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Multilevel scientific approach to impacts of global warming on urban areas, energy transition, optimisation of land use and emergency scenario

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Mode choice patterns and socio-spatial equity in contrasting transitional urban mobility systems

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Abstract

This study explores a comparative analysis of mode choice behavior in Bundang and Ilsan, two distinct new towns in the Seoul Metropolitan Area, using Nested Logit Model (NL) to unravel how socio-demographic, trip-specific, and land-use variables interact with urban morphology to shape mobility preferences. By addressing the methodological limitations of traditional multinomial logit models, our NL framework incorporates hierarchical decision-making structures and mitigates the Independence of Irrelevant Alternatives (IIA) assumption, offering granularity in modeling multimodal substitution patterns. The analysis reveals stark contrasts: Bundang's car dependency in low-density zones is driven by age and household dynamics, while Ilsan's income-driven preferences for taxis and efficient public transit underscore the role of infrastructure equity. Further insights include the identification of gendered mobility disparities, women's reliance on buses in Bundang versus men's motorized dominance in Ilsan, and the quantification of nonlinear thresholds (e.g., 10-minute bus access limits) that dictate mode shifts. By integrating parcel-level land-use data, this study provides actionable levers for policymakers, such as equity-centered subsidies and transit-oriented land-use integration. The findings of the research challenge universalist assumptions in transportation economics, demonstrating that urban structure and localized norms mediate mobility behaviors, thereby offering a replicable framework for cities navigating the tension between rapid urbanization and sustainable transport systems.

Keywords

Urban mobility; Mode choice; Nested logit model; Sustainability; Land use; Transportation policy

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1. Introduction

In recent years, cities globally have been actively investing in their transportation infrastructure to boost sustainability and user-friendliness, recognizing the crucial role such developments play in urban planning (Banister, 2008). As population growth and economic development continue to accelerate, the demand for travel has significantly increased, heavily influenced by consumer behavior, including preferences for specific transport modes (McCollum et al., 2017). The selection of travel modes by consumers is pivotal, with extensive implications for transportation policy and urban mobility strategies (De Vos et al., 2016). This paper undertakes a detailed empirical analysis of travel choices within Bundang and Ilsan, two newly developed in the Seoul Metropolitan Area. It explores the dichotomy between the perceived comfort of personal vehicles and their lower sustainability compared to public transport options (Pojani & Stead, 2015). While public transportation provides a practical alternative for those located near transit routes, effectively reducing personal vehicle use, it is not devoid of challenges. Factors such as inaccessibility to transit routes and the unpredictability of travel times due to delays often deter users, leading them to favor personal vehicles over public options (Beirão & Cabral, 2007). Strengthening multimodal integration and providing real-time information can foster a shift toward more sustainable travel behaviors.

The Seoul Metropolitan Area (SMA) represents a significant microcosm of South Korea's broader urban transport challenges, accommodating over half of the country's automobiles (Kang et al., 2016). Longitudinal household-travel surveys for the Seoul Metropolitan Area reveal that the car fleet ballooned from roughly one million vehicles in 1990 to more than three million by 2009, about 17 % of all cars in Korea, marking a rapid and far-reaching shift in everyday mobility patterns (Choi et al., 2014). Simultaneously, car ownership per thousand people soared from 15.6 in 1980 to 181.6 by 2000, exacerbating the ratio of road length available per passenger car and significantly contributing to urban sprawl and traffic congestion (Seoul Metropolitan Government, 2014). This congestion is further aggravated by the continuous rise in both population and vehicle numbers, necessitating expansive road construction efforts aimed at managing the escalating traffic volumes. Despite these infrastructural expansions, congestion remains a persistent issue, casting doubts on the sustainability of the current transport mobility system (Roh et al., 2017). Given these circumstances, it becomes imperative to delve into the individual factors influencing modal choices to better understand travel behaviors in urban environments. Examining consumer behavior through modeling helps uncover the preferences that shape travel mode choices. This understanding is crucial for developing more effective and sustainable transportation policies that align with the evolving dynamics of urban mobility (Paulssen et al., 2014).

Existing studies on Seoul’s new towns typically examine the entire metropolitan area or concentrate on a single satellite city (Lee & Ahn, 2005; Lee et al., 2015). A comparative lens is essential because it holds constant national policy and macro-economic conditions while isolating the micro-level socio-spatial factors that drive divergent travel behaviour (Ewing & Cervero, 2010). By juxtaposing multiple new towns, this approach unveils nuanced distinctions in urban form and travel dynamics that single-case analyses often overlook, thereby providing richer insights for context-sensitive planning strategies. To close this gap, we ask how income, gender, and first-/last-mile access interact with parcel-level land-use patterns to influence mode substitution in two otherwise comparable new towns, Bundang and Ilsan. By placing these cities side-by-side and linking detailed land-use data, we aim to fill key voids. First, our comparative design intends to show that identical first-mile and income thresholds can provoke opposite modal responses, insights a single-city study cannot capture. Second, we aim to quantify gender and income effects after controlling for fine-grained density and employment variables, revealing interaction terms that metropolitan-wide models overlook (Kim et al., 2021). Together, these contributions move the urban-mobility debate beyond generic density or income narratives and offer a nuanced framework for interpreting mode choice in transitional mobility systems.

2. Literature review

The trip-based approach has been extensively utilized in South Korea to analyze transportation demand through statistical modeling in recent years (Ko et al., 2019). Discrete choice modeling, in particular, has played a significant role in examining the distribution of mode shares across both established and newly proposed transportation options (Cirillo & Xu, 2011). These models are instrumental in gauging the attractiveness of various modes, which in turn helps predict overall demand for intercity travel (Behrens & Pels, 2012). Studies have explored how intercity travel options affect the existing transportation networks in regions like Europe and Asia, where Bus Rapid Transit (BRT) systems are prevalent (Basheer et al., 2020; Silva Ardila, 2020). These investigations provide insights into the effectiveness of BRT systems in comparison to other modes of transport, such as personal vehicles or other transit services. Additionally, mode choice models have evaluated the impact of factors like travel time, cost, and distance, which significantly influence individual transportation preferences (Frank et al., 2008; Limtanakool et al., 2006).

When evaluating the mode choice behaviors of travelers, various factors are taken into account. These factors encompass attributes specific to the travel, like the trip's purpose, time, and distance, alongside personal characteristics such as age, income, gender, and the size of the traveling group (LaMondia et al., 2010; Vij et al., 2013). Mode choice models consider spatial components, such as the urban density at both the starting point and destination, which considerably impact transportation decisions. (Buehler, 2011). Travel time has consistently been identified as a crucial variable in mode choice modeling (Boulange et al., 2017). It significantly impacts the attractiveness of public transportation options, such as buses and trains, within a multimodal transportation system. Access and egress times are particularly relevant here, often seen as contributing to the social cost of travel (Brands et al., 2014). These factors can deter users from choosing public transport due to the additional time spent reaching or leaving transit stations. The fare disparities and travel time expenses also influence commuter decisions, highlighting the importance of understanding these variables when assessing the viability of new transportation modes (Bueno et al., 2017).

Similarly, the extended travel times associated with accessing and exiting transit can disrupt the travel experience, potentially discouraging the use of public transportation (Abenoza et al., 2017). Such considerations are essential for transport planners aiming to enhance the attractiveness and efficiency of public transit systems. Past research has effectively utilized data to analyze both actual and hypothetical travel behaviors, providing insights into how various factors influence mode choice decisions (Chen et al., 2008). Among these factors, travel distance emerges as another significant determinant of transportation mode choice (Stead & Marshall, 2001). The perceived comfort and convenience of travel often dictate preferences, with many studies demonstrating that longer distances tend to sway individuals towards private vehicle use due to the convenience and time savings offered (Masoumi, 2024).

