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The Long-Lasting Impact of Past Mobility Dependence on Travel Mode Share in a New Neighborhood: The Case of the Seoul Metropolitan Area, South Korea

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Abstract: Travel behavior researchers have dominantly explored the influence of increase in development densities with mixed pattern of land-uses, and investment in infrastructures related to public transit toward more sustainable-transportation policies. However, little has been known about the long-term interdependencies between people's decisions on travel behavior and individual biographies relating to residential relocation and habitual behavior over a longer time period. To fill this gap, the present study aims to investigate the long-lasting impact of past travel behavior on current travel behavior after a process of residential relocation. For this purpose, aggregate analysis at a neighborhood level was carried out, focusing on cause-effect relationships between current travel mode share and the size of in-migrants dependent on a certain mode in the past by using Household Travel Surveys (HTS) and Internal Migration Statistics collected during 2006–2015 (10 years). Accordingly, the size of in-migrants who have their pre-determined travel behavior in the past play an important role in explaining the mode share of a neighborhood on the current state. Further, this study attempted to divide the influence of residential relocation from the influence of habitual behavior on travel behavior after residential relocation. The finding suggested that the habitualized travel pattern can affect the travel patterns in the new neighborhood even after separating the effect of self-selection. Specifically, the past dependency on public transportation represented significant influences on the current travel mode share. This study on travel behavior informs consideration of role of habitual qualities during the process of residential relocation.

Keywords: travel behavior; residential relocation; habitual behaviors; past mode dependence

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1. Introduction

One of the enduring concerns of urban planners is the undesirable consequences of urban sprawl, which contributes to high-automobile dependency, traffic accidents, and air pollution. As a reaction to the continuous growth in automobile usage and its associated cost, planning efforts have been focused on encouraging people to drive less while promoting active transportation (i.e., walking, biking, or public transit) and physical activities. A significant amount of studies scrutinize the relationship between the built environment, socio-demographic characteristics, and transportation in the discourse on compact cities, transit-oriented development, sustainable development, or smart growth [1–3]. Common guidelines derived from those studies include increasing development densities, land-use mixtures, and investments in public transit.

Along with the intervention strategies to discourage automobile use, one of the essential questions that have not been well documented is whether the current influence of planning practices for transit-oriented development on individuals' travel behavior would persist in the future. The generation theory explains that the experiences and memories at a particular time point may have long-lasting effects on later behavior by creating behavioral preferences or unique tastes [4]. One of the possible reasons for the persistent travel behavior is related to a well-established tendency to choose a specific travel mode in the past, which directly influences past behavioral choices on travel behaviors in the present, regardless of environmental conditions. For instance, theoretical propositions about habitual decision-making [5,6] describe how routinized decisions, such as commute travel, are executed, without much deliberation on current spatial status. The other interpretation from the perspective of residential self-selection explains that individual preference to a certain travel behavior may determine their residential location choice [7]. Due to the self-selected residential environments conducive to travel with their preferred travel mode, the travel behavior before the relocation could be consistent with their present behavior and may even intensify their already established mobility-related preferences.

In this light, the previous studies suggest that mobility dependency formed at a specific time plays an influential role in deciding long-term mobility behaviors [8–10]. In other words, individuals' travel behavior could be interrelated with their past propensity to use a particular travel behavior, even after residential relocation. However, to the best of our knowledge, the underlying mechanisms of how planning intervention in the past persist or stagnate in the current state has not been empirically investigated. Understanding the mechanisms of the mobility patterns intertwined over life course is essential to developing effective strategies to influence long-term mobility decisions from the perspective of biographical dependences [10].

The present study separates the influence of residential self-selection from the influence of habitual behavior on the persistence of travel mode dependency during the decade 2006–2015 in Seoul Metropolitan Area. More specifically, we aim to investigate whether aggregated mode choice at a neighborhood level (mode shares of a neighborhood) previously can influence the aggregated mode choice at present while migrations are accounted for. Hypothetically, the larger size of in-migrants dependent on a specific travel mode in the past has a positive influence on the mode share at present even after separating the influence of self-selection. Although this study cannot identify this hypothetical relationship at the individual level, an aggregated approach allows us to understand this relationship on a regional scale at different time points.

