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Transit-oriented Development (TOD) and Local Economic Vitality: Assessing TOD Effects on Consumer Expenditures in Seoul

Sangwan Lee and Kuk Cho*

LX Spatial Information Research Institute, Korea Land and Geospatial Informatix Corporation, 42, Jisaje 2-ro, Iseo-myeon, Wanju, 55365, and Republic of Korea

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We quantified the impact of transit-oriented development (TOD) on consumer expenditures in seven sectors, including retail, healthcare, culture, and education, in Seoul, South Korea, employing propensity score matching, ordinary least square regression, and geographically weighted regression (GWR). Our findings revealed that TOD significantly increases consumer expenditures, with sectoral effects ranging between 20.1 and 21.3%. Crucially, the GWR analysis highlights the spatially dependent nature of TOD impact, uncovering substantial local variations. Districts such as Gangnam, Songpa, Gangdong, and Gangseo-gu exhibit pronounced positive effects, with consumer spending increases exceeding 88.3%, indicating the potential of TOD as a catalyst for economic growth in these strategic areas. Conversely, areas such as Dobong, Seodaemun, and Geumcheon-gu show marginally negative effects, suggesting that TOD benefits are not uniformly distributed and may pose challenges in certain contexts. This study contributes to the literature by providing empirical evidence of the economic impact of TOD across diverse sectors and offering valuable insights for transportation and urban planning, emphasizing the need for context-sensitive approaches to maximize TOD outcomes.

1. Introduction

The landscape of transportation and urban planning is transitioning from the traditional model of disjointed land uses linked by highways and roads to a trend favoring compact, diversified developments connected by efficient public transit systems.[1,2] This paradigm shift has propelled transit-oriented development (TOD) to the forefront of urban discourse, with scholars consistently highlighting its potential to harmonize land use and transportation infrastructure.[3–5] TOD seeks to optimize the spatial configuration of land uses and transportation networks to maximize the ease and efficiency with which individuals can access destinations such as employment centers, retail establishments, and recreational amenities.[6,7]

*Corresponding author: e-mail: kcho@lx.or.kr
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Central to the discussion of TOD is the concept of agglomeration economies, which explains how spatial clustering of economic activities leads to productivity gains and innovation spillovers through improved knowledge exchange, labor market pooling, and economies of scale. With the seminal work of Marshall,[8] agglomeration economies posit that the spatial clustering of economic activities engenders productivity gains and innovation spillovers owing to enhanced knowledge exchange, labor market pooling, and economies of scale.[9,10] In TOD contexts, the concentration of diverse land uses and job opportunities around transit hubs can stimulate synergistic interactions among businesses, employees, and consumers, thereby boosting local economic vitality and fostering economic agglomeration effects.[11–13]

A considerable body of research has already been committed to examining the economic effects of TOD. A focal point has been the property value premium associated with TOD, with the majority of studies indicating that to-transit and by-transit accessibilities[14] contribute to a higher property value. Another significant aspect is the examination of consumer spending patterns, particularly in transportation expenditures, in TOD compared with other areas. However, a few studies have quantified the effect size.[15] For instance, Dong[16] found significant differences in transportation expenditures between households in TODs in California and those in non-TOD areas, with TOD households saving approximately 6% annually, or $429, after adjusting for demographic and neighborhood factors. Similarly, Lee[17] revealed that households in TODs saved $493 on transportation expenditures annually compared with those in non-TODs in the U.S.

Despite these findings, there is limited research into how TOD influences consumer spending in other sectors such as retail, healthcare, education, and entertainment. Most studies focus predominantly on housing and transportation expenditures, overlooking the broader economic impacts of TOD. Moreover, while existing research provides insights into the effects of TOD at a macrolevel, there is a paucity of studies that delve into the local-level analysis of TOD impact on consumer expenditures. Variations in TOD impacts across different neighborhoods within a city have not been sufficiently explored, leaving a gap in understanding how TOD influences economic activity at a more granular scale.

Therefore, in this study, we aimed to empirically investigate the economic impact of TOD in Seoul, Republic of Korea, with a particular focus on elucidating the spending behaviors of individuals in diverse sectors (i.e., retail, healthcare, transportation, leisure, culture, education, and entertainment). Moreover, we employed geographically weighted regression (GWR) to explore the spatially varying effects of TOD on consumer expenditure patterns at the local level. We also employed a combination of advanced econometric techniques such as propensity score matching (PSM) to disentangle the TOD effect compared with non-TOD with similar characteristics.