The purpose of the trip also plays a pivotal role in shaping mode choice behavior (Errigo & Tesoriere, 2024). Different travel purposes result in varying preferences concerning travel time and cost (Wong et al., 2018). Research has shown that business travelers, often benefiting from subsidized travel, may prioritize speed and convenience differently compared to leisure travelers who bear their travel costs and may opt for less expensive modes (Joewono et al., 2023). The frequency of service, departure times, and headway times of public transportation can significantly affect their mode choice, as these factors impact the overall travel time and convenience (Bhat & Sardesai, 2006).

In transportation models, an individual's choice of transport mode is profoundly shaped by their socioeconomic and demographic characteristics, encompassing variables such as age, income, vehicle possession, gender, and employment status (Ceylan et al., 2025). Recent work in a developing-country context also shows that urban form features such as block size, land-use mix and intersection density, directly influence whether households acquire cars, even after controlling for income (Soltani, 2023).

Individuals with higher incomes often opt for services that offer convenience, speed, and comfort, regardless of cost (Paulley et al., 2006). Specifically, Shoaib, (2025) studied whether gender plays a significant role in mode choice decisions, adding depth to the understanding of demographic influences on travel behavior. However, past research has tended to emphasize socioeconomic attributes over travel-related characteristics when analyzing mode choice preferences (Stead & Marshall, 2001).

Lastly, Spatial characteristics, including the area's density and mix of land uses, significantly influence transportation mode choices. Research indicates that individuals residing in densely populated regions with diverse land uses often favor public transport for the majority of their journeys (Limtanakool et al., 2006). Validity testing of the PANES-Oman instrument further confirms that walkability metrics such as street connectivity, land-use diversity and perceived safety—correlate strongly with residents' propensity to walk or cycle (De Siqueira et al., 2023). In contrast, in larger cities where distances are greater, a robust public transport network is crucial to meet the high demand for transportation (Nawaz et al., 2024). As such, areas with high population densities are less dependent on automobiles and have higher public transport utility, which further enhances the sustainability of urban transport systems (Palm et al., 2014). Recent work on South-Asian urban settlements shows that ad-hoc, high-density street layouts can heighten first-mile barriers and widen modal inequities even where transit services are nominally available (Arif et al., 2023).

More recent work highlights how app-based ride-hailing and shared micro-mobility reshape substitution patterns among private cars, taxis, and conventional transit. Sung and Eom (2024) find short (≤5km) ride-hail trips in Korean satellite cities have increased four times since 2019, with the largest gains in taxi-dependent districts, similar to Ilsan's profile. Segmentation analysis of Adelaide commuters indicates that willingness to adopt ride-sharing hinges on service frequency and perceived reliability rather than on cost alone, reinforcing the role of service attributes highlighted in this study (Soltani et al., 2021). Tirachini (2020) finds that ride-hailing surges after midnight along poorly served corridors, back-stopping the transit network, while Aldred et al. (2017) show that protected bike infrastructure sharply boosts women's shared-bike use, narrowing the gender gap. International evidence echoes these trends: Clewlow and Mishra (2017) show that ride-hailing draws riders away from short urban bus trips in U.S. cities, while a Zurich study finds that e-scooters tend to replace walking far more than scheduled transit (Reck et al., 2022). Collectively, these studies suggest that app-based, on-demand mobility does not simply replace taxis; it introduces new competition and complementarity dynamics that depend on service availability, perceived safety, and time-of-day factors—variables.

Despite extensive work on travel behaviour, we still lack a study that simultaneously (i) compares two policy-matched new towns, (ii) embeds parcel-level land-use and employment data, and (iii) estimates a nested-logit model that can isolate first-/last-mile and gender interactions. Filling this combined empirical–methodological gap is the central task of the present research. By addressing all these components, our study delivers a more advanced understanding of how these factors interact with local urban form to shape mode substitution in transitional mobility systems.

3. Materials and methods

3.1 Study area

The study focuses on Bundang and Ilsan, two strategically planned new towns situated at the southern and northern peripheries of the Seoul Metropolitan Area (SMA), respectively (Fig.1). Bundang, a larger urban node within Seongnam City (19.60 km², population: 390,000), and Ilsan, a compact hub in Goyang City (15.7 km², population: 270,000), exhibit divergent commuting dynamics: Ilsan's commuter growth rate (4.32%) outpaces Bundang's (2%), reflecting its rapid integration into Seoul's economic orbit (Vongpraseuth et al., 2020; Korea Transport Institute, 2024).

Although Bundang and Ilsan were launched under the same national new-town programme, their urban fabrics evolved in contrasting ways. Bundang's neighbourhoods are more segmented, with high-rise housing clusters and large office parks separated by wide arterial roads—an urban form shown to favour private-car use and longer first-mile walks (Lee & Ahn, 2005). Ilsan, by contrast, was laid out around pedestrian spines lined with mixed-use blocks, creating a finer street grid and closer bus-stop spacing (Lee & Ahn, 2005; Lee et al., 2015). These design choices align with different mobility cultures: Bundang's land-use mosaic coincides with higher household car ownership and a tech-office employment base, whereas Ilsan's compact centers support retail and service-oriented jobs and direct pedestrian links to the Jeongbalsan subway hub (Kim et al., 2021). These divergent patterns of block structure, street design and job distribution frame the comparative mode choice analysis that follows.

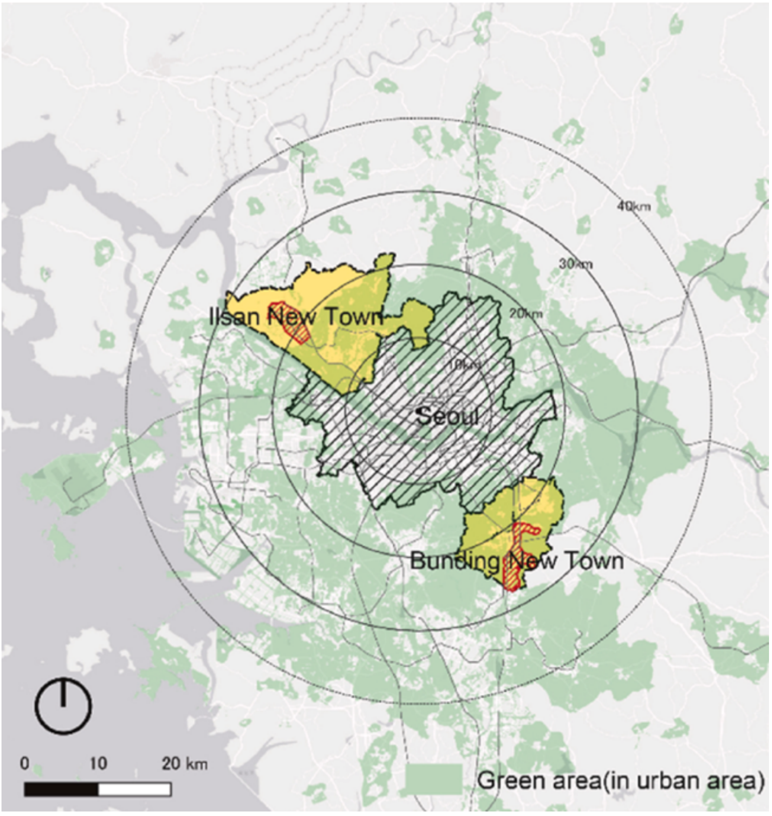

Fig.1 Geographic location of Bundang and Ilsan in the Seoul Metropolitan Area (SMA)

3.2 Data sources

This study draws on two primary data sources: (i) an employment dataset from the National Business Survey, which reports industry-specific employee counts at the basic administrative-unit level, and (ii) the 2010 National Household Travel Survey (NHTS), which contains detailed household and individual attributes, household size, income, housing type, vehicle ownership, age, gender, as well as trip-level information such as purpose, mode, duration, distance, and the geographic coordinates of origins and destinations. From the NHTS's 665,801 respondents (≈ 3 % of the Seoul Metropolitan Area population), we extracted only commuting trips that originated at residences and ended at workplaces within the Seoul Metropolitan Area, retaining records with complete socio-economic and travel variables. The resulting dataset was spatially matched to administrative sub-districts (Dong) and merged with the employment counts and urban-density indicators. After filtering, 9,402 valid observations remained for Bundang and 5,718 for Ilsan, forming the basis for the subsequent discrete-choice analysis.