2. State of Research and Theoretical Background

2.1. Habitual Behavior and Residential Relocation

Some critical elements of travel-related decision-making, such as habits and their formation and underlying rationales, have not been given much attention in the body of travel studies [11]. Most of the studies analyze the choice of an alternative mode using the theory of planned behavior [12] or expectancy-value models of behavior based on reasonable considerations of the cost and benefit of that behavior [13]. These models assumed that a traveler chooses the mode that maximizes their utility in the process of balancing costs and benefits [13,14]. The utility is specified by assigning weights to the different determinants of mode choice, such as the availability of a specific mode, travel time, and travel costs [15,16]. Thus, the models suggest that people should be sensitive to changes in the pay-off structure and go through a deliberate decisional process of travel mode choice. In this perspective of planned behavior theory, Bamberg, Ajzen, and Schmidt [17]; Kearney and De Young [18] concluded that providing an intervention to promote public transport use and monetary incentives can be effective in changing automobile dependency.

However, it has frequently been noted that daily travel patterns tend to be routinely performed in everyday life, and thereby the routinized decisions may not have originated from reasoning [5,19]. Although a traveler may scrutinize available modes of transportation as a function of different attributes (travel frequency, distance, monetary and time cost, service of a specific mode, etc.) when encountering new mobility-related environments, after this deliberative phase, the chosen transportation mode may become a firmly established habit in everyday life [20]. Therefore, once the habitual behavior is well established, the mode choice requires few cognitive resources and cues. Indeed, the existing studies have acknowledged habitual qualities as essential factors in mode choice behaviors [21–23]. In light of habitual behavior theory, previous research about habitual behavior in transport mode choice indicated that travel mode is primarily influenced by past performance when the social and spatial contexts remain stable.

However, the effects of habitual quality in newly residential environments are still open for debate. On the one hand, the well-known hypothesis of "habitual discontinuity" [23] suggested that residential relocation has the potential to make new choices and decisions since individuals become attentive and deliberate about behavior-relevant information. Accounting for the fact that residential built environments affect travel behavior, it is natural to assume that residential relocation may change individuals' travel behaviors [24]. One of the common rationales involves whether travel behavior is more affected by environmental components, such as urban form and infrastructure supply, than more individual factors, such as the lifestyle preferences and personal mobility patterns [25]. Therefore, these researchers suggested that the built environment of a new neighborhood and its potentially routine-breaking character (e.g., the transport options available in the new location) affect travel behavior after a residential relocation. Thus, planning interventions to promote alternative transportation use may be effective when implemented right before, during, or right after a residential relocation.

On the other hand, others explained that transportation characteristics and the neighborhood's built environment are already considered before choosing a new neighborhood [26]. In other words, the relative persistence of pre-determined mobility-related attitudes may influence the location choice, which is known as "residential self-selection" [7,27], migrants with strong travel mode habits show a stronger propensity to maintain their values and preferences by self-selecting to live in a neighborhood during the residential relocation [28]. Possible evidence for the residential self-selection is shown in related work about the spatial migration pattern of young people, who are well-educated, and racially diverse. They are more likely to move into central locations and toward compact, transit-oriented, and sustainable places than preceding generations [29–32]. Therefore, their unique traits to value more walkability, transportation availability, and proximity to amenities could persist even after the residential relocation. In addition, Walker, Thomas, and Verplanken [33] suggest the possibility of a temporary suppression of old habits. They explain that the old habit-related mode of choice is merely weakened rather than abruptly breaking because the overlap between old and new habitual behavior lead to re-appearing habitual behavior.

2.2. Association of Travel Behavior with the Built Environment and Socioeconomic Characteristics

A vast literature has shown empirical evidence on the associations between built environments and travel choice mode [34–38]. Researchers have frequently contended that dense areas with well-connected streets will raise the price of driving and reduce the cost of walking. Testing this idea, Ewing and Cervero [1] compared the effect sizes of five D-variables (i.e., density, diversity, design, destination accessibility, and distance to transit) on travel choices quantitatively by employing meta-analysis. They concluded that changing the built environment could substantially influence travel mode choices (VMT, walking, and bus and train).

Meanwhile, some studies with similar subjects presented that compact development did not appear to have much impact on driving. Stevens [39] used meta-regression analysis to explain why the associations between the built environment and automobile usage vary because of sampling error, residential self-selection, selective reporting bias. Adjusting elasticities to remove the effects of these biases, he argued that driving is not sensitive to changes in the built environment. Moreover, some planning experts and policymakers are doubtful about the application of compact development features to Asian contexts like Korea and Hong Kong, compared to low-density cities in Western countries, since development density in those contexts is higher than the desirable levels suggested by Smart Growth and Transit-oriented development (TOD) proponents [3]. Sung and Oh [3] claimed that a policy to promote land-use diversity and connectivity rather than increasing high-density development is more beneficial to create a pedestrian-friendly environment.

