can provide valuable insights into the cities' digital maturity, their businesses' modernization level, and the potential for leveraging technology to transition into smart cities. A higher number of businesses using cloud services may signify a more digitally advanced business ecosystem conducive to smart city development.

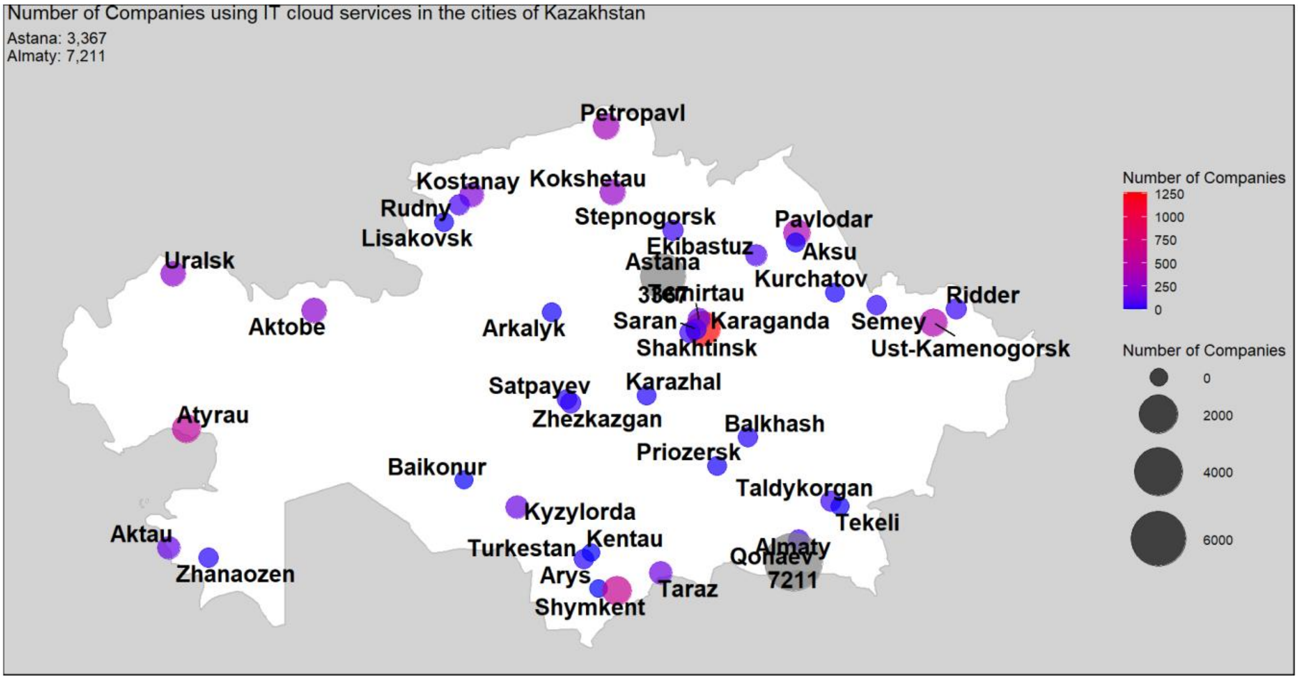

Figure 5. Number of Companies using IT cloud services in the cities of Kazakhstan. Source: Bureau of National Statistics (2021).

3.3. Companies using electronic invoices

The variable "Companies Using Electronic Invoices" quantifies the number of firms in each city that have adopted electronic invoicing in their operations. Electronic invoicing, or e-invoicing, refers to the digital interchange of billing documents between a supplier and a buyer. This technology streamlines the billing process, reduces administrative costs, accelerates payment cycles, and improves data accuracy (Siagian et al., 2021).