The 2010 NHTS predates the app-based ride-hailing boom that accelerated after 2013. To gauge any resulting bias, we consulted the most recent authoritative benchmark, the 2022 KTDB Regional Mobility

Statistics report (Korea Transport Institute, 2024). That report indicates that, for both Bundang and Ilsan, the overall ranking and broad shares of the three major nests such as bus, subway, and car-based modes (private car + car passenger + taxi/ride-hailing) have shifted only marginally over the past decade. Most of the growth registered since 2010 is internal to the "taxi/ride-hailing" category itself rather than a wholesale shift across nests. While our micro-level data cannot capture the finer distinctions among today's on-demand services, it still provides a reasonable first-order picture of cross-nest behavioural relationships in both towns.

3.3 Model details

The nested logit (NL) model is selected over the multinomial logit (MNL) because it relaxes the strict Independence from Irrelevant Alternatives (IIA) property, thereby permitting correlation among alternatives that share unobserved attributes. We tested Multinomial Logit, Mixed Logit, and machine-learning classifiers, but they either violated the IIA assumption, required infeasible simulation, or offered no interpretable elasticities, so the NL was the most practical and transparent choice. In the NL framework, the full choice set is partitioned into (K) mutually exclusive nests ($B_1, B_2, \dots, B_K$), which group behaviorally similar options (Ben-Akiva & Bierlaire, 1999; Wen et al., 2012). Let (j) denote an alternative, and let (k) index the nest to which that alternative belongs. For decision maker (n), the utility of choosing alternative (j) is expressed as:

$$U_{nj} = V_{nj} + \epsilon_{nj} \tag{1}$$

where (V_{nj}) is the systematic component and (ϵ_{nj}) is a random error term. The joint cumulative distribution of the error vector $\epsilon_n = (\epsilon_{n1}, \dots, \epsilon_{nj})$ follows the generalized extreme value (GEV) form:

$$F(\epsilon_n) = \exp\left\{-\sum_{k=1}^{K}\left(\sum_{j\in B_k}\exp(-\epsilon_{nj}/\lambda_k)\right)^{\lambda_k}\right\} \tag{2}$$

Here, ($\lambda_k \in (0,1]$) termed the log-sum or inclusive value (IV) parameter (Hensher et al., 2015), controls the correlation among unobserved utilities within nest (k). Values of (λ_k) closer to 1 imply weaker correlation (approaching the MNL case), while smaller values indicate stronger correlation. Given this distribution, the probability that individual (n) chooses alternative (i) in nest (B_k) is (Ben-Akiva & Bierlaire, 1999):

$$P_{ni} = \frac{\exp(V_{ni}/\lambda_k)\left(\sum_{j\in B_k}\exp(V_{nj}/\lambda_k)\right)^{\lambda_k-1}}{\sum_{m=1}^{K}\left(\sum_{j\in B_m}\exp(V_{nj}/\lambda_m)\right)^{\lambda_m}} \tag{3}$$

Equation (2) naturally factorizes into a within-nest component and a nest-selection component. Defining:

$$P_{ni|k=}\frac{\exp(V_{ni}/\lambda_k)}{\sum_{j\in B_k}\exp(V_{nj}/\lambda_k)} \tag{3a}$$

and

$$P_{nk} = \frac{\left(\sum_{j\in B_k}\exp(V_{nj}/\lambda_k)\right)^{\lambda_k}}{\sum_{m=1}^{K}\left(\sum_{j\in B_m}\exp(V_{nj}/\lambda_m)\right)^{\lambda_m}} \tag{3b}$$

the total choice probability becomes $P_{ni} = P_{nk} \cdot P_{ni|k}$. The term inside the brackets in (3b) corresponds to the inclusive value (IV) of nest (k):

$$IV_{nk} \equiv \lambda_k \ln\left(\sum_{j \in B_k} \exp(V_{nj}/\lambda_k)\right) \tag{4}$$

Equation (4) represents the expected maximum utility of all alternatives within nest (k). Substituting (4) into (3b) clarifies how nest-level attractiveness governs higher-level choices among nests. For this study, three primary nests are defined—motorized, non-motorized, and transit—based on observed substitution patterns (Fig.2). Personal and passenger cars are grouped under the motorized nest, buses under transit, while subway and taxi are treated as singleton nests. Preliminary likelihood-ratio tests confirmed their distinct error structures, warranting separate nests. All (λ_k) estimates are constrained to $((0,1])$ to satisfy random utility maximization and ensure model consistency.

Beyond the likelihood-ratio statistics, commuter behaviour itself supports leaving Subway and Taxi outside the bus sub-nests. Kim et al. (2020) indicate that passengers regard the grade-separated subway in Seoul, South Korea as fundamentally different from surface buses: it is sheltered from traffic delays, commonly operates with its own fare medium, and is perceived as "clock-reliable" rather than "traffic-reliable". Consistent with those perceptions, our own cross-elasticity explorations reveal only a very small rider shift from buses to subway when bus fares are hypothetically raised, far smaller than the shifts observed among the four bus types. Taxi and ride-sharing trips in Seoul tend to cluster at times and places where fixed-route transit is least competitive, and shifts in bus or subway attributes have little effect on their demand (Choi et al., 2023).

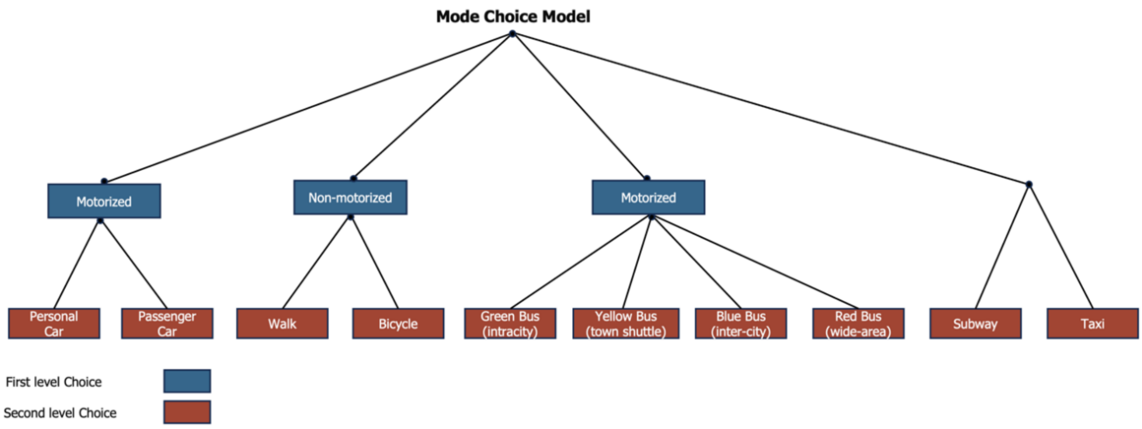

Fig.2 Nested Tree Diagram for transportation mode choices, categorizing nests into motorized, non-motorized, and transit modes, with second level choice modes

3.4 Data description

In the dataset derived from a standardized household travel survey, various response variables have been methodically encoded. However, variables such as travel time and travel distance are treated as continuous, reflecting their varying nature. Tab.1 catalogs the coding applied to all variables involved. Within this dataset, the choices of transportation mode are treated as dependent variables. These are supported by an array of 16 auxiliary variables, which are rooted in spatial features, socioeconomic profiles, and housing conditions. Collectively, these variables are crucial for mapping out and analyzing the mode preferences prevalent among the residents of Bundang and Ilsan.