Through the synthesis of theoretical insights from transportation economics and empirical analysis of real-world data, we aimed to deepen our understanding of the mechanisms driving the economic dynamics of TOD. By examining expenditures in sectors such as retail, healthcare, transportation, leisure, culture, education, and entertainment, this study will extend the understanding of TOD impact beyond housing and transportation, providing valuable insights into how TOD influences various consumer spending behaviors. Moreover, building upon the

agglomeration economies framework, we investigated how the clustering of economic activities around transit nodes contributes to local economic vibrancy and productivity gains. Ultimately, our findings will guide evidence-based urban policy formulation and infrastructure planning, contributing to sustainable and inclusive urban growth.

2. Data, Materials, and Methods

2.1 Study area

We selected commercial areas in Seoul, Republic of Korea, as study areas for the following reasons. First, Seoul has been at the forefront of TOD initiatives, with extensive investments in public transportation infrastructure such as the Seoul Metropolitan Subway system and integrated bus networks. The commitment to TOD principles, characterized by compact, mixed-use developments centered on transit nodes, makes it an ideal case study for investigating the economic impacts of TOD. Second, as one of the largest metropolitan areas in the world, Seoul boasts a diverse economic landscape encompassing various sectors such as finance, technology, manufacturing, retail, healthcare, and entertainment. Third, the proactive stance of Seoul on urban planning and sustainable development is evident from initiatives such as "Green New Deal" and "2030 Seoul Plan." These initiatives underscore the policy significance of studying TOD within the urban context, offering valuable insights for urban policymakers and planners seeking to leverage TOD as a catalyst for economic growth, social inclusion, and environmental stewardship. Fourth, Seoul benefits from robust data infrastructure and accessibility, with comprehensive datasets available from various government agencies, research institutions, and private sector entities. This abundance of data facilitates rigorous empirical analysis and enhances the reliability and validity of research findings. Therefore, the selection of Seoul as the study area offers a strategic vantage point for our study.

2.2 Data

In this study, the dependent variables focus on the amount of consumer expenditure aggregated at the commercial district level, as defined by the Seoul Metropolitan Government, and are measured on a quarterly basis in 2023. The consumer expenditure data is derived from credit/debit card transactions and is categorized into seven distinct sectors: (1) retail, (2) healthcare, (3) transportation, (4) leisure, (5) culture, (6) education, and (7) drinking (see Table 1). This classification follows the Korean Standard Industrial Classification. Each sector represents a key dimension of economic activity within TOD, providing insights into the diverse spending patterns and economic dynamics shaping urban environments. The total number of commercial areas analyzed in Seoul was 1651.

Table 1
Description and descriptive statistics of variables on consumer spending in seven sectors

Name	Description	Descriptive Statistics			
		Matched (N = 3654)		Unmatched (N = 5789)	
		Mean	S.D.	Mean	S.D.
Total	Total amount of spending on all sectors	21	1.0	21	1.1
Sector 1	Log-transformed amount of spending on retail sector, including groceries, clothing, electronics, and other consumer products	20	1.0	20	1.0
Sector 2	Log-transformed amount of spending on healthcare sector, including medical services, prescription medications, and healthcare-related expenses	19	1.0	19	1.0
Sector 3	Log-transformed amount of spending on transportation costs incurred by individuals for commuting, travel, and transportation-related services	19	1.0	19	1.1
Sector 4	Log-transformed amount of spending on recreational activities, including restaurants, theaters, and sports facilities	18	1.0	17	1.1
Sector 5	Log-transformed amount of spending on cultural events, arts, and heritage activities, including museum visits, art exhibitions, and cultural festivals	17	1.0	17	1.1
Sector 6	Log-transformed amount of spending on education expenses, including tuition fees, school supplies, private educational institutions, and educational programs	19	1.0	19	1.1
Sector 7	Log-transformed amount of spending on drinking expenses, including ale, beer, wine, liquor, and other alcoholic beverages	18	1.0	17	1.1

Matched refers to the paired sets of TOD and non-TOD areas created through a matching process (i.e., PSM). Unmatched denotes the sets of TOD and non-TOD areas prior to the application of PSM.

2.3 Operationalization of TOD

We operationalized TOD on the basis of commercial area designations defined by the Seoul Metropolitan Government. While previous studies widely define TODs as compact, mixed-use developments near transit facilities, characterized by (1) relative density (multistory development), (2) mixed land uses (residential, retail, entertainment, and sometimes office), and (3) adjacency to transit facilities,[18] it is imperative to assess the appropriateness of TOD designation by the Seoul Metropolitan Government. Table 2 illustrates that the density of residents, de facto population, and commercial building density within TOD areas significantly surpass those of non-TOD areas. Moreover, the point of interest (POI) diversity within TOD zones, with a value of 11.054, exceeds that of non-TOD areas, which recorded 10.752. Based on this validation process, our study adheres to the TOD designation set forth by the Seoul Metropolitan Government.