Data shows considerable disparity in the number of companies using electronic invoices across the cities in the study, from a low of 15 in Baikonur to a high of 26,113 in Almaty. These differences reveal varying levels of e-invoicing adoption, indicating different degrees of digital transformation among businesses in these cities. The adoption of e-invoicing is not only a measure of a company's digital savviness but also a potential influencer on a city's transition towards smart city status. Electronic invoices, through their capacity to streamline processes, save resources, and enhance data accuracy, can contribute to increased operational efficiencies and sustainable growth, integral aspects of smart cities (Zanella et al., 2014).

Additionally, a city with many companies using electronic invoices can be seen as a digitally mature ecosystem, ready to leverage technology to optimize business operations. This adoption can drive the city's industrial productivity, economic growth and contribute to its smart city evolution (Ruhlandt, 2018). Furthermore, the adoption of e-invoicing is an integral part of the overall digital transformation strategy of companies and cities alike. The diffusion of this technology can significantly impact a city's industrial output, facilitating the shift towards a digital economy and ultimately contributing to the formation of a smart city (Hollands, 2008). In conclusion, by investigating the number of companies using electronic invoices, it is possible to assess the level of digital transformation within a city, understand the efficiency of its business processes, and identify the potential for smart city formation and development.

The variables incorporated in the analysis are as follows:

Dependent variable: The volume of production of industrial products (goods, services), denoted in million tenge. This variable was chosen as a proxy for the level of smart city development, as increased industrial production is one of the expected outcomes of smart city formation (Batty et al., 2012). Smart cities, through the integration of ICTs into city infrastructures, are anticipated to enhance service delivery and foster economic development (Komninos, 2002). Therefore, by examining the impact of various technological factors on industrial production, this study aims to gain insights into the process of smart city formation in Kazakhstan.

Independent variables: The measure of Internet of Things (IoT) is approximated by the number of companies using IT cloud services. Electronic mobility is gauged through the number of companies using electronic invoices. Lastly, data connectivity is represented by the number of servers.

The use of these variables aligns with prior studies that underscore the significant role of technology in influencing the growth and development of smart cities (Toppeta, 2010; Zanella et al., 2014; Albino et al., 2015).

Our SAR model is expressed as follows:

$$Y = \rho WY + X\beta + u \tag{1}$$

where Y is the volume of production of industrial products (goods, services), the dependent variable, ρ is the spatial autoregressive coefficient, WY represents the spatially lagged dependent variable, a matrix W that captures the spatial weight between regions and Y, the dependent variable, X is a matrix of independent variables (Internet of Things, Electronic Mobility, Data Connectivity), β is a vector of coefficients to be estimated and u is an error term.

This model has been widely used in the literature to examine spatially dependent phenomena and has shown its robustness in highlighting spatial differences (Elhorst, 2014; Arribas-Bel, 2014). Furthermore, using technology-related indicators as independent variables allows us to extend the application of the SAR model beyond traditional socioeconomic variables, reflecting the technological nuances of smart city formation. Subsequent to estimating the model, we will employ spatial autocorrelation analysis to assess the degree of correlation among the variables. This will provide a deeper understanding of the spatial dynamics at play, as has been highlighted in prior research (Paelinck and Klaassen, 1979; LeSage and Pace, 2009).

In interpreting the results, it is crucial to note that the coefficient β measures the direct impact of a change in the independent variable on the dependent variable. In contrast, the spatially lagged dependent variable ρWY captures the spillover or indirect effects (LeSage and Pace, 2009). Through this methodology, we anticipate offering a nuanced understanding of the factors influencing the development of smart cities in Kazakhstan, thereby contributing to the growing body of research in this field.

4. Findings

The Spatial Autoregressive Model (SAR) implemented in this research focused on investigating the spatial differences in the factors influencing smart city formation in Kazakhstan. The primary variables of interest included the number of servers, companies using IT cloud services, and companies using electronic invoices. These variables were chosen to represent the different aspects of digital transformation associated with smart city development. The Spatial Autoregressive Model (SAR) results are given in **Table 1**.

Table 1. Results of The Spatial Autoregressive Model (SAR).

