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## Conference Paper

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# Are Smart Cities Smart Managers for Digital Equity? : Focusing on spatial autocorrelation among 229 cities in South Korea

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## 1. Introduction

In the relentless pursuit of urban prosperity and sustainability, cities worldwide are undergoing transformative changes, spurred by the Fourth Industrial Revolution and digital transformation (DX). At the forefront of this evolution are Smart Cities, which leverage cutting-edge information and communication technologies (ICT) to enhance public services and improve the overall quality of life for their inhabitants. These technologically advanced cities utilize data-driven decision-making to optimize various sectors, from mobility to governance, promising a new era of urban living. However, technologies that enable smart cities to develop, also risk deepening the digital divide. ICT infrastructure is a crucial element to smart cities' development, but it often overlooks the disparities in digital access and skills among different demographic groups. Preliminary research predominantly focuses on the technological and industrial components necessary for developing smart cities but falls short in addressing the social dimension, particularly the digital divide.

This study aims to bridge this gap by exploring the digital divide within the context of Korean smart cities. The research conducts an empirical analysis of whole South Korean 229 cities and analyzes the impact of ICT infrastructure provision, knowledge-intensive industry specialization, and local governance capability alleviating or exacerbating digital divide.

## 2. Literature Review and Hypothesis

Smart City, which emerged in the era of the Industrial Revolution 4.0. and digital transformation, has now become a global trend. In general, smart cities are defined as cities that aim to enhance the lives of citizens by promoting the convenience of public services such as mobility through technology. Although there is no universal agreement regarding the definition of smart cities, the existing definition on what is 'smart' and 'intelligent' shares a common ground. As the word 'smart' was conceptualized by Apple in 2007 to highlight a certain feature of electronic devices, 'smart' resonated with the quality of supplying real-time digital information and services to the users (Damen, R., 2013). The coined term of smart cities was born in 1994 but it was after 2008, the global dialogue was initiated. The discourse emphasized the role of ICT technology in effectively monitoring urban management and technology-driven innovation (Bollier, 1998). In the early 2010s, the concept was confronted with its ambiguity was questioned by multiple scholars on whether the integration of technology could lead to efficiency in the urban landscape (Hollands, 2008; Neirotti, De Marco, et. al., 2014; Soderstrom et al., 2014). The criticism regarding the lack of emphasis on people, civil society, and institutional governance, expanded the understanding of what makes 'smart city smart'. Subsequently, the terminology added elements of human capital, government, creativity, and

education which led its definition to be diversified and inclusive. In other words, the prior neoliberal urbanism theories that centered around the coined term have expanded their focus to a relatively human-centered approach. Multiple literature highlight the interconnected role of technology, residents and governance of institutions for a smart city to be sustainable of innovative (Nam and Pardo, 2011; Alawadhi et al., 2012, Winters, 2011). Thus, ‘smart city’ elements can be classified into two categories; ‘hard’ domains and ‘soft’ domains (Praharaj and Han, 2019). Hard domains refer to physical infrastructures such as buildings, grids, logistics, technology, etc. Soft domains refer to the application of technology such as education, social capital, policy, inclusion, and division, etc. While ‘smart cities’ aim for a harmonious balance between hard and soft domains, the imbalanced distribution of domains contributes to the debate on whether smart cities alleviate or exacerbate digital disparity.

### 2.1. Smart City in the Republic of Korea

The Republic of Korea (ROK) has been an early adopter of the smart city agenda, being one of the first countries to conceptualize, institutionalize, and innovate the smart city agenda. The initial ‘U-City’ project (abbreviated for ubiquitous city) faced multiple changes in the early 2000s. Though the u-City projects carried out development projects by incorporating new ICT infrastructure, it faced problems of sustainable implementation and maintenance (Hwang et. at., 2022). As a result, the shift of management responsibility from developers to individuals or municipalities compromised long-term sustainability. Additionally, the lack of comprehensive planning and coordination at city and national levels resulted in stagnant development, creating silos that complicated management and technological integration. Based on this experience, the Korean government focused on concrete planning and institutional governance when supporting future smart city initiatives. *The Special Act on the Construction of*

*u-City* was Korea’s first smart city law that ensured that government institutions took part in the designing and urban planning process of smart city development and ultimately enhanced national involvement in its prosperity stages. With the 4th Industrial Revolution Wave, Korean smart cities developed to integrate big data analytics, artificial intelligence, virtual reality, etc as a technological element contributing to the smart city framework. Korea’s smart city regions illustrate the distinctiveness of each smart city project as their vision, core values, and strategic goals are distinct (Kim, 2022).