Table 2
Description and descriptive statistics of control factors used in PSM.

Variables		Mean			
		Matched (N = 3654)		Unmatched (N = 5789)	
		TOD	Non-TOD	TOD	Non-TOD
1	Resident density	0.026	0.026	10.307	9.152
2	De facto population density	10.585	10.366	0.026	0.028
3	Area	123702	111664	129943	93354
4	Average income of residents	2903561	2939314	2924661	2759819
5	Averaged apartment price	254329156	260333144	259706957	249248049
6	Building density	1368.3	1343.5	1683.573	1127.154
7	Place of interest (POI) diversity	11.088	11.157	11.054	10.752
8	Compactness	157.489	156.696	160.247	147.222

Matched refers to the paired sets of TOD and non-TOD areas created through a matching process (i.e., PSM). Unmatched denotes the sets of TOD and non-TOD areas prior to the application of PSM.

2.4 Methodological approach

We used two-step processes to quantify the treatment effect, which is the impact of TOD on consumer spending in each sector. As shown in Fig. 1, the two steps include (1) finding appropriate TODs and non-TODs that share similar characteristics using PSM, and (2) exploring the treatment effect using paired t-test, ordinary least square (OLS) regression, and GWR. By employing a combination of advanced econometric techniques and spatial analysis, we aimed to provide a robust empirical assessment of the economic impacts of TOD in Seoul.

2.5 Propensity score matching and treatment effect

We used PSM to create comparable groups, which are TODs (treatment group) and non-TODs (control group) in this study, of subjects on the basis of their propensities.[19,20] That is, since PSM is a statistical technique commonly used in observational studies to reduce bias, we used it to find matched samples of commercial areas within TOD and non-TOD, ensuring that the two groups are comparable in terms of observed characteristics in Table 3. Leveraging this method, we endeavored to disentangle the direct effects of TOD from confounding factors, shedding light on the true economic dividends associated with this urban development strategy.

The process of PSM is as follows. First, we defined the pools of the treatment group, which is commercial areas defined as TOD by the Seoul Metropolitan Government. Second, we estimated the propensity scores for each individual commercial area in the dataset. The propensity score is the probability of being assigned to the treatment group on the basis of observed covariates by using the nearest neighborhood method with the calipers of 0.2.[21] Third, after matching, the balance of covariates between the treatment and control groups was assessed to ensure that matched samples are comparable. Here, we used standardized differences, variance ratio, and empirical cumulative distribution functions (eCDF) mean, and the results in Table 3 confirm that our PSM model finds comparable matched sets and rules out confounding effects.

Then, by employing paired t-test and OLS regression, we assessed the treatment effects of TOD on consumer spending in each sector at both the global and local levels, providing a

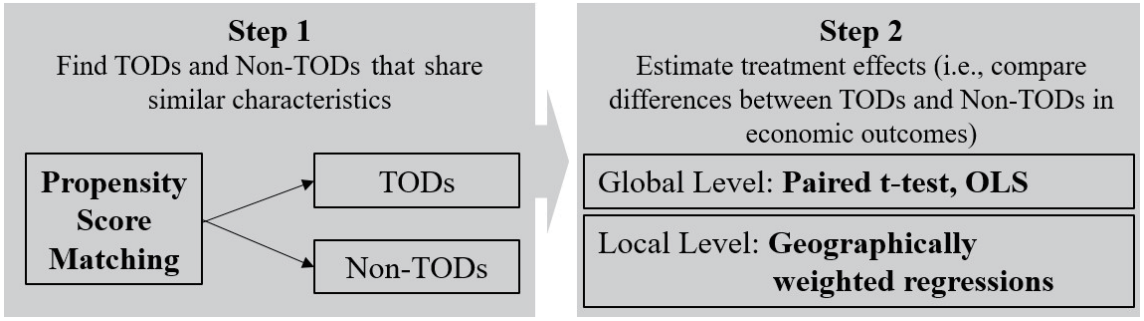

Fig. 1. Experimental setup used in this study.

Table 3
Balance of PSM for matched and unmatched data.