Variable/Statistic	Value	Std. Error	Z Value	Pr (>|z|)
Intercept	343733.063	112418.825	3.0576	0.002231
Servers	−248.925	132.294	−1.8816	0.059891
Cloud Companies	−194.468	166.489	−1.1681	0.242784
Invoices Companies	229.249	70.073	3.2716	0.001070

The residuals of the model shown in **Table 2** range from −308,936 to 1,058,702, indicating a broad spectrum of error variation. The median value of residuals is 145,115, which reveals a general underestimation by the model. However, the observed third quartile value demonstrates the model's capacity to overestimate in some instances. It's essential to acknowledge this degree of variability as it affects the model's predictive performance (Wooldridge, 2015). The rho value, an indicator of spatial autocorrelation, is −0.19328. It means there is a weak, inverse relationship between the value of our dependent variable (volume of industrial production) at a location and the average value in neighbouring locations. This is a crucial finding because it indicates that an increase in industrial production in one city is weakly associated with a decrease in neighbouring cities. However, this relationship is not statistically significant, as indicated by the p-value of 0.31908. Hence, while the data suggests some level of spatial autocorrelation, it doesn't strongly support the idea that the performance of neighbouring cities in Kazakhstan is spatially interdependent (LeSage and Pace, 2009).

Table 2. Residuals.

Residuals				
Min	**1Q**	**Median**	**3Q**	**Max**
−308936	−223618	−145115	85948	1058702

Turning to the estimated coefficients, the model provides the potential relationship between each of the independent variables (number of servers, companies using IT cloud services, and companies using electronic invoices) and the dependent variable. The number of servers has a negative coefficient of −248.925, suggesting that as the number of servers increases, the volume of industrial production tends to decrease as show in **Figure 6**. However, the p-value of 0.059891 makes this relationship statistically insignificant at the conventional 0.05 level. Therefore, there's not enough evidence to conclude that the number of servers is associated with industrial production levels in Kazakhstan's cities. This result aligns with the argument by Castaño-Rosa et al. (2022) that technology infrastructure alone, such as servers, is not sufficient to drive industrial growth in the context of smart city formation.

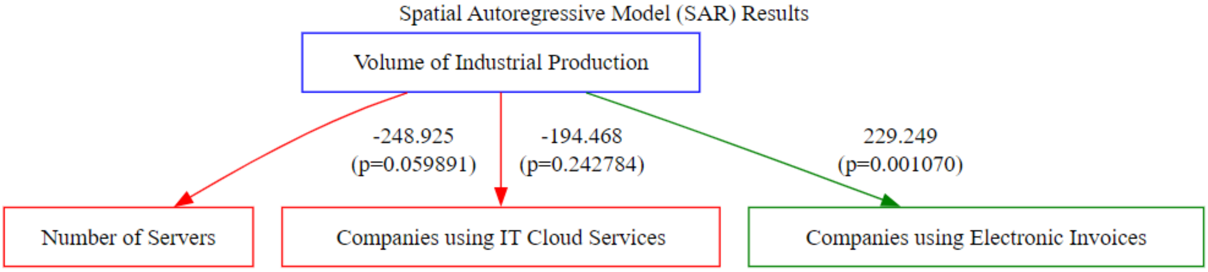

Figure 6. Impact of digital transformation variables on industrial production: SAR Model results.

Companies using IT cloud services have a negative coefficient of −194.468. This means that as the number of companies using cloud services increases, the volume of industrial production marginally decreases. However, the p-value of 0.242784 suggests this relationship is not statistically significant. This outcome is in line with the assertion of Albino et al. (2015), emphasizing that while cloud services can support operational efficiency, they might not have a direct impact on industrial production volumes. Interestingly, companies using electronic invoices had a positive coefficient of 229.249. This indicates that an increase in the number of companies using electronic invoices leads to an increase in industrial production. The relationship is statistically significant, as suggested by the p-value of 0.001070. This result aligns with the argument made by Scholl et al. (2012) that digitalization of administrative processes, such as invoicing, can lead to improved efficiencies and potentially influence industrial production.