### 2.2. Concept of Digital Divide

Digital divide(DD) is a complex and multifaceted issue that encompasses disparities in access to technology, digital literacy, and the ability to leverage digital tools for economic and social benefits. The term was first proposed by Lloyd Morriest, the Chair of the Markle Foundation, to address the imbalanced access of ICT technology between the global North and South countries (Compaine, 2001). Preliminary research has laid a foundation by identifying key factors contributing to the divide and assessing various interventions (Papp, 2003; Van Dijk, 2005; Selwyn, 2004; DiMaggio, 2001). Digital divide can be categorized into three levels (Song, 2020; Caragliu, 2023);

- 1st Order: DD in ICT access of connectivity;
- 2nd Order: DD in ICT use or capability;
- 3rd Order: DD in ICT outcomes or content

The 1st order encompasses physical infrastructure such as wifi, broadband, etc. and its impact with DD and the 2nd, 3rd order focus on the humans and their accessibility to resources (education, occupation, social capital) influences DD. While recent literature focuses on the 2nd and 3rd level of DD, this research aims to analyze the physical and social factors that contribute to the urban digital divide. Specifically, within smart cities in Korea, the research analyzes how physical infrastructure, concentration of Knowledge-Based Industries, and institutional governance can

positively or negatively influence digital divide.

### **2.2.1. Digital Divide and ICT Infrastructure**

The role of ICT infrastructure in enhancing digital connectivity has been widely discussed throughout preexisting literature. Preliminary literature illustrates that ICT technology infrastructure (such as high-speed broadband, mobile networks, etc.) enhances accessibility and availability. Norris (2001) and Van Dijk (2005) both emphasize the crucial roles of ICT infrastructure and its contribution towards digital inclusion. Although the infrastructure intends to narrow the digital gap between regions, the disparities of the preexisting constructed infrastructure can lead to impacting the digital divide. Areas with high-speed internet and advanced telecommunication services have stronger connectivity towards government services and accessibility to information, which can be the means for future development (Pew Research Center, 2017). Lynne and Jamison (2009) discuss on this matter, explaining how infrastructure such as broadband technology can contribute to economic growth and sustainable development of the region. Thus ICT infrastructure, although it intends to bridge the digital gap, when its allocation is concentrated to a specific spatial location, the gap can be widened. Based on this understanding, the paper's first hypothesis is as follows;

*H1: ICT infrastructure provision will exacerbate the digital divide in a city.*

### **2.2.2. Digital Divide and Knowledge-Intensive Industry**

Preliminary literature raised questions about the relationship between urban environmental factors and their association with human capital growth (Simon and Nardonelli 2002; Glaeser and Shapiro 2003). Specific urban characteristics can be associated with the spatial allocation of human capital and regional studies throughout academia have attempted to explain this correlation. Winter (2001) explains that 'smart cities' grow apart

based on their ability to retain graduates for their local universities. Moretti (2004) illustrates that highly skilled workers tend to produce knowledge spillovers and earn a higher income when working with other highly- skilled, educated workers. This can explain the phenomenon of 'innovation clusters' like the Silicon Valley (US) or Pango Complex (South Korea) as educated, knowledge-based industries tend to be clustered within close proximity as it can stimulate productivity spillovers. As the concept of smart cities is open to fostering innovation among individuals and firms, smart city regions have a higher possibility to attract entrepreneurs, corporates associated with technology, and skilled individuals, as the abovementioned groups will have the incentive to maximize their potential within smart cities. Thus, based on the preliminary literature, the second hypothesis is as follows;

*H2: Knowledge-intensive industry specialization will deepen the digital divide in a city.*

### **2.2.3. Digital Divide and Governance**

Smart city governance refers to the interaction and decision-making processes by relevant stakeholders regarding urban development. This 'soft' element is emphasized in numerous literatures for its role in vision setting, resource allocation, and information dissemination (Kim, et al., 2022). The absence of effective governance could lead to misrepresentation and lack of inclusion of crucial stakeholders throughout the smart city development and policy-making process. Not only government institutions but also citizens, corporations, academia and civil society need to be informed and involved in the construction process as it could be the foundation for an inclusive urban ecosystem that can prioritize both hard and soft domains (Batty, 2012; Biswas, 2019). Additionally, governance can influence the intensity of knowledge spillovers (Prescott, 1998; Parente and Prescott, 2000). Thus, the governance of openly distributing information

to citizens can alleviate the digital divide in smart cities. *The 22@Barcelona District* is a case in point where the local governance is equipped with high-technology infrastructure, aimed to provide up-to-date information to citizens through open public data (Bakici et al., 2012). Consequently, knowledge spillover occurred within different parts of the region which led to open communication and interactive dialogues between stakeholders. Thus, based on the preliminary literature, the third hypothesis is as below;