Variables		Std. Mean Diff		Var. Ratio		eCDF Mean	
		Matched	Unmatched	Matched	Unmatched	Matched	Unmatched
	Distance	0.020	0.527	1.043	1.349	0.003	0.175
1	Pop Den	0.009	0.147	1.048	1.748	0.012	0.061
2	De facto Pop	0.027	0.164	1.257	1.007	0.016	0.047
3	Area	0.113	0.343	0.550	0.780	0.076	0.141
4	Income	0.049	0.226	0.791	1.084	0.031	0.099
5	Housing price	0.027	0.048	1.021	0.922	0.034	0.058
6	Building density	0.005	0.121	0.854	4.928	0.018	0.057
7	Old buildings	0.022	0.172	0.968	1.051	0.013	0.053
8	POI diversity	0.031	0.135	0.821	0.863	0.015	0.017
9	Compactness	0.011	0.183	0.838	1.224	0.027	0.055

Matched refers to the paired sets of TOD and non-TOD areas created through a matching process (i.e., PSM). Unmatched denotes the sets of TOD and non-TOD areas prior to the application of PSM.

comprehensive understanding of the economic impacts of TOD in Seoul. To estimate the treatment effect for paired matched sets of TODs and non-TODs, we employed the paired t-test and OLS regression. A paired t-test was conducted to compare the mean consumer spending in each sector between TOD and non-TOD areas.[22] The null hypothesis states that there is no difference in mean consumer spending between the two groups, while the alternative hypothesis posits that there is a significant difference. Also, OLS models were constructed to estimate the relationship between TOD (treatment variable) and log-transformed consumer spending outcomes in each sector (dependent variable) while controlling for seasonal effects.[17]

2.6 Geographically weighted regression

Recognizing the spatial heterogeneity inherent in urban environments, we augmented our analysis with GWR models. GWR provides a nuanced understanding of how the economic impacts of TOD vary across different geographic contexts, accounting for localized factors.[23,24] By incorporating spatially explicit techniques, our study transcends the limitations of traditional regression analysis, offering insights into the spatially contingent nature of the economic benefits engendered by TOD. The spatially varying coefficients from the GWR models provide insights into how the impact of TOD on consumer spending varies across different neighborhoods within Seoul.

3. Results

In this section, we present three analysis results: (1) spatial distribution of spending patterns in each sector using heat map and hotspot analysis, (2) the impact of TOD on spending at the global level using PSM, paired t-test, and OLS, and (3) the locally varying economic impact of TOD using GWR.

3.1 Spatial distribution of consumer expenditure patterns

Before delving into the estimation of treatment effects, we conducted a comprehensive spatial analysis to scrutinize the distribution of total consumer expenditures across various districts within Seoul. The findings, as depicted in Fig. 2, revealed several notable patterns and trends that are crucial for understanding the economic dynamics of the city.

Our analysis identified a pronounced spatial concentration of consumer expenditures in specific high-activity areas, including Gangnam, Lotte World, Hyundai Department Store Mokdong, Gimpo International Airport, Eunpyeong Hanok Village, and Seoul Children's Grand Park. These locations are characterized by a significant influx of consumer spending, indicating their role as economic hubs within the city. Notably, these areas are also in close proximity to key subway stations, highlighting a strong correlation between public transit accessibility and economic vibrancy. This spatial congruence suggests that TOD corridors play a pivotal role in shaping consumer behavior, with public transit accessibility acting as a catalyst for increased economic activity.