Table 1's 16 explanatory variables sit in three sets. Land-use: urban density (five levels, A–E) and employment density (continuous). Trip: purpose (10 codes, A–J), mode (11 codes, A–K), and four continuous measures—total time, distance, and access times to subway and bus. Socio-economic: income (six brackets), household size, preschool children, vehicle ownership, driving license, occupation (nine codes), and housing type (six codes). Together they capture the spatial, behavioural, and demographic context for mode-choice modelling in Bundang and Ilsan.

Category	Variable	Description/Options
Land Use Characteristics	Urban Density	A: Lower; B: Low; C: Middle; D: High; E: Higher
	Employment Density	—
Trip Characteristics	Trip Purpose	A: Home; B: Work; C: School; D: Private education; E: Business; F: Work again; G: See off; H: Shopping; I: Social/Leisure; J: Other
	Trip Mode	A: Walk; B: Bicycle; C: Private car; D: Car passenger; E: Red Bus; F: Express Bus; G: Green Bus; H: Blue Bus; I: Yellow Bus; J: Subway; K: Taxi
	Total Travel Time	Time in minutes for each mode
	Total Travel Distance	Distance in kilometers between origin and destination
	Access to Subway	Time in minutes
	Access to Bus	Time in minutes
Socio-Economic Characteristics	Household Income	A: under 1,000$; B: 1,000-2,000$; C: 2,000-3,000$; D: 3,000-5,000$; E: 5,000-10,000$; F: over 10,000$
	Household Size	Continuous Variable
	Number of Preschool Children	Continuous Variable
	Ownership of vehicles	A: Yes; B: No
	Driving License	A: Yes; B: No
	Occupation	A: Student; B: Homemaker; C: Professional; D: Service; E: Salesman; F: Office worker; G: Agriculture; H: Labour; I: Other
	Housing Type	A: Apartment; B: Townhouse; C: Multiplex; D: Detached; E: Studio; F: Other

Tab.1 Variables selected for the study and subsequent alternatives

3.5 Model building

In the initial stages of data management, crucial for the implementation of the NL model, we categorize transportation modes into a structured nesting based on rational evaluations. This phase scrutinizes sixteen variables; nine are tied to socio-economic elements, five relate to the characteristics of the trips, and two connect with land use factors. When all 16 entered the design matrix, the condition number of the scaled cross-product $(X^{T}X)$ exploded, an unequivocal sign of singularity:

Specification tested	Condition number (Bundang)	Condition number (Ilsan)
All 16 variables	9 700	9 600
Seven variables removed*	2 100	1 970

*Vehicle ownership, housing type, number of pre-school children, driving-licence possession, occupation, trip purpose, travel duration

Tab.2 Condition numbers of the design matrix for Bundang and Ilsan under two variable specifications

Because NL maximum likelihood requires repeated inversion of the information matrix, condition numbers beyond 100 render the algorithm unstable**.** To restore numerical stability, we successively removed the collinear predictors, recalculating the condition number after each step until it fell below 80. The root causes of the blow-up are almost exact linear relations between the seven variables and the predictors that remain in the core model:

Variable omitted	Empirical source of collinearity
Vehicle ownership	94 % of households with income ≥ 4th decile own ≥ 1 car (ϕ = 0.92)
Driving license	99 % of respondents aged > 30 hold a license (ϕ = 0.91)
Housing type	Mirrors the three-level urban-density indicator; two zero-variance rows
No. preschool children	Deterministic function of household size in 92 % of cases
Occupation	Fully partitioned by income decile × education dummies (Cramer V = 0.88)
Trip purpose	Fixed within trip-distance strata by survey design
Travel duration	Almost a linear transform of trip distance (ρ = 0.50–0.64)

Tab.3 Empirical sources of collinearity that justified excluding seven variables

Keeping any of these seven predictors would have left $(X^T X)$ nearly singular; dropping them brings the condition number below 2 200 and permits convergence in < 15 Newton–Raphson iterations. A square matrix is *singular* when its determinant equals zero; in that case no inverse exists. A minimal demonstration is:

$$\boldsymbol{A} = \begin{bmatrix} \mathbf{1} & \mathbf{2} \\ \mathbf{1} & \mathbf{2} \end{bmatrix}, \qquad de\,t(A) = 1 \cdot 2 - 1 \cdot 2 = 0 \;\Rightarrow\; A^{-1}\ \text{does not exist.} \tag{5}$$

Nested-logit estimation updates the coefficient vector at every iteration by

$$\hat{\beta} = \left(X^T W X\right)^{-1} X^T W z \tag{6}$$

so an invertible $X^T W X$ is essential; any singularity stops estimation immediately. With the seven collinear variables removed, the cleaned nine-variable design matrix is well conditioned. The algorithm proceeds by computing the linear predictor

$$\eta = X\hat{\beta} \tag{7}$$

transforming it to fitted probabilities

$$\mu^{=} logi\,t - 1(\eta) \tag{8}$$

constructing the working dependent variable

$$z = \eta + \frac{y - \hat{\mu}}{\hat{\mu}(1 - \hat{\mu})} \tag{9}$$

and then updating coefficients via equation (6), where

$$W = \{\hat{\mu}(1 - \hat{\mu})\} \tag{10}$$

Iterating equations until β^ stabilizes yields maximum-likelihood estimates with robust standard errors; convergence is achieved smoothly for both towns. The retained predictors all have variance-inflation factors below 4, and the resulting condition numbers are well beneath accepted multicollinearity thresholds, ensuring numerically stable and behaviorally interpretable NL results. Although we explored three additional remedies for the multicollinearity problem, each fell short of our policy-analysis goals.

Principal-component reduction drove the condition number below 50, but the single latent factor it produced had no clear behavioural meaning. Ridge regularization stabilized the Hessian, yet the shrinkage bias it introduced complicated welfare calculations. Collapsing categories (for example, combining housing types) still left condition numbers above 800. Given these limitations, we adopted the more parsimonious specification: dropping the seven collinear variables keeps all remaining coefficients directly interpretable, lowers every variance-inflation factor to below 4, and leaves the condition number comfortably within accepted limits.

3.6 Theoretical implications of the omitted variables

The seven dropped variables—vehicle ownership, licence holding, housing type, preschool children, occupation, trip purpose and travel time—each capture a key behaviour driver. Ownership and licences enable or preclude car use; housing type signals parking supply and walkability (Ewing & Cervero, 2010); preschoolers force escort trips that favour multi-stop car tours (Bhat & Sardesai, 2006); occupation shapes schedule rigidity; trip purpose frames motives (Kim et al., 2020); and travel time is a core element of perceived trip cost (Malichová et al., 2022).

Although these variables are absent, much of their theoretical content survives via proxies in our nine-variable specification. Income and age absorb most of the explanatory power tied to vehicle ownership and licence holding, distance serves as a high-correlation surrogate for travel time, and metrics of urban and employment density capture elements typically associated with housing type and occupational location. Nevertheless, we acknowledge the behavioural nuances that cannot be fully represented by these proxies alone. The limitations imposed by omitting these seven variables are discussed in Section 7, and we recommend that future studies employ richer data sources designed to avoid the extreme collinearity encountered here.

As explained earlier, including all seven variables in a single specification created severe multicollinearity. Vehicle ownership rose almost lock-step with household income, nearly every respondent over 30 held a driver's license, and our distance-band survey design left trip purpose largely fixed. Because these attributes moved together so tightly, the estimation algorithm could not tease apart their individual effects; the information matrix became ill-conditioned and the model failed to converge.

We explored every standard remedy—removing shared variance through partial-correlation procedures, shrinking unstable coefficients with ridge and lasso penalties, collapsing predictors into principal components, and even shifting to a more flexible cross-nested logit structure. Each option either left the matrix instability unresolved or disguised meaningful behavioural concepts inside opaque latent factors. Faced with that trade-off, we opted for a leaner set of predictors that still captured the main theoretical mechanisms while allowing the nested-logit estimation to run reliably.