Besides the built environment, socioeconomic characteristics are the most influential factors to determine travel mode choice. Previous researchers have long studied travel mode changes associated with socioeconomic attributes such as car ownership, income, education level, gender, age, and marital status. Studies conducted in various contexts, such as the U.S. [34], China [40], Hong Kong [41], Germany [42], and Spain [43], South Korea [3,44], commonly used these socioeconomic variables as control variables and attempted to accurately identify the influence of the built environment and TOD policies.

Recent works have increasingly focused on travel behavior from a long-term perspective. For instance, Müggenburg, Busch-Geertsema, and Lanzendorf [11] distinguished four domains of factors for travel behavior change in terms of daily mobility decisions, exogenous interventions, and adaptations to long-term mobility decisions caused by life events and long-term processes that are not perceived as particular events. They considered residential relocations (or migration) as key influences on long-term mobility decisions. Zhang et al. [10] noted that residential relocation and everyday mobility patterns had intertwined relationships over a lifetime from the perspective of biographical dependences, and they represented the important role of long-term mobility dependence established in the past in travel behavior within and across the residential relocation processes. From these findings, they explained the long-term influences of the transportation systems or policy on people's travel behaviors.

2.3. Present Study

Our study aims to estimate long-lasting effects of habitual behavior on travel behavior by separating from influence of residential self-selection. Rather than examining the influence of specific transportation policy or interventions, we focused on analyzing the observable evidence which distinguishes two underlying mechanisms responsible for the relationship between current travel mode choice and the past travel patterns after residential relocation. In this progress, the present study contributes to the understanding of the interdependencies between migration patterns and changes to travel behavior. To our best knowledge, the persistence of the past mobility dependency in newly residential context is not only debatable, but also few studies have empirically scrutinized the underlying mechanisms of how pre-determined travel behavior works during a process of residential relocation.

It is important to note that the influence of habitual travel behavior in the past does not necessarily mean the effect of residential self-selection. However, the formation of travel mode preferences can be influenced partly by habitual travel behaviors. Therefore, we attempted to divide the influence of residential self-selection from the influence of habitual behavior using the migration survey information for "motivations of relocation" (Figure 1). We divided the motivations of residential relocations into forced and voluntary moves, given that residential self-selection implies that households voluntarily locate to places that provide conducive conditions for their preferred way of travelling [45]. We assumed that individuals who forced to relocate due to an exogenous life event are more likely to play a minimal role in initiating or controlling the move [46], while those who voluntarily moved have a reasonable degree of control over when and where they relocate [33]. In this assumption, the former addresses relocations due to housing (e.g., gentrification and redevelopment) and workplace (e.g., employment and workplace relocation) issues. The latter is mainly motivated by environmental (e.g., education, amenities, transportation, health, etc.) factors and family-related issues (e.g., marriage, and separation from parents) [28,46]. Although the motivation of relocation does not fully address their preference of travel modes, our definition of a voluntary move may reflect the preferred environmental attributes of respondents.