*H3. Local governance capability will alleviate the digital divide in a city.*

### 3. Data and Methodology

#### 3.1. Variable Description

For empirical modeling of the hypotheses, e-commerce transaction frequency score variance in a city level was calculated as proxy for digital divide in a city, set as dependent variable. The frequency score data in end of 2021 was extracted from Nonghyup issuing bank, which belongs to National Agricultural Cooperative Federation (NACF) of Korea.

And for independent variables, ICT infrastructure data such as Public Wi-Fi and

Transportation CCTV provision till 2020, were collected from Ministry of Interior and Safety in Korea. Also, Knowledge-Intensive Industry employee number and Governance Capacity data in 2020 were gathered from Ministry of Land, Infrastructure and Transport in Korea.

Last, for control variables, regional characteristics including local tax per capita in a city and road-contact housing ratio were selected as proxy for income level and infrastructure accessibility level respectively. Same as independent variables, data was collected from 2020 period. All variables are introduced in detail in Table 1.

#### 3.2. Ordinary Least Square (OLS) model

Multiple linear regression will be first used for estimation. The Ordinary Least Square (OLS) model equation will be structured as following:

$$\text{Digital Divide}_c = \beta_0 + \beta_1 x_i + \beta_2 k_x + \beta_3 g_x + \beta_4 r_x + \epsilon$$

*c*=city unit

*i*=ict infrastructure provision

*k*=knowledge-intensive industry specialization

*g*=governance capacity

*r*=regional characteristics (control variables)

**Table 1**

*Variables used in the empirical model.*

Variables	Description	Mean (SD)
Digital Divide (DD, Dependent Variable)	Variance of Digital Living Index Score in a city	17,555 (6,766)
WIFI	Number of public Wi-Fi per urban population	0.003 (0.003)
CCTV	Number of CCTV(for public transportation) per urban population	0.001 (0.001)
Data Openness	Number of open data file of local government per urban population	0.001 (0.001)
Urban Governance Network (UGN, dummy)	Whether a city joined (1) Smart City Local Council of South Korea or not (0)	0.520 (0.501)
Urban Governance Systematization (UGS, dummy)	Whether a city got approval (1) of Smart City Plan Document or not (0)	0.162 (0.369)
Creative & Digital industry Specialization (CDI, dummy)	Whether *Location Quotient of the industry in a city is over 1 (1) or not (0)	0.118 (0.323)
Income Level	Local tax per urban population	1,526 (1,125)
Urban Infrastructure Accessibility (UIA)	Road Contact Housing Ratio	24.19 (13.17)

*Note.* \*Location Quotient = (Urban CDI Emp / Urban Total Emp) / (National CDI Emp / National Total Emp)

$\epsilon$ =error term

### 3.3. Spatial Autocorrelation and Spatial Regression model

Tober's First Law of Geography states that "everything is related to everything else, but near things are more related than distant things." This suggests that spatial objects do not exist randomly but rather influence and interact with each other.

According to Doreian (1981), "Traditional linear analysis methods, which assume that variables are random and that error terms are independent and identically distributed, fail to account for spatial dependence and spatial interaction—characteristics exhibited by many socioeconomic phenomena, demographic phenomena, and natural phenomena—in spatially-referenced data." This implies that the OLS model may overestimate or underestimate the influence of each variable.

The term 'Spatial autocorrelation' includes 'positive spatial autocorrelation' and 'negative spatial autocorrelation.' Positive spatial autocorrelation occurs when spatial entities have similar values and are clustered together. Conversely, negative spatial autocorrelation occurs when spatial entities have dissimilar values and are clustered together.

Prior studies have demonstrated the spatial dependence of digital capacity across regions. Consequently, to address the estimation errors expected from spatial autocorrelation in the OLS model, this study first verified the spatial autocorrelation of the dependent variable and the error terms. To confirm the spatial autocorrelation of the variables, a spatial weight matrix reflecting the adjacency of cities on a map was constructed, and statistical tests were conducted. Table 2 shows the results of these tests.