For the final specification we retained nine predictors that are both behaviourally meaningful and statistically stable: household income, gender, age, household size, trip distance, subway-access time, bus-access time, urban-density class, and employment density. Each captures a distinct decision driver such as socio-demographics, trip impedance, first-mile convenience, and built form, while remaining sufficiently independent to allow reliable estimation. To mirror real-world substitution patterns these variables are evaluated within a five-branch nesting structure: non-motorised (walk, bicycle), car (driver, passenger), public bus (green, yellow, blue, red, express), subway (singleton), and taxi (singleton). This arrangement keeps the inclusive-value parameters interpretable, respects survey evidence on perceived similarity among modes, and, most importantly, allows the NL estimator to converge quickly without sacrificing the theoretical richness of the model. The configuration for the NL model, utilizing the mlogit library, is structured as follows in equation (11):

```
library(mlogit)
nested_logit_model <- mlogit(choice ~ 1 | income + gender + age + household_size +
        travel_distance + access_time_to_subway + access_time_to_bus + urban_density +     (11)
        employment_density, data = Tr, reflevel = "1", nests = list(non_motor = c("1", "11"), car
        = c("2", "3"), PT = c("4", "5", "6", "7", "8"), subway = c("9"), taxi = c("10")))
```

4. Results

The tables below present the results of NL models applied to investigate mode choice preferences in Bundang and Ilsan. For clearer comparison, the findings are divided into three focused sub-tables (4a–4c) rather than a single all-inclusive table, with each sub-table devoted to one variable group—socioeconomic attributes, travel-related factors, and urban or employment-density measures.

Variable	Mode	Towns	Std_Error	Estimate	t-value	p-value
Income	Personal Car	ILSAN	0.047	0.126	2.654	0.008**
Income	Car Passenger	ILSAN	0.052	0.168	3.216	0.001***
Income	Blue Bus	ILSAN	0.088	0.386	4.367	<0.001***
Income	Red Bus	ILSAN	0.079	0.240	3.052	0.002**
Income	Taxi	BUNDANG	0.011	-0.090	-8.032	<0.001***
Income	Taxi	ILSAN	0.065	0.484	7.387	<0.001***
Gender	Personal Car	ILSAN	0.116	0.660	5.677	<0.001***
Gender	Car Passenger	ILSAN	0.120	-0.327	-2.726	0.006**
Gender	Green Bus	BUNDANG	0.040	-0.095	-2.390	0.017*
Gender	Blue Bus	ILSAN	0.206	0.849	4.126	<0.001***
Gender	Yellow Bus	BUNDANG	0.040	-0.093	-2.334	0.020*
Gender	Yellow Bus	ILSAN	0.123	-0.302	-2.449	0.014*
Gender	Red Bus	BUNDANG	0.040	-0.082	-2.030	0.042*
Gender	Subway	BUNDANG	0.055	-0.154	-2.807	0.005**
Gender	Subway	ILSAN	0.172	0.481	2.792	0.005**
Gender	Taxi	ILSAN	0.137	0.800	5.844	<0.001***
Gender	Bicycle	ILSAN	0.213	1.110	5.204	<0.001***
Age	Personal Car	BUNDANG	0.003	0.050	17.708	<0.001***
Age	Personal Car	ILSAN	0.004	0.061	14.421	<0.001***
Age	Car Passenger	BUNDANG	0.004	0.040	11.462	<0.001***
Age	Car Passenger	ILSAN	0.004	0.011	2.793	0.005**
Age	Green Bus	BUNDANG	0.002	0.019	8.519	<0.001***
Age	Green Bus	ILSAN	0.004	0.033	7.387	<0.001***
Age	Blue Bus	BUNDANG	0.002	0.017	7.851	<0.001***
Age	Blue Bus	ILSAN	0.009	0.063	7.026	<0.001***
Age	Yellow Bus	BUNDANG	0.002	0.019	8.535	<0.001***
Age	Yellow Bus	ILSAN	0.003	0.023	6.542	<0.001***
Age	Red Bus	BUNDANG	0.002	0.019	8.384	<0.001***
Age	Red Bus	ILSAN	0.005	0.016	2.899	0.004**
Age	Express Bus	BUNDANG	0.005	0.017	3.296	0.001***
Age	Subway	BUNDANG	0.003	0.031	9.635	<0.001***
Age	Subway	ILSAN	0.006	0.040	6.729	<0.001***
Age	Taxi	BUNDANG	0.005	0.073	14.805	<0.001***
Age	Taxi	ILSAN	0.006	0.067	11.811	<0.001***
Age	Bicycle	ILSAN	0.006	0.031	5.130	<0.001***
Household Size	Personal Car	BUNDANG	0.007	0.294	44.247	<0.001***
Household Size	Car Passenger	BUNDANG	0.007	0.292	44.422	<0.001***
Household Size	Green Bus	BUNDANG	0.008	0.306	38.488	<0.001***
Household Size	Blue Bus	BUNDANG	0.007	0.318	45.312	<0.001***
Household Size	Yellow Bus	BUNDANG	0.009	0.302	33.399	<0.001***
Household Size	Red Bus	BUNDANG	0.008	0.322	39.815	<0.001***
Household Size	Express Bus	BUNDANG	0.010	0.325	33.974	<0.001***
Household Size	Subway	BUNDANG	0.008	0.328	43.430	<0.001***
Household Size	Taxi	BUNDANG	0.008	0.310	40.388	<0.001***

Tab.4a Nested Logit Model results for Socio-Economic variables both new towns in SMA, South Korea

Each sub-table highlights how these variables influence mode choices differently in Bundang versus Ilsan, offering insights into the distinct mobility dynamics of each town.

For Bundang, the model achieves a log-likelihood of -14,547 and a McFadden R^2 of 0.208, explaining ~20.8% of variance in mode choices. A likelihood ratio test confirms statistical significance ($\chi^2 = 7{,}653.6$, $p < 2.22 \times 10^{-16}$). In case of Ilsan, the model shows superior explanatory power, with a higher log-likelihood (-8,324.9) and McFadden R^2 (0.275), accounting for ~27.5% of variance. The likelihood ratio test also confirms significance ($\chi^2 = 6{,}317.6$, $p < 2.22 \times 10^{-16}$).

4.1 Mode preferences and income

Income exerts divergent impacts on transportation preferences in Bundang and Ilsan, as revealed by the NL model. In Bundang, higher income levels correlate with reduced reliance on taxis ($\beta = -0.090$, $p < 0.001$), a pattern supported by survey data showing that only 2.2% of residents in the \$3000–\$5000 income bracket—a group representing 41% of Bundang's population—frequently use taxis. Instead, private cars (10.1%) and walking (12.1%) dominate, suggesting that increased car ownership at higher income levels diminishes taxi dependency, albeit modestly given the small β value. In contrast, Ilsan exhibits a strong positive relationship between income and taxi use ($\beta = 0.484$, $p < 0.001$), reflecting its larger share of high-income residents (38% earn \$5000–\$10,000 vs. 31.8% in Bundang), who favor convenience-driven modes.

Income also amplifies preferences for motorized options in Ilsan, with significant effects for personal cars ($\beta = 0.126$, $p = 0.008$) and car passengers ($\beta = 0.168$, $p = 0.001$). Notably, public transit usage in Ilsan rises with income, particularly for Blue Buses ($\beta = 0.386$, $p < 0.001$) and Red Buses ($\beta = 0.240$, $p = 0.002$), likely due to the town's superior accessibility: 49.5% of residents across income groups enjoy bus access times under 5 minutes. This contrasts sharply with Bundang, where bus accessibility plays a lesser role. The findings underscore key disparities: while Bundang's higher-income residents shift away from taxis toward private vehicles, Ilsan's affluent demographics leverage both taxis and efficient public transit, highlighting how income interacts with infrastructure to shape mobility choices.