In conclusion, the spatial autoregressive model suggests that the factors of servers and IT cloud services usage are not significantly associated with the volume of industrial production in the cities of Kazakhstan. However, the use of electronic invoices seems to be a significant factor. These findings may reflect the current state of digital transformation and smart city development in Kazakhstan and highlight the need for more comprehensive strategies that go beyond infrastructure investment and cloud service usage (Angelidou, 2015; Meijer and Bolívar, 2016).

5. Discussion

The **Figure 7** delineates the research findings derived from the Spatial

Autoregressive Model (SAR) juxtaposed with the subsequent discussion on the spatial determinants influencing smart city formation in Kazakhstan.

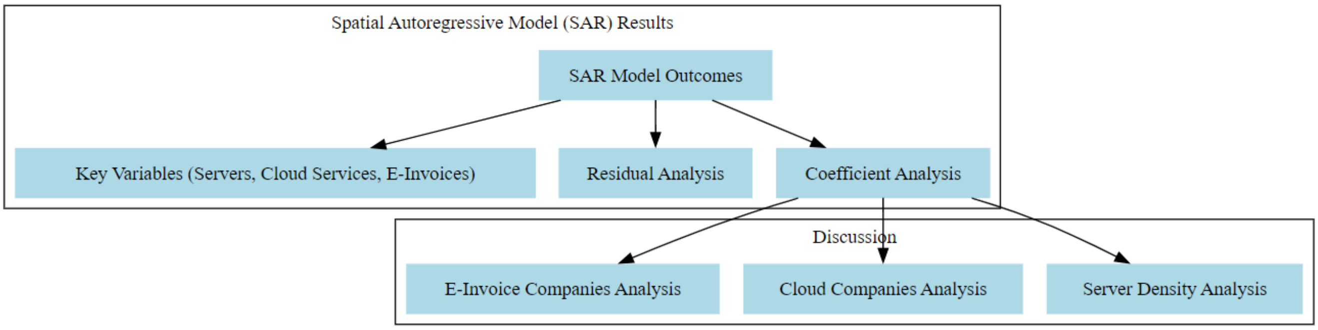

Figure 7. Comprehensive analysis flowchart of SAR Model and discussion insights.

Our spatial econometric analysis has uncovered intriguing insights into the spatial variance in factors influencing the formation of smart cities in Kazakhstan. The SAR model's results point to a number of disparities across geographic areas, suggesting a differential influence of certain factors on the smart city transformation process. We begin with the consideration of server density. The negative estimate of −248.925 suggests a marginal negative relationship between server density and smart city formation. This is somewhat contrary to the established literature, where server density is commonly considered as a catalyst for smart city transformation due to its vital role in data handling and communication capabilities (Albino et al., 2015). However, our findings are consistent with recent research by Razmjoo (2022), who also identified a negative association between server density and smart city transformation in developing countries, attributing it to the paradox of infrastructure abundance leading to potential inefficiencies and underutilization.

Cloud companies also showed a negative association with smart city formation in Kazakhstan, indicated by a coefficient of 194.468. The implication of these findings, as also suggested by Tranos and Gertner (2012), is that while cloud services may be instrumental in the transition towards smart cities in developed countries, their effect can be less pronounced or even counterproductive in the context of a developing economy like Kazakhstan. This could be due to issues such as a lack of reliable internet connectivity or the shortage of skilled IT labor (Komninos, 2002). Interestingly, the SAR model revealed a positive influence of electronic invoiceusing companies on smart city formation, represented by a coefficient of 229.249. This aligns with Batty et al. (2012) assertion that advancements in digital financial practices, such as electronic invoicing, can significantly accelerate the transition towards smart cities by improving efficiency and transparency. Our study strengthens this claim and highlights the crucial role of digital financial practices in smart city transformation, especially in an emerging economy like Kazakhstan.