Global Moran's I indicator for dependent variable was calculated to check spatial autocorrelation in range of -1 to 1. The indicator value was 0.378 and significant, which shows high positive spatial autocorrelation of digital divide in a city between cities. Positive spatial autocorrelation in errors was also specified as

significant, which leads to necessity of spatial regression model.

According to Anselin (2005), when Lagrange Multiplier of both lag and error are statistically significant, Robust LM of lag and error are checked. Spatial Lag Model (SLM) is conducted when Robust LM of lag is significant, and Spatial Error Model (SEM) is conducted when Robust LM of error is significant. According to Table 2 result, SEM is recommended to be conducted for

**Table 2**

*Diagnostics for Spatial Dependence of the Weight Matrix*

Test	Value	p-value
<b>Moran's I (error)</b>	<b>6.0616</b>	<b>&lt; 0.001</b>
<b>Lagrange Multiplier (lag)</b>	<b>15.514</b>	<b>&lt; 0.001</b>
Robust LM (lag)	0.065	0.799
<b>Lagrange Multiplier (error)</b>	<b>31.832</b>	<b>&lt; 0.001</b>
<b>Robust LM (error)</b>	<b>16.383</b>	<b>&lt; 0.001</b>

analysis.

## 4. Analysis and Result

Empirical model estimation on 229 observations of South Korean cities were conducted. To confirm the test results in Table 2, total three estimation models were conducted including OLS, SLM and SEM and selected most fitted model.

### 4.1. OLS model Estimation

From Table 3, OLS model result showed that ICT infrastructures provision variables (WIFI, CCTV) and Knowledge-Intensive industry specialization (CDI) deepen DD. On the other hand, Local Governance Capacity (UGN, UGS) and Regional Characteristics (Income Level, UIA) curbed DD.

The model explained 16.7% of dependent variable. Multicollinearity condition number was checked and was not considered suspect. Normality of errors (Jarque-Bera) and heteroskedasticity tests (Breusch-Pagan Test) were conducted and both were significant.

**Table 3***Ordinary Least Squares (OLS) estimations on digital divide (DD)*

Variables	Coefficient	p-value	t-Statistic
constant	20388.5	0.000	14.1952
<b>WIFI</b>	<b>324,940</b>	<b>0.072</b>	<b>1.807</b>
<b>CCTV</b>	<b>964,282</b>	<b>0.098</b>	<b>1.660</b>
Data Openness	-111,983	0.774	-0.288
<b>UGN</b>	<b>-2,556.7</b>	<b>0.005</b>	<b>-2.8612</b>
<b>UGS</b>	<b>-2,141.98</b>	<b>0.075</b>	<b>-1.791</b>
<b>CDI</b>	<b>3,276.35</b>	<b>0.019</b>	<b>2.362</b>
<b>Income Level</b>	<b>-1.104</b>	<b>0.005</b>	<b>-2.814</b>
<b>UIA</b>	<b>-63.782</b>	<b>0.064</b>	<b>-1.862</b>
Observations	229	Log likelihood	-2,319.23
R <sup>2</sup> (adjusted)	0.166	Akaike info criterion (AIC)	4,656.47
		Schwarz criterion (SC)	4,687.37
Regression Diagnostics	Value	p-value	
Multicollinearity Condition Number	9.203		
<b>Test on Normality of Errors (Jarque-Bera)</b>	<b>13.0127</b>	<b>0.001</b>	
<b>Diagnostics for Heteroskedasticity (Breusch-Pagan Test)</b>	<b>21.640</b>	<b>0.006</b>	

Note. According to Center for Geographic Analysis in Harvard University, multicollinearity is suspected when the condition number is greater than 20.

## 4.2. SLM Estimation

From Table 4, SLM model result showed that still ICT infrastructures provision variables (WIFI, CCTV) and Knowledge-Intensive industry specialization (CDI) deepen DD. On the other hand, only UGN was significant in Local Governance Capacity variables and both Regional Characteristics (Income Level, UIA) curbed DD. Which means UGS curb effect on DD was overestimated in OLS model without controlling spatial autocorrelation.

Rho shows that DD in a city getting 25.1% spillover effect from adjacent cities. The model explained 25.2% of dependent variable. Heteroskedasticity tests (Breusch-Pagan Test) and likelihood ratio test result shows SLM model significant.

According to Anselin (2005), higher the value of Log Likelihood, and lower the value of Akaike info criterion (AIC) and Schwarz criterion (SC), more the fitted model, which shows SLM more fitted than OLS model.