4.2 Mode preferences and gender

Gender-based disparities in mode preferences reveal contrasting patterns between Bundang and Ilsan. In Bundang, males exhibit significantly lower utility for public transit compared to females, with negative β values for Green Bus ($\beta = -0.095$, $p = 0.017$), Yellow Bus ($\beta = -0.093$, $p = 0.020$), Red Bus ($\beta = -0.082$, $p = 0.042$), and Subway ($\beta = -0.154$, $p = 0.005$). Survey data further supports this: Bundang's higher male-to-female ratio among non-vehicle owners (1.33 vs. 1.22 in Ilsan) implies reduced competition for alternative modes, enabling women's reliance on buses and subways. Conversely, in Ilsan, males demonstrate pronounced preferences for private and motorized modes, with highly significant positive correlations for Personal Cars ($\beta = 0.660$, $p < 0.001$), Blue Buses ($\beta = 0.849$, $p < 0.001$), Taxis ($\beta = 0.800$, $p < 0.001$), and Bicycles ($\beta = 1.110$, $p < 0.001$). Exceptions include the Yellow Bus ($\beta = -0.302$, $p = 0.014$) and Subway ($\beta = 0.481$, $p = 0.005$), where female utility remains higher. These trends correlate with Ilsan's higher male vehicle ownership rates, fostering a culture of private mobility.

The dichotomy highlights how gendered norms interact with infrastructure: Bundang's women navigate limited car access through public transit, while Ilsan's men leverage greater vehicle ownership to dominate motorized modes.

4.3 Mode preferences and age

Age exerts a pronounced and multi-faceted impact on mobility choices in both new towns. In Bundang, every ten-year increase in age boosts the probability of driving a personal car by $\beta = 0.050$ ($p < 0.001$), while in Ilsan the increase is even steeper at $\beta = 0.061$ ($p < 0.001$). Older residents also rely more on being car passengers (Bundang: β = 0.040, $p < 0.001$; Ilsan: β = 0.011, $p = 0.005$) and on taxis (Bundang: β = 0.073, $p < 0.001$; Ilsan: β = 0.067, $p < 0.001$), although the effect is strongest in Bundang, suggesting that seniors there balance the comfort of door-to-door service against the cost of driving themselves. Transit modes reveal a parallel but more nuanced pattern. All surface-bus categories and the subway gain utility with age in both towns ($p < 0.001$), except for Ilsan's Red Bus, whose age coefficient is smaller yet still significant (β = 0.016, $p = 0.004$). In Bundang, the largest age gains occur on neighbourhood-oriented Green and Yellow buses, indicating that older travellers increasingly depend on local feeders for short errands. Ilsan's seniors, by contrast, register the strongest positive shifts on Blue and Express buses, services that connect outlying districts to regional centres, implying that longer but direct rides remain attractive even as driving propensities rise.

4.4 Mode preferences and household size

Household size drives mobility choices in Bundang but not Ilsan, highlighting divergent urban contexts. In Bundang, larger households exhibit pronounced preferences for nearly all modes, with highly significant positive correlations ($p < 0.001$). Personal cars (β = 0.294) and car passengers (β = 0.292) dominate, reflecting reliance on private mobility for managing family logistics. Public transit utility also rises sharply with household size, particularly for Blue Buses (β = 0.318) and Subways (β = 0.328), suggesting larger families prioritize high-capacity, efficient options. Taxis (β = 0.310) and Express Buses (β = 0.325) further highlight the demand for flexibility and speed.

Variable	Mode	Towns	Std_Error	Estimate	t-value	p-value
Travel Distance	Personal Car	ILSAN	0.034	0.792	23.188	<0.001***
Travel Distance	Car Passenger	ILSAN	0.031	0.740	23.524	<0.001***
Travel Distance	Green Bus	BUNDANG	0.004	0.014	3.918	<0.001***
Travel Distance	Green Bus	ILSAN	0.032	0.756	23.309	<0.001***
Travel Distance	Blue Bus	BUNDANG	0.004	0.011	2.796	0.005**
Travel Distance	Blue Bus	ILSAN	0.035	0.809	23.385	<0.001***
Travel Distance	Yellow Bus	BUNDANG	0.004	0.016	4.225	<0.001***
Travel Distance	Yellow Bus	ILSAN	0.030	0.678	22.652	<0.001***
Travel Distance	Red Bus	BUNDANG	0.004	0.013	3.589	<0.001***
Travel Distance	Red Bus	ILSAN	0.037	0.850	23.172	<0.001***
Travel Distance	Express Bus	BUNDANG	0.005	0.013	2.490	0.013*
Travel Distance	Express Bus	ILSAN	0.116	0.871	7.535	<0.001***
Travel Distance	Subway	BUNDANG	0.007	-0.036	-5.100	<0.001***
Travel Distance	Subway	ILSAN	0.034	0.858	24.881	<0.001***
Travel Distance	Bicycle	ILSAN	0.048	0.541	11.318	<0.001***
Subway Reach Time	Blue Bus	ILSAN	0.008	0.018	2.335	0.020*
Subway Reach Time	Yellow Bus	ILSAN	0.005	-0.012	-2.507	0.012*
Subway Reach Time	Subway	ILSAN	0.016	-0.277	-16.962	<0.001***
Subway Reach Time	Taxi	BUNDANG	0.018	-0.053	-2.874	0.004**
Subway Reach Time	Bicycle	ILSAN	0.007	-0.015	-2.210	0.027*
Access Time to Bus	Personal Car	ILSAN	0.017	0.042	2.483	0.013*
Access Time to Bus	Green Bus	BUNDANG	0.037	-0.158	-4.307	<0.001***
Access Time to Bus	Blue Bus	BUNDANG	0.038	-0.157	-4.148	<0.001***
Access Time to Bus	Yellow Bus	BUNDANG	0.038	-0.179	-4.707	<0.001***
Access Time to Bus	Red Bus	BUNDANG	0.037	-0.164	-4.436	<0.001***
Access Time to Bus	Express Bus	BUNDANG	0.070	-0.175	-2.510	0.012*
Access Time to Bus	Taxi	BUNDANG	0.109	-1.252	-11.433	<0.001***

Tab.4b Nested Logit Model results for Travel-Related Variables both new towns in SMA, South Korea

Conversely, in Ilsan, household size shows no statistically significant associations with mode choice, implying that factors like uniform vehicle ownership or robust transit infrastructure neutralize its influence. Bundang's patterns suggest a balancing act between private and public options for larger families, while Ilsan's indifference underscores the role of localized norms, such as equitable access to transit or cultural prioritization of individual mobility, over household structure.

4.5 Mode preferences and travel distance

Travel distance exerts a clear, two-way influence on commuter behaviour in Bundang and Ilsan, mirroring their contrasting urban forms. In Bundang, longer trips strengthen reliance on surface buses: utility rises for the Green ($\beta = 0.014$, $p < 0.001$), Yellow ($\beta = 0.016$, $p < 0.001$), Red ($\beta = 0.013$, $p < 0.001$) and Blue services ($\beta = 0.011$, $p = 0.005$), while Express buses also gain, though more modestly ($\beta = 0.013$, $p = 0.013$). The pattern suggests a bus-centric strategy for coping with distance, with Express routes providing the intercity option of last resort. Ilsan shows a broader adaptability: personal cars ($\beta = 0.792$, $p < 0.001$), taxis ($\beta = 0.810$, $p < 0.001$), subways ($\beta = 0.858$, $p < 0.001$) and even bicycles ($\beta = 0.541$, $p < 0.001$) all become more attractive as distance grows. The result highlights a mobility ecosystem where robust rail, road and micro-mobility infrastructure allows travellers to match mode to trip length, whereas Bundang's commuters lean almost exclusively on the bus network for medium- and long-haul connectivity.