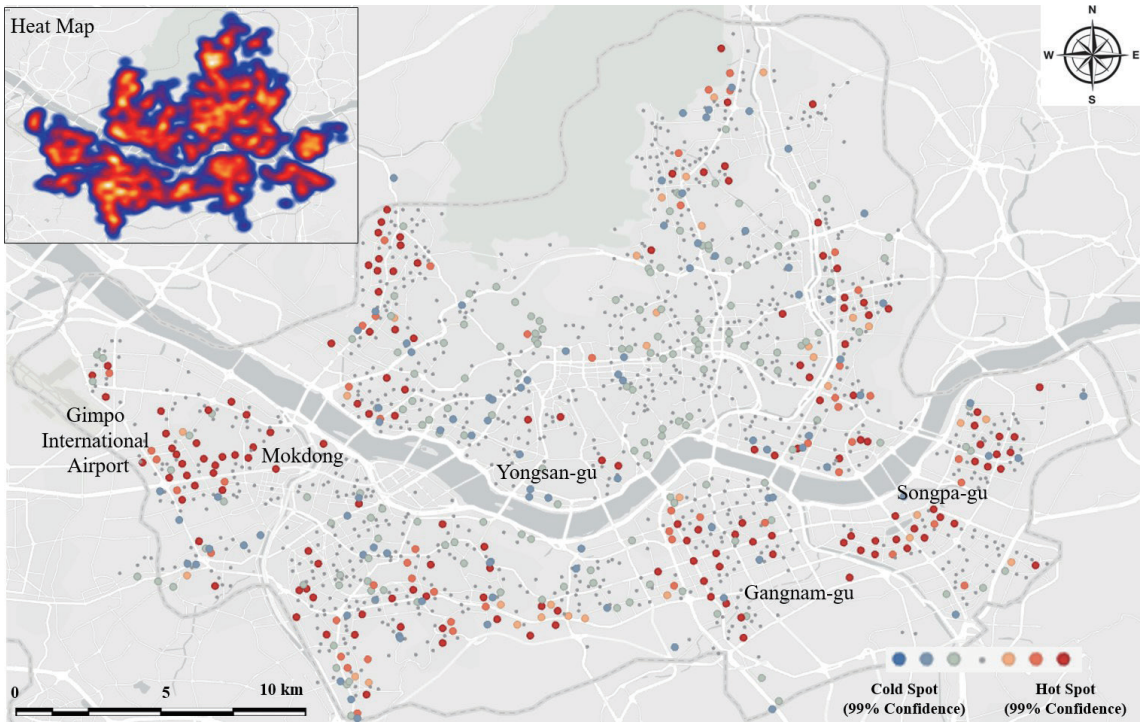

Fig. 2. (Color online) Hot spot analysis results on total consumer expenditures in Seoul.

Additionally, the spatial analysis further revealed that consumer expenditure patterns exhibit a consistent distribution across various economic sectors, including retail, entertainment, and education. Despite the diverse nature of these sectors, the spatial distribution of spending is remarkably homogeneous, with only marginal differences observed between them. This uniformity suggests that the influence of TOD on consumer spending is not limited to specific sectors but rather permeates across different types of economic activity. The consistent spatial patterns across sectors underscore the broad impact of TOD, implying that areas with enhanced transit accessibility are likely to benefit from increased consumer engagement across multiple economic domains.

3.3 Difference in consumer expenditures between TOD and non-TOD areas

Table 4 presents the results of comparing average consumer spending across different economic sectors between TOD and non-TOD areas, expressed in Korean Won. The analysis includes both a matched sample, derived using PSM, and an unmatched sample to facilitate a robust comparison. The data revealed a clear and consistent trend: consumer spending is significantly higher in TOD areas than in non-TOD areas. This pattern holds true across both the matched and unmatched samples, with average total consumer spending in TOD areas recorded at 1664285994 won in the matched sample and 1680293963 won in the unmatched sample. This substantial spending disparity underscores the enhanced economic activity within TOD areas, suggesting that proximity to transit hubs may play a pivotal role in stimulating consumer behavior.

The expenditure gap between TOD and non-TOD areas is evident across all seven sectors analyzed (Sectors 1 to 7). The consistency of this trend, regardless of the matching methodology, indicates that TOD areas not only attract higher overall consumer spending but also do so uniformly across diverse economic sectors. This finding aligns with previous research that highlights the multisectoral benefits of TOD, where enhanced accessibility and connectivity foster economic vibrancy across various domains, including retail, entertainment, and services.

Table 4
Difference in average consumer spending in each sector between TOD and non-TOD areas.

Variables	Matched		Unmatched	
	TOD	Non-TOD	TOD	Non-TOD
Total	1664285994	1405527349	1680293963	1249604396
Sector 1	754055337	639156690	760332185	570880023
Sector 2	207751819	177060552	209144796	160512298
Sector 3	275466279	230145841	278425232	203665980
Sector 4	65243649	55314762	66244599	48270290
Sector 5	51740380	43844233	52173721	38710427
Sector 6	238898695	199844704	242205397	174493002
Sector 7	71129835	60160566	71768033	53072376

Note: the unit is Korean currency (Won).
Matched refers to the paired sets of TOD and non-TOD areas created through a matching process (i.e. PSM). Unmatched denotes the sets of TOD and non-TOD areas prior to the application of PSM.

Table 5 shows the results of extending this analysis by estimating the treatment effects of TOD on consumer spending using both paired t-tests and OLS regression models. These models quantify the impact of TOD on consumer behavior, providing a more nuanced understanding of the economic implications. The results from both the paired t-tests and OLS regression models indicate that TOD areas experience a statistically significant increase in consumer spending compared with non-TOD areas. Specifically, the estimated treatment effect size for total consumer spending is 20.6%, signifying a notable increase in the volume of goods and services purchased in TOD areas. This effect size is consistent across all sectors and ranges from 20.1 to 21.3%, reinforcing the robustness of the finding that TOD areas drive higher economic activity.