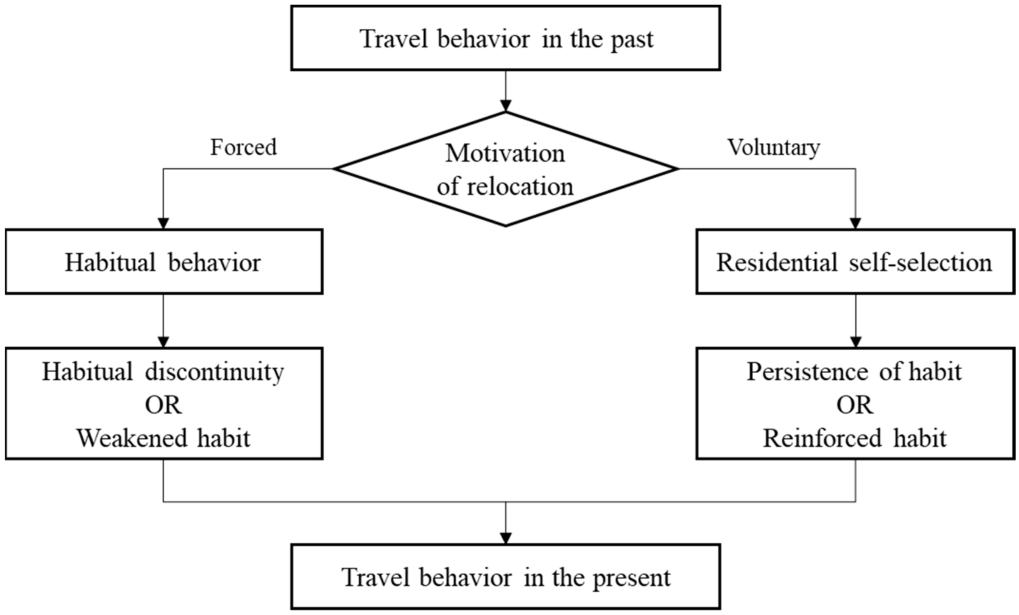

Figure 1. Relationship between travel behavior, self-selection and habitual behavior.

3. Methods

3.1. Study Area

We used the travel mode share and the residential movement data in the spatial scope of the Seoul Metropolitan Area (SMA), including the city of Seoul, Incheon, and Kyunggi province, to examine the travel patterns of the present and the past (Figure 2). Seoul has unique land-use features related to travel mode choice. First, Seoul is known as one of the fastest-growing cities globally, from 2.4 million in 1960 to 9.7 million in 2018 (Korean Statistical Information Service: http://kosis.kr, accessed on 4 April 2020). The population density as of 2018 is 16,604 inhabitants per square kilometer (Seoul Open Data Plaza: https://data.seoul.go.kr 4 April 2020). Second, land-uses are highly mixed. The dense development of Seoul is one of the factors that increase land-use mixture. In addition, building regulations in Korea allow various non-residential uses to be incorporated into residential uses for improving occupants' convenience [47]. Third, the SMA subway system is one of the most extensive transit systems in the world. In 2020, 22 subway lines are operating within the SMA, and ten lines that extend 343.4 km (Railway Industry Information Center: http://www.kric.go.kr accessed on 4 April 2020) are operating in Seoul, which is equivalent to the London underground, and New York City subway.

Seoul has experienced a massive suburbanization process in both population and employment due to large-scale suburban development, including five new towns in the 1990s [44]. The new town development plan for the SMA, announced in 1989 to stabilize housing prices, supplied a total of approximately 333,000 housing units in a short period [48]. These new towns in Seoul, developed in the 20–28 km range from the CBD of Seoul, have been severely criticized due to the social costs incurred from sprawl, such as longer commuting distance and additional environmental costs. In addition to the major large-scale suburban development, substantial amounts of "parasitic" towns dependent on the basic urban infrastructures of existing cities have developed since 1990. Approximately 13% of new residential development occurred within 15 kms of the CBD, and 60% of it was between 20 km and 40 km distance to the CBD of the SMA. These enormous suburban residential developments have attracted around 3.3 million residents to the suburban area.

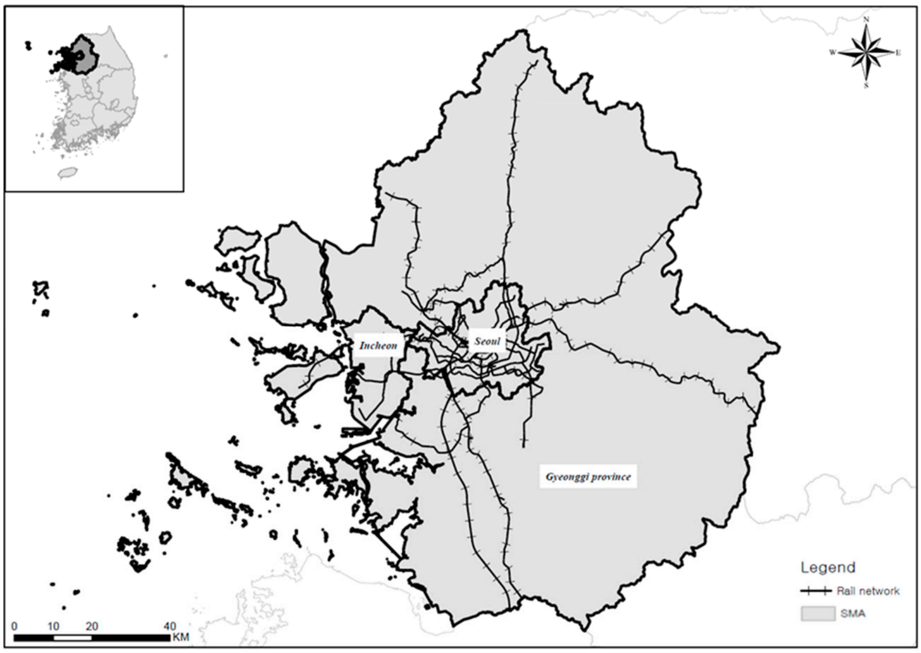

Figure 2. Research boundary [Seoul Metropolitan Area (SMA)].