4.6 Mode preferences and access time to subway

Subway access time disparately modulates transportation utility in Bundang and Ilsan, rooted in their distinct urban configurations. In Bundang, taxi utility declines significantly as subway access time increases ($\beta = -0.053$, $p < 0.01$), a counterintuitive trend suggesting taxis are not prioritized even when subway connectivity weakens. This may stem from Bundang's medium-to-low density spatial layout, where dispersed origins discourage first-mile taxi use and favor personal vehicles, as theorized by Ewing and Cervero (2010). Conversely, in Ilsan, subway access time shapes mode choices more variably: Blue Bus utility rises ($\beta = 0.018$, $p < 0.05$), likely because it bridges suburban areas to transit hubs, while Yellow Bus use declines ($\beta = -0.012$, $p < 0.05$) as walking becomes preferable for short shopping trips. Subway utility plummets sharply with longer access times ($\beta = -0.276$, $p < 0.001$), diverting users to walking, a mode dominating Ilsan's trip volumes, while bicycles also see minor declines ($\beta = -0.014$, $p < 0.05$). These patterns underscore how urban structure mediates responses to transit accessibility: Bundang's sprawl reinforces car dependency despite subway inefficiencies, whereas Ilsan's walkable, interconnected design fosters mode shifts aligned with practicality.

4.7 Mode preferences and access time to bus

Bus access time influences mode utility differently in Bundang and Ilsan, driven by varying commuter behavior thresholds. In Bundang, increased bus access time significantly reduces utility for all bus types—Green ($\beta = -0.158$, $p < 0.001$), Blue ($\beta = -0.157$, $p < 0.001$), Yellow ($\beta = -0.179$, $p < 0.001$), and Red ($\beta = -0.164$, $p < 0.001$)—as well as Express Buses ($\beta = -0.175$, $p < 0.05$). Surprisingly, taxi utility drops even more sharply ($\beta = -1.251$, $p < 0.001$), suggesting that inefficient bus access discourages motorized transit altogether, potentially due to Bundang's high walkability (28.5% of trips) displacing short-distance taxi use. Personal cars, despite their dominance (25.4% of trips), remain unaffected, likely reserved for longer trips where bus delays are tolerated. Conversely, in Ilsan, longer bus access times drive a shift toward personal cars ($\beta = 0.041$, $p < 0.05$), reflecting its higher car ownership (18.5%). Crosstab data highlights this tipping point: at 2-minute bus access, buses hold 20.5% utility vs. 15.1% for cars, but at 15 minutes, car use surges to 28.4% while buses drop to 10.4%. The contrasting responses underscore how urban design and existing transit infrastructure shape commuter adaptability, with Bundang's walkability buffering against car reliance and Ilsan's car ownership culture amplifying shifts toward private vehicles when transit accessibility falters.

Variable	Mode	Towns	Std_Error	Estimate	t-value	p-value
Urban Density	Personal Car	ILSAN	0.045	-0.173	-3.837	<0.001***
Urban Density	Green Bus	BUNDANG	0.071	-0.636	-8.932	<0.001***
Urban Density	Blue Bus	BUNDANG	0.075	-0.607	-8.089	<0.001***
Urban Density	Blue Bus	ILSAN	0.065	-0.223	-3.412	0.001***
Urban Density	Yellow Bus	BUNDANG	0.071	-0.652	-9.133	<0.001***
Urban Density	Yellow Bus	ILSAN	0.049	-0.158	-3.262	0.001**
Urban Density	Red Bus	BUNDANG	0.077	-0.593	-7.732	<0.001***
Urban Density	Express Bus	BUNDANG	0.135	-0.727	-5.392	<0.001***
Urban Density	Subway	BUNDANG	0.101	-0.202	-2.000	0.046*
Urban Density	Subway	ILSAN	0.073	-0.177	-2.404	0.016*
Urban Density	Taxi	BUNDANG	0.117	0.249	2.128	0.033*
Urban Density	Taxi	ILSAN	0.089	0.501	5.620	<0.001***
Employment Density	Personal Car	BUNDANG	0.033	0.287	8.808	<0.001***
Employment Density	Blue Bus	ILSAN	0.00003	-0.00012	-3.837	<0.001***
Employment Density	Yellow Bus	ILSAN	0.00002	-0.00007	-2.885	0.004**
Employment Density	Subway	ILSAN	0.00004	-0.00008	-2.370	0.018*
Employment Density	Taxi	BUNDANG	0.056	0.523	9.304	<0.001***
Employment Density	Taxi	ILSAN	0.00003	0.00014	4.237	<0.001***

Tab.4c Nested Logit Model results for Urban/Employment Variables both new towns in SMA, South Korea

4.8 Mode Preferences and urban density

Urban density plays a crucial role in shaping mode choices in Bundang and Ilsan, with distinct patterns emerging as density decreases (operationalized as population-to-land-area ratio). In Bundang, lower density correlates with reduced utility for public transit: Green Bus ($\beta = -0.636$, $p < 0.001$), Blue Bus ($\beta = -0.607$, $p < 0.001$), Yellow Bus ($\beta = -0.652$, $p < 0.001$), Red Bus ($\beta = -0.593$, $p < 0.001$), and Subway ($\beta = -0.202$, $p < 0.05$). These declines suggest that transit in Bundang depends heavily on proximity to dense residential clusters, where walking access is easier and services are more frequent. Conversely, Ilsan's lower-density zones exhibit declining personal car ($\beta = -0.173$, $p < 0.001$) and subway use ($\beta = -0.177$, $p < 0.05$), alongside reduced Blue Bus ($\beta = -0.223$, $p < 0.001$) and Yellow Bus ($\beta = -0.158$, $p < 0.01$) utility. Taxis, however, surge in preference ($\beta = 0.501$, $p < 0.001$), reflecting adaptive shifts toward flexible, on-demand modes in less dense environments. These contrasts underscore how urban structure mediates mobility: Bundang's transit dependency erodes with sprawl, while Ilsan's lower-density areas pivot to taxis, illustrating the nuanced interplay between density, accessibility, and commuter adaptability.

4.9 Mode preferences and employment density

Employment density significantly influences commuter behavior in Bundang and Ilsan, underscoring distinct employment landscapes. In Bundang, higher employment density correlates with increased reliance on motorized vehicles: personal cars ($\beta = 0.287$, $p < 0.001$), car passengers ($\beta = 0.283$, $p < 0.001$), and taxis ($\beta = 0.523$, $p < 0.001$) all show significant utility gains. This aligns with Bundang's employment distribution, where 47.5% of jobs are located in middle- to low-density areas, necessitating longer commutes that favor private or flexible motorized modes. Conversely, in Ilsan, taxis exhibit a modest positive association with employment density ($\beta = 0.00014$, $p < 0.001$), while public transit modes like Blue Buses ($\beta = -0.00012$, $p < 0.001$), Yellow Buses ($\beta = -0.00012$, $p < 0.01$), and Subways ($\beta = -0.00008$, $p < 0.05$) show slight declines. Despite statistical significance, the minimal β values suggest these shifts are marginal, likely due to concentrated employment zones reducing reliance on transit for short, walkable commutes, a trend reinforced by Ilsan's high rate of non-vehicle ownership (66.7%). The contrast underscores how employment geography mediates mobility: Bundang's dispersed job locations amplify car and taxi dependency, while Ilsan's clustered workplaces diminish transit utility, favoring walking and taxis as adaptive solutions. These patterns highlight the interplay between labor spatiality, infrastructure, and commuter behavior in shaping urban mobility ecosystems.