Notably, when PSM is not applied, the treatment effect size is slightly inflated in the unmatched sample, with estimates ranging from 24.9 to 26.5%. This overestimation highlights the importance of employing rigorous matching techniques, such as PSM, to accurately assess the true impact of TOD on consumer expenditures. The adjustment provided by PSM ensures that the treatment effect is not confounded by other factors, thereby offering a more precise measurement of the TOD effect.

3.3 Local variations in the economic effect of TOD

After identifying the matched sample through PSM, we advanced to parameter estimation using the GWR model. This approach allowed us to quantify the locally varying treatment effects of TOD on total consumer expenditures across different areas of Seoul. While GWR models were developed for each sector, the marginal differences observed between sectors, as previously noted, led us to focus primarily on total consumer expenditures for this analysis.

Unlike the global treatment effects captured by PSM and descriptive statistics, the GWR model uncovers significant spatial variations in the economic impact of TOD across Seoul. Figure 3 illustrates the spatial distribution of TOD coefficients at the local level, revealing a highly heterogeneous economic landscape. In particular, areas such as Gangnam, Songpa, Gangdong, and Gangseo-gu exhibit the most substantial positive treatment effects, with

Table 5
Treatment effects estimated using paired t-test and OLS regression models.

Variables	Matched		Unmatched	
	Paired *t*-test	OLS	*t*-test	OLS
Total	0.219***	0.206***	0.363***	0.255***
Sector 1	0.222***	0.208***	0.357***	0.256***
Sector 2	0.220***	0.206***	0.337***	0.249***
Sector 3	0.217***	0.202***	0.366***	0.253***
Sector 4	0.216***	0.201***	0.379***	0.251***
Sector 5	0.226***	0.213***	0.375***	0.265***
Sector 6	0.215***	0.203***	0.391***	0.257***
Sector 7	0.221***	0.208***	0.374***	0.261***

Note: *Significant at $p < 0.10$; ***Significant at $p < 0.05$; ***Significant at $p < 0.01$.
Matched refers to the paired sets of TOD and non-TOD areas created through a matching process (i.e., PSM). Unmatched denotes the sets of TOD and non-TOD areas prior to the application of PSM.

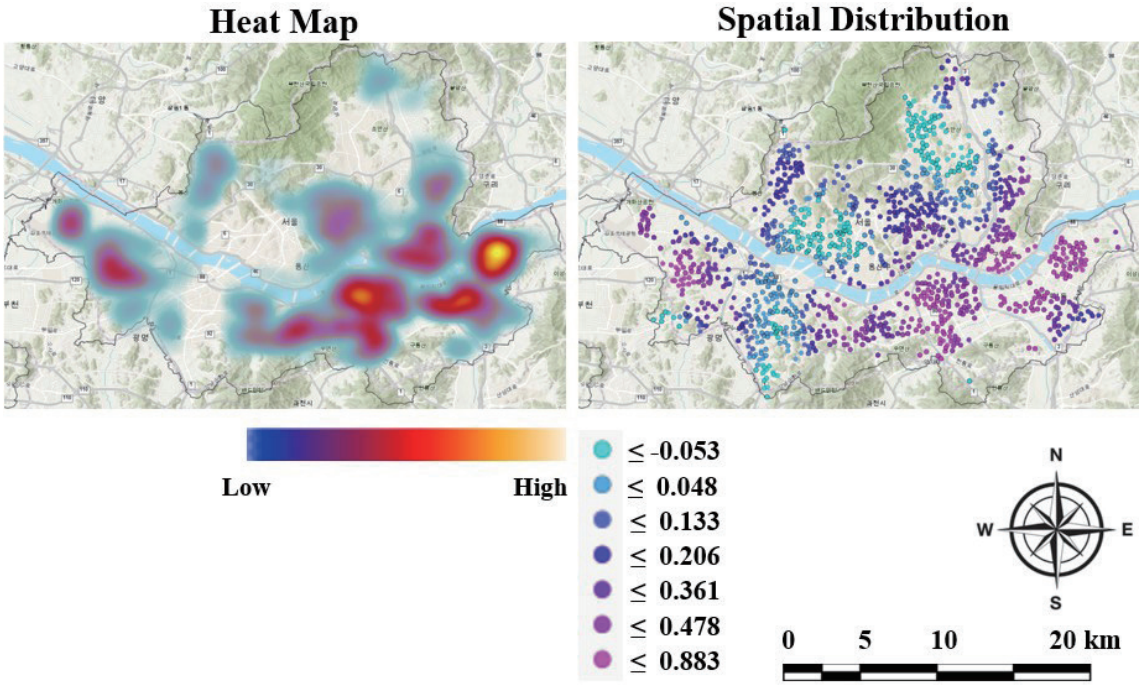

Fig. 3. (Color online) Spatial variations in the treatment effect of TOD on total consumer expenditures using GWR.

increases in consumer spending surpassing 88.3%. This suggests that TOD implementation in these districts is particularly effective in driving economic activity.