3.2. Data Description

We focused on working groups aged 30 to 59 years since that age group is supposed to free from the restrictions when choosing a transportation mode. In general, the young and old age groups have relatively higher use of active modes of travel rather than a motorized vehicle in the consideration of legal restrictions, financial issues, and physiological limitation in the cohorts.

The primary sources used in this study are household Travel Surveys (HTS) for the SMA (Seoul Metropolitan Government) collected in 2006 and 2016 and Internal Migration Statistics [Microdata Integrated Service (MIDS)] during 2006–2015 (10 years). Control variables, including the built environment in 2016, were derived from land cover in 2014 (Environmental Geographic Information Service), building area (National Spatial Data Infrastructure Portal), the road network in 2016 (Korea Transport Database), locations of bus stops in 2018, and subway stations in 2017 (GyeongGi Bus Information & Seoul Open Data Plaza). The HTS data provide information for details of individuals' trip characteristics, including trip origin and destination, travel mode, departure and arrival time, and trip purpose during weekdays. Furthermore, individuals' socio-demographic information such as residence location at the neighborhood (dong) level, gender, age, income, car ownership, and occupation are included. The Internal Migration Statistics data comprise the number of in- and out-migrants at the neighborhood (dong) level, date and purpose (e.g., occupational, educational, marital status, and residential environment) of residential relocation, and migrants' age and gender. Since the form of the individuals' trip diaries reported in 2016 HTS were not identical with the forms for 2006, it is necessary to convert the 2016 data into the 2006 data format. The significant distinction between the two datasets lies in the method used to record the sequential mode choices within a single trip. In the 2006 HTS report, only the primary travel mode in the trip chain is documented. To align with this reporting format, the 2016 HTS data needs to be transformed in a similar manner. Consequently, we have opted to designate the farthest distance mode among the sequential mode choices. For instance, if modes for a certain trip are in the order of walking-subway-walking sequence, it is assumed to be a single trip by subway excluding the information on walking trips from data.

3.3. Statistical Models and Variables

Ordinary least squares (OLS) models were developed. Each mode share in 2016 was considered a function of the size of migration, socioeconomic factors, and the built environment to investigate the effects of the past travel behavior on the mode shares [1]. We created OLS models for 2016 to determine the mode share at the neighborhood level. Although we could not precisely control the individual-level demographic and socioeconomic characteristics in these models, the aggregate approach allows for examining the change of travel behavior for a relatively large study area over a long period [49].

We analyzed 590 and 545 neighborhoods in SMA to compare the impacts of the past travel behavior on travel share models for overall and commute trips, respectively. Neighborhoods with fewer than ten samples for each travel mode were excluded. In a similar approach, 590 neighborhoods were used for generating models for forced and voluntary relocation.

For i = 1, 2, ..., n neighborhoods, our specified OLS models are of the form:

$$Y_{ik} = \alpha + \beta_1 MD_{ik} + \beta_2 D_i + \beta_3 S_i + \varepsilon_i, \quad (1)$$

$$MD_{ik} = \sum_{j=1}^{n} (M_{jk06} * I_{ij}) / P_{i16}, \quad (2)$$

Here, Y_{ik} reflects the share of mode k in neighborhood i within the SMA in 2016, D_i and S_i are control vectors for the demographic and spatial characteristics in neighborhood i, respectively. D_i includes the car ownership ratio and the ratio of males. The mode dependence variable (MD_{ik}) represents the proportion of in-migrants who may use a specific travel mode k in the past neighborhood. M_{jk06} represents a specific mode share k of the past neighborhood j in 2006; I_{ij} is the number of in-migrants moving from the past neighborhood j to present neighborhood i at each year during 2006–2015; P_{i16} is the number of populations in present neighborhood i in 2016. In the model, we hypothesized that a larger value of MD_{ik} reflects the strength of the past habitual travel behavior given the fact that the frequency of past behavior is closely related to a habit's strength [19], which influences future behavior [8,23]. Meanwhile, the number of in-migrants motivated by housing and workplace issues are used for generating the models under the case of forced relocation, whereas the relocations related to environmental and family-related factors were used for models under the case of voluntary move.