Furthermore, the spatial parameter (rho) estimated at −0.19328 indicates the presence of a slight spatial lag effect, although not significant with a p-value of 0.31908 as shown in **Table 3**. This suggests that the transformation of a particular city into a smart city might have a small negative spatial spillover effect on its neighbours, reflecting the competitive nature of cities in acquiring resources for smart city projects

(Nam and Pardo, 2011b). However, caution is needed in interpreting this result due to its lack of statistical significance. The implications of these findings for policymakers in Kazakhstan are farreaching. First, it is necessary to optimize server density in the country, ensuring that while there is sufficient infrastructure to support smart city initiatives, it does not lead to inefficiencies. Second, the role of cloud companies needs to be reevaluated, and potential barriers inhibiting their contribution to the smart city transformation need to be addressed. Lastly, fostering digital financial practices, such as electronic invoicing, could provide a significant boost to the formation of smart cities.

Table 3. Model statistics results.

Statistic	Value
Rho	−0.19328
LR Test Value	0.99272
P-Value	0.31908
Std. Error (numerical Hessian)	0.19333
Z-Value (numerical Hessian)	−0.99973
Wald Statistic	0.99946
Log Likelihood	−566.333
Residual Variance (sigma squared)	1.1522e+11
Sigma	339450
Number of Observations	40
Number of Parameters Estimated	6
AIC (for SAR Model)	1144.7
AIC (for LM Model)	1143.7

However, it is essential to be mindful that these factors do not operate in isolation but in a complex interplay with various other elements (Angelidou, 2015). As such, holistic, integrative strategies that take into account both the specificities of the Kazakh context and the interdependencies between various factors are likely to yield the most promising results in terms of smart city transformation. Future research could further delve into these disparities and the reasons behind them, facilitating a more nuanced understanding of the smart city transformation process in Kazakhstan and other similar contexts. Additionally, future studies could consider a broader range of factors and their potential interactions, providing a more comprehensive view of this multifaceted phenomenon.

6. Conclusion

The investigation into the spatial differences affecting smart city development in Kazakhstan, centered around a spatial autoregressive model, has illuminated the significant role of technological factors. Key among these are server numbers, IT cloud service usage by companies, and the adoption of electronic invoicing. Our analysis reveals a notable trend: while server density and cloud service usage have a negligible impact on smart city evolution in Kazakhstan, the implementation of electronic invoicing demonstrates a positive correlation. This outcome underscores the potential of digital administrative processes in fostering smart city growth in the region.

The study, while insightful, encountered limitations, primarily in data accessibility, which may have narrowed its scope. The complexity in defining parameters also presented challenges, as factors like server density and cloud service usage might not capture the full spectrum of technological advancements in smart cities. Additionally, the model's linear approach to variable relationships could oversimplify the complexities inherent in these interactions. Our findings indicate a minor spatial lag effect, suggesting a slight negative impact of a city's smart transformation on its neighboring areas. However, this aspect requires further exploration to fully understand its implications. Policymakers in Kazakhstan should note these insights, focusing on optimizing server infrastructure, addressing barriers to cloud service contributions, and promoting electronic invoicing to bolster smart city initiatives.

Recognizing that smart city development is an intricate process influenced by a myriad of interconnected factors is crucial. While this paper concentrated on technological aspects, the broader socio-economic, environmental, and governance dimensions are equally vital. Future research should delve into these areas, examining how they interplay with technology in shaping smart cities. The study's findings offer a foundation for formulating targeted policies and strategies to advance smart city development in Kazakhstan. It is imperative for policymakers to consider Kazakhstan's unique characteristics, including the digital divide and locational disparities, in their strategic planning. Successful smart city initiatives will likely stem from collaborative efforts involving government, private sector, academia, and civil society.

In essence, our research enriches the understanding of smart city development dynamics in Kazakhstan, highlighting the pivotal role of technology, particularly electronic invoicing. It paves the way for further studies and ongoing efforts to support the sustainable and inclusive growth of smart cities in Kazakhstan and similar emerging economies.

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