Interestingly, the GWR analysis also identifies areas where TOD has marginally negative effects on consumer spending, a finding that is not evident in PSM or descriptive statistics. For example, districts such as Dobong, Seodaemun, and Geumcheon-gu showed slight declines in consumer expenditures, with treatment effects of around −5.3%. These localized negative impacts highlight the complexity of the TOD effect, suggesting that the benefits of TOD are not uniformly distributed across all areas and may even result in adverse effects in certain contexts.

Figure 4 presents the spatial distribution of local R-squared values from the GWR model, indicating the statistical significance of the TOD economic impact across different areas. Higher local R-squared values, exceeding 0.167 in some regions, point to areas where the TOD influence on consumer spending is both statistically significant and more pronounced. This spatial variability emphasizes that the strength and significance of the TOD economic impact vary considerably across Seoul, underlining the importance of localized analysis.

4. Discussion

In this study, we delved into the impact of TOD on consumer expenditures across various sectors in Seoul, South Korea. By leveraging publicly available datasets and employing advanced econometric techniques such as PSM, OLS, and GWR, we have uncovered key insights into the economic dynamics of TOD and its broader implications for urban policy and planning. Our rigorous analytical approach provides robust empirical evidence of the economic impacts of

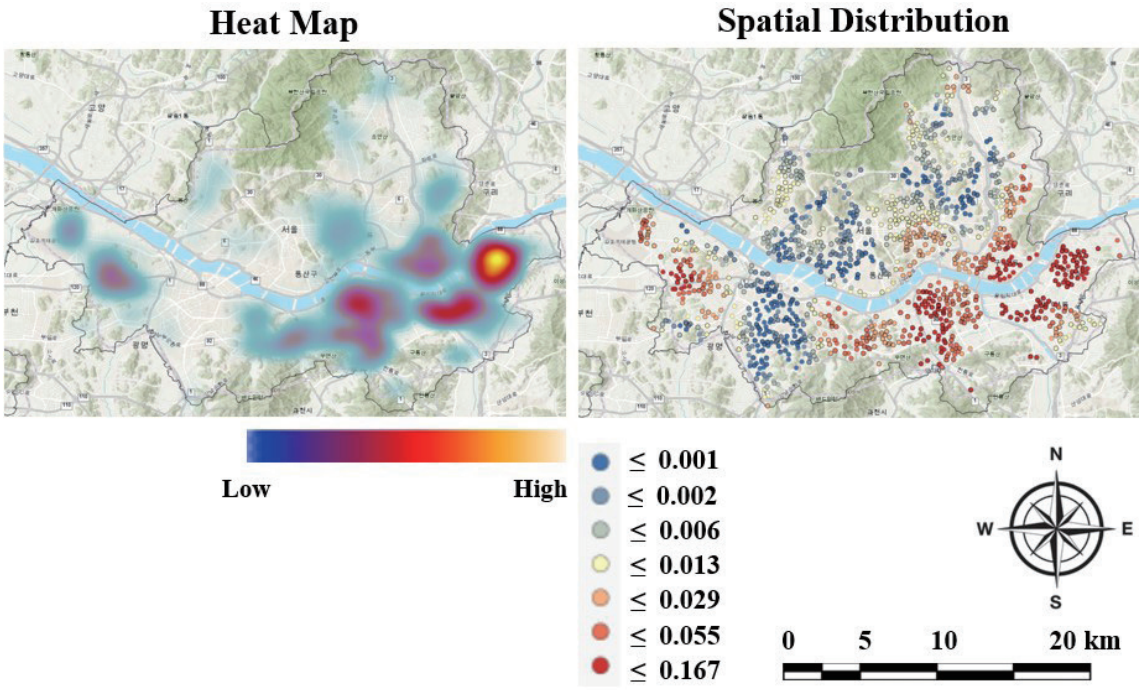

Fig. 4. (Color online) Spatial variations in local R-squared for the coefficient of TOD in the GWR model.

TOD in Seoul, offering valuable insights that contribute to the existing body of knowledge on urban development.

One of the most significant contributions of this study is the identification of the spatially dependent nature of TOD impact. Unlike previous studies that have primarily focused on aggregated or global effects, our use of the GWR model allows us to reveal substantial local variations in TOD's influence on consumer spending across Seoul. Specifically, districts such as Gangnam, Songpa, Gangdong, and Gangseo-gu exhibit pronounced positive treatment effects, with consumer spending increases exceeding 88.3%. This finding highlights the potential of TOD to act as a catalyst for economic growth in strategically important areas. Conversely, the discovery of marginally negative treatment effects in areas such as Dobong, Seodaemun, and Geumcheon-gu suggests that TOD benefits are not universally distributed and may even present challenges in certain contexts.