**Table 4***Spatial Lag Model (SLM) estimations on DD*

Variables	Coefficient	p-value	z-value
<b>Rho</b>	<b>0.251</b>	<b>&lt; 0.001</b>	<b>3.652</b>
constant	15,772.9	< 0.001	8.297
<b>WIFI</b>	<b>289,772</b>	<b>0.088</b>	<b>1.704</b>
<b>CCTV</b>	<b>990,733</b>	<b>0.071</b>	<b>1.804</b>
Data Openness	-142,856	0.697	-0.389
<b>UGN</b>	<b>-2,235.11</b>	<b>0.008</b>	<b>-2.634</b>
UGS	-1,433.69	0.206	-1.265
<b>CDI</b>	<b>3,237.39</b>	<b>0.014</b>	<b>2.469</b>
<b>Income Level</b>	<b>-1.065</b>	<b>0.004</b>	<b>-2.871</b>
<b>UIA</b>	<b>-54.564</b>	<b>0.094</b>	<b>-1.673</b>
Observations	229	Log likelihood	-2,312.39
R <sup>2</sup>	0.252	Akaike info criterion (AIC)	4,644.79
		Schwarz criterion (SC)	4,679.12

## 4.3. SEM Estimation

From Table 5, SEM model result showed that only CCTV was significant in ICT infrastructures provision variables and still Knowledge-Intensive industry specialization (CDI) deepen DD. On the other hand, UGN of Governance Capacity variables and only Income Level was significant among Regional Characteristics variables, which alleviated DD. This shows exacerbating effect of WIFI and mitigating effect of UIA on DD was overestimated in SLM model without controlling spatial autocorrelation.

Lambda shows the error terms of OLS equation are affected by 51.4% of spillover effect from nearby cities. The model explained 34.1% of dependent variable. Heteroskedasticity tests (Breusch-Pagan Test) and likelihood ratio test result shows SEM model significant.

## 4.4. Model Selection

Summarizing the results of estimation models, SEM model was selected as most fitted model due to the highest R-squared and Log Likelihood, also due to the lowest AIC and SC.

Though some variables were excluded because of overestimation regarding uncontrolled spatial autocorrelation effect, the SEM model still approves and supports the hypotheses of the study.

**Table 5***Spatial Error Model (SEM) estimations on DD*

Variables	Coefficient	p-value	z-value
<b>Lambda</b>	<b>0.514</b>	<b>&lt; 0.001</b>	<b>6.970</b>
constant	20733.1	< 0.001	13.533
WIFI	141,122	0.394	0.852
CCTV	<b>948,947</b>	<b>0.059</b>	<b>1.890</b>
Data Openness	-117,638	0.736	-0.337
UGN	<b>-2,195.78</b>	<b>0.006</b>	<b>-2.726</b>
UGS	-688.487	0.539	-0.614
CDI	<b>3,028.91</b>	<b>0.037</b>	<b>2.083</b>
Income Level	<b>-0.959</b>	<b>0.008</b>	<b>-2.645</b>
UIA	-57.987	0.137	-1.485
Observations	229	Log likelihood	-2,303.25
R <sup>2</sup>	0.341	Akaike info criterion (AIC)	4,624.5
		Schwarz criterion (SC)	4655.41

## 5. Discussion and Conclusion

In the era of digital transformation, smart cities became one of urban innovation trends. This study aims to empirically examine the factors influencing the digital divide and their way of effects in South Korean cities, which have high level of ICT Infrastructure development. Additionally, considering that digital capabilities have spatial dependence among neighboring regions, spatial regression model was implemented.

The analysis result showed that the supply of regional ICT infrastructure and the specialization in knowledge-intensive industries exacerbate the digital divide, while higher regional governance capabilities, infrastructure accessibility, and living standards mitigate it. This confirms that the provision of technological and industrial infrastructure to achieve smart city goals without considering governance capacity, can actually deepen the digital divide, negatively affecting citizens' lives.

This study suggests to urban planners and policymakers that, as demonstrated by the failures of Korea's existing U-City projects in 2000s, the development of technology and industrial infrastructure must be accompanied by improvements in governance capabilities. Furthermore, this study not only emphasizes the importance of local governance capabilities but also highlights that, even with digital technologies

that overcame spatial constraints, the users are eventually humans. Therefore, digital transformation cannot be out of sight from the unique characteristics of regions and the neighboring effects between them. Urban geography remains significant in the digital transformation age.

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