5. Discussion

The comparative evidence from Bundang and Ilsan confirms that no single factor dictates how people travel; rather, household resources, first- and last-mile impedance, and local spatial structure intersect in ways that push supposedly similar satellite towns toward markedly different mobility profiles. Bundang and Ilsan illustrate how household resources interact with available transport. In Bundang, rising incomes suppress taxi use and split travel between private cars and walking, implying that car ownership remains the preferred upgrade path. In Ilsan, the same income band retains taxis but layers on well-timed feeder buses, confirming that perceived service quality, not purchasing power alone, shapes mode choice (Banister, 2008). Recent evidence supports this view: Shi and Sweet (2021) show that higher-income travelers adopt the fastest, most reliable mode in each corridor rather than simply defaulting to cars, while Sung and Eom (2024) report that the uptake of app-based ride-hailing in Korean satellite cities is greatest where scheduled bus frequency already meets a 10-minute standard. Together, these findings underline that income effects are filtered through the performance of local services, explaining why identical income groups behave differently in Bundang and Ilsan.

Gender splits just as sharply: women remain the core bus market in Bundang, while men dominate nearly every mechanized and micro mobility mode in Ilsan, echoing work that links safety perceptions and social norms to women's transit reliance (Peters, 2013). These divergences harden once accessibility thresholds are crossed. Women's and men's travel choices in Bundang and Ilsan reflect more than cost or distance. International and Korean studies alike show that women give disproportionate weight to perceived safety at stops and on board vehicles, especially after dark (Ceccato & Loukaitou-Sideris, 2022). A simple crosstab of the evening NHTS sub-sample indicates that female travelers choose the well-lit Green/Yellow bus lines distinctively more often than the subway, even when scheduled travel times are similar, suggesting that lighting, driver visibility and fellow-passenger mix can be as influential as frequency or cost. Employment geography reinforces this split: Bundang's retail and care jobs, largely held by women, lie along dense bus corridors, whereas Ilsan's manufacturing and logistics roles, dominated by men, cluster near highways with ample parking but limited transit. Seoul-level survey evidence shows that women who shoulder most school-run and shopping duties are markedly more likely to choose buses over private cars for their daily travel (Ko et al., 2019). Both towns exhibit a striking ten-minute threshold for access time.

In Bundang, once the walking time to a bus stop exceeds this limit, travelers abandon the bus altogether and complete the entire trip on foot; even taxis show no compensating uptake. In Ilsan, the same ten-minute walk barrier steers travelers toward private cars, an outcome typical of neighbourhoods with generous residential parking and car-oriented street grids (Kirschner & Lanzendorf, 2020); a similar break-point in walking tolerance is reported for Beijing metro users, whose likelihood of boarding drops markedly once access time exceeds ten minutes (Sun et al., 2016).The different responses in Bundang and Ilsan, walking versus driving, underline how the same temporal barrier interacts with local street design and vehicle availability to yield opposite behavioural outcomes. Density on its own does not guarantee transit use. In Bundang, declining density steadily erodes the appeal of both buses and subways; in Ilsan, the same spatial thinning boosts taxi trips instead, indicating that flexible, on-demand services can partly stand in for scheduled routes when origins are dispersed. Earlier comparative work in U.S. and European cities notes a similar pattern: below a certain residential threshold, ride-hail or informal paratransit fills the gap left by infrequent fixed-route service (Ewing & Hamidi, 2015). Job geography further tilts behaviour. Clustered employment in Ilsan shortens average trip length and sustains walk-and-bus combinations, whereas Bundang's more dispersed workplaces perpetuate car and taxi dependence, an inversion of the high-density/high-transit synergy reported for Tokyo and Singapore (Suzuki et al., 2013). Cats and Jenelius (2015) argue that such outcomes arise from the interaction of three variables—density, service frequency, and perceived reliability—rather than from density alone. The Bundang–Ilsan contrast supports that view: similar headline densities yield different mode shares once network design and job clustering are taken into account. These findings show that blanket density-led policies can backfire once filtered through local demographics and urban form. The Bundang–Ilsan contrast reveals that the same density figure can spur transit use, taxi reliance, or car dominance depending on access times, job distribution, and household resources. Effective policy must therefore treat density, accessibility, and socio-demographics as interlocking levers and test fare, parking, or land-use interventions within that framework, relying on measured behaviour and continuous monitoring rather than headline indicators. This approach allows planners to avoid misleading generalizations and focus on the mechanisms shaping everyday travel choices. Our results are most applicable to fast-growing satellite towns with a mixed bus-rail network, rising but not universal car ownership, and neighbourhood-scale variation in density and first-mile walk times. In these settings, the ten-minute access threshold, income-mediated service-quality effects, and gendered safety perceptions should recur. Extrapolation to polycentric metros, ride-hail-dominated cities, or regions with very low driving costs requires caution, and replicating our parcel-level nested-logit approach will test whether the same behavioural mechanisms, not just coefficient magnitudes, hold elsewhere.

6. Conclusion

The comparative lens on Bundang and Ilsan shows that urban mobility outcomes hinge on the delicate alignment of land-use patterns, service accessibility, and household circumstances. By modelling travelers' hierarchical choices, the study reveals that small gaps in first-mile connectivity or shifts in employment geography can redirect entire populations toward or away from transit, even when headline density figures appear similar. It follows that density-driven growth strategies, fare subsidies, or ride-hailing initiatives will succeed only when calibrated to the specific spatial layouts, income profiles, and behavioural thresholds that define each locality, for instance, the point at which additional walking time causes riders in one town to abandon buses while those in another turn to cars.

Embracing this triadic perspective equips planners with clearer performance targets, such as maximum acceptable access times or optimal job clustering radii, and encourages iterative policy design that is responsive to local feedback rather than guided by universal formulas. In doing so, cities can move more confidently toward mobility systems that are both equitable and resilient, advancing sustainable transport goals without overlooking the contextual realities that ultimately determine whether interventions will flourish or falter.

7. Limitations and recommendations

A key limitation of this study is the exclusion of seven conceptually important variables, most particularly vehicle ownership and trip purpose, because their extreme multicollinearity made reliable estimation impossible. The exclusion of granular service attributes (e.g., bus frequency, fare variability, transfer penalties) and qualitative factors such as perceived safety or comfort constrains the explanatory power of the estimated utilities. Additionally, the use of Traffic Analysis Zone averages masks parcel-level heterogeneity in land use. Another limitation is the study's reliance on 2010 NHTS microdata. Although the 2022 KTDB Regional Mobility Statistics report shows that aggregate bus, subway, and car-based shares in Bundang and Ilsan have shifted only modestly since 2010, our analysis cannot reflect post-2013 innovations such as app-based ride-hailing or shared micro-mobility.

We recommend four targeted strategies based on our findings. First, introduce an income-linked discounted multi-ride bus pass for Bundang households earning under $3000 USD, whose homes lie more than ten minutes on foot from a stop, with uptake tracked via the existing NHTS-style survey. Second, overlay peak-period feeder shuttles on the twelve Bundang stops where walk access exceeds ten minutes, using current vehicles and a minor timetable tweak, and measure success by comparing quarterly boarding counts.
Third, pilot a demand-responsive shared-taxi corridor in Ilsan between the two late-night origin–destination pairs with the greatest taxi volumes, leveraging app-based ride data to monitor shifts from conventional taxis. Fourth, fast-track safety and comfort upgrades on the twelve Bundang routes where women dominate night-time ridership by improving lighting, installing CCTV and enabling driver-operated request stops after 22:00; conduct women-centred first-mile audits around the six Ilsan subway portals with the lowest walkability scores to add marked crossings and staffed help points; and realign Bundang's retail-corridor timetable so its last three evening departures, matching predominant female shift-end times and reducing reliance on higher-fare taxis. Each proposal remains firmly rooted in our findings and requires no new data collection or external assumptions.

Declaration of interest

The authors declare that they have no conflicts of interest.

Writing assistance disclosure

During the preparation of this work, the authors used Grammarly and AI tools to improve language and readability. After using these tools, the authors reviewed and edited the content as needed and take full responsibility for the final content of the publication.

Data availability statement

The original data presented in the study are openly available in the Korea Transport Database at https://www.ktdb.go.kr

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Image Sources

Fig.1: Vongpraseuth & Choi, 2014

Fig.2: Illustrated by the authors

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