Furthermore, our study provides consistent and robust evidence of the positive impact of TOD on consumer expenditures across various sectors, with statistically significant treatment effects ranging between 20.1% and 21.3%. This sectoral consistency reinforces the role of TOD in stimulating economic activity and fostering vibrant urban economies. The validation of our findings through PSM enhances confidence in these results by ensuring the comparability of matched samples, thereby offering a more reliable basis for understanding the economic benefits of TOD.

The findings of this study underscore the strategic importance of TOD as a policy tool for promoting sustainable urban development and enhancing mobility in Seoul. The identification of spatially heterogeneous impacts suggests that TOD policies should be tailored to the specific

characteristics of each district to maximize their effectiveness. In high-impact areas such as Gangnam and Songpa, TOD initiatives can be further intensified to capitalize on their economic potential. Conversely, areas exhibiting negative or marginal impacts may require targeted interventions, such as infrastructure improvements or complementary economic policies, to address the underlying challenges and ensure more equitable development outcomes.

Moreover, the consistent positive impact of TOD across various sectors implies that TOD strategies can be instrumental in fostering economic resilience by diversifying the urban economy. Policymakers should consider integrating TOD with other urban development initiatives to create compact and mixed-use developments centered on transit nodes, thereby enhancing accessibility and improving the overall quality of life for urban residents.

Despite the contributions of this study, several limitations warrant acknowledgment. First, the reliance on secondary data sources for consumer spending across different sectors may introduce potential biases related to data quality and coverage. The analysis, conducted at the level of administrative districts, may not fully capture microlevel variations in TOD impacts within specific neighborhoods or transit corridors. Additionally, the cross-sectional nature of the study, focusing on consumer spending at a single point in time, may overlook temporal dynamics and changes over time, potentially limiting the generalizability of the findings. Furthermore, the context-specific nature of this study may restrict the direct applicability of its findings to other urban areas with different economic, cultural, or infrastructural contexts. Lastly, while associations between TOD and consumer spending are identified, establishing definitive causal relationships remains challenging owing to the observational nature of the data.

To build on the insights provided by this study, future research can address the aforementioned limitations and explore several key areas. First, longitudinal studies can be conducted to examine the temporal dynamics of TOD impact on consumer expenditures, providing a more comprehensive understanding of how these effects evolve over time. Second, microlevel analyses at the neighborhood or corridor level can offer more granular insights into the localized effects of TOD, revealing variations that are not apparent at the district level. Third, future research can incorporate primary data collection methods, such as surveys or interviews, to supplement secondary data and enhance the robustness of the findings. Additionally, comparative studies across different cities or countries can help to contextualize the findings and assess the broader applicability of TOD strategies. Finally, advanced causal inference techniques, such as instrumental variable analysis or difference-in-differences approaches, can be employed to better establish causal relationships between TOD and consumer spending.

5. Conclusions

In this study, we explored the economic vitality of TOD compared with non-TOD by analyzing consumer expenditure patterns across various sectors. By focusing on expenditures in retail, healthcare, transportation, leisure, culture, education, and drinking, we provided a comprehensive understanding of how TOD influences economic activities within urban environments. Consumer spending is a critical indicator of economic health, reflecting the level of commercial activity and the attractiveness of TOD areas. By examining these patterns, we

aimed to shed light on the multifaceted economic impacts of TOD, highlighting its potential to stimulate economic growth, enhance accessibility, and promote sustainable urban development. Through this analysis, we sought to inform policymakers and urban planners about the effectiveness of TOD as a strategy for fostering vibrant, economically robust communities.

Acknowledgments

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About the Authors

Sangwan Lee received his B.S. and M.S. degrees from Jeonbuk National University, South Korea, his second M.S. degree from Rutgers University, and his Ph.D. degree from Portland State University in 2022. Since 2022, he has been a research associate at the LX Spatial Information Research Institute. His research interests are in transportation and land use planning, built environments, and spatial analysis. (esangwan@lx.or.kr)

Kuk Cho received his B.S. degree from Chosun University, South Korea, and his Ph.D. degree from the University of Science and Technology, South Korea in 2014. Since 2016, he has been working on mobility infrastructure at the LX Spatial Information Research Institute, Korea. His research interests include 3D data processing, environmental recognition, machine learning, and automated vehicles. (kcho@lx.or.kr)