The five D-variables were used to measure the built environment of a neighborhood (S_i). A variable for density is estimated by calculating the population density (person/m^2). The diversity factor is derived from a land-use mix (LUM) index computed via the entropy for two land-use types (i.e., residential and non-residential areas). That approach has been commonly used by other researchers [3,50]. The design factor is the proportion of four-way intersections. A measure for distance to destination represents network distances (km) to central business districts (CBDs), including City Hall, Kangnam, and Yeoido [51]. Finally, the distance to transit variable is estimated by measuring the number of rail and bus stations in a given area (km^2).

4. Results

4.1. Descriptive Statistics

Table 1 shows summary statistics of variables used in the models. The mode share of private vehicles (35.8%) is similar to the public transit mode share (33.7%). The car dependency of the SMA is lower than Chinese cities such as Beijing and Shanghai, but higher than Tokyo [52]. The SMA has an extensive public transportation system. The number of subways and bus stations are 0.982 and 8.446 per 1 km square, respectively. The average population density for the selected neighborhoods in this study is approximately 21,000 people/km^2. The mode dependence variable (i.e., the size of in-migrant dependent on each mode) represents the proportion of in-migrants who may use a specific travel mode in the past neighborhood. Like the mode share in 2016, these variables show the most dependency on private vehicles (Mean value = 0.430) and the least dependence on railways (Mean value = 0.270).

Table 1. Summary statistics of variables (number of samples = 590).

Variable	Mean	STD	Min	Max
Mode share				
vehicle (%)	35.8	11.7	7.9	69.6
rail (%)	14.6	8.5	1.6	47.7
bus (%)	19.1	8.5	5.7	50.7
vehicle (commute) (%)	40.1	13.2	10.3	80.4
rail (commute) (%)	18.4	10.8	2.3	53.6
bus (commute) (%)	21.6	10.2	5.7	55.6
Size of in-migrant dependent on each mode				
vehicle (%)	0.430	0.146	0.045	1.006
rail (%)	0.270	0.114	0.016	0.586
bus (%)	0.298	0.091	0.023	0.674
Socio-demographics				
vehicle ownership (%)	81.0	11.0	38.3	100.0
male (%)	52.3	52.0	37.6	90.0
Built environments				
pop density (person/m^2)	0.021	0.013	0.000	0.057
entropy	0.686	0.294	0.000	1.000
4-way intersections (proportion)	0.135	0.083	0.000	0.583
distance to CBDs (km)	13.307	9.142	0.000	49.544
subway density (number per 1000/km^2)	0.001	0.002	0.000	0.028
bus density (number per 1000/km^2)	0.008	0.007	0.000	0.048

4.2. Spatial Pattern of Internal Migration

For a first insight into the relationship between a residential relocation and travel mode share in the target year, we investigated the spatial distribution of in-migrants dependent for each mode type (MD_{ik}) within SMA. Figure 3 shows the travel mode share in 2016 and the size of in-migrants dependent on each travel mode. The grey-colored area represents a smaller size of in-migrants dependent on each mode, and thereby the neighborhood is less influenced by past dependency on a certain travel mode. Meanwhile, the red-colored area stands for a larger size of in-migrants dependent on each mode. The spatial distributions of the travel mode share and size of in-migrants dependent on each travel mode show a moderate correlation in the cases of vehicle (Corr = 0.277, $p < 0.001$) and bus (Corr = 0.182, $p < 0.001$), and a strong correlation in the case of rail (Corr = 0.466, $p < 0.001$). The positive correlations between the two imply that larger size of in-migrants, who depended on a certain travel mode in the past, increases the share of the travel mode in the present neighborhood.

In more detail, the spatial pattern stands out that the in-migrants, who resided in car-dependent neighborhoods in the past, have tended to move to suburbs or the periphery of the metropolitan area (e.g., the city of Incheon and Kyunggi province). Conversely, those who resided in rail-dependent neighborhoods in the past tended to be relocated close to the center of the metropolitan area (e.g., the city of Seoul). These patterns show a neighborhood self-selection process. Those who may have used a private vehicle in the past neighborhood tend to prefer private vehicle trips and are more likely to choose a car-friendly neighborhood in a suburban area. Indeed, our exploratory data analysis showed that the variable reflecting distance to CBD is correlated positively with the vehicle-dependent in-migrants (Corr = 0.395, $p < 0.001$), whereas negatively with the rail-dependent in-migrants (Corr = -0.629, $p < 0.001$). It may also represent that people are more likely to relocate near their previous neighborhoods. For instance, those who may use a private-car in the past tend to move from one suburban neighborhood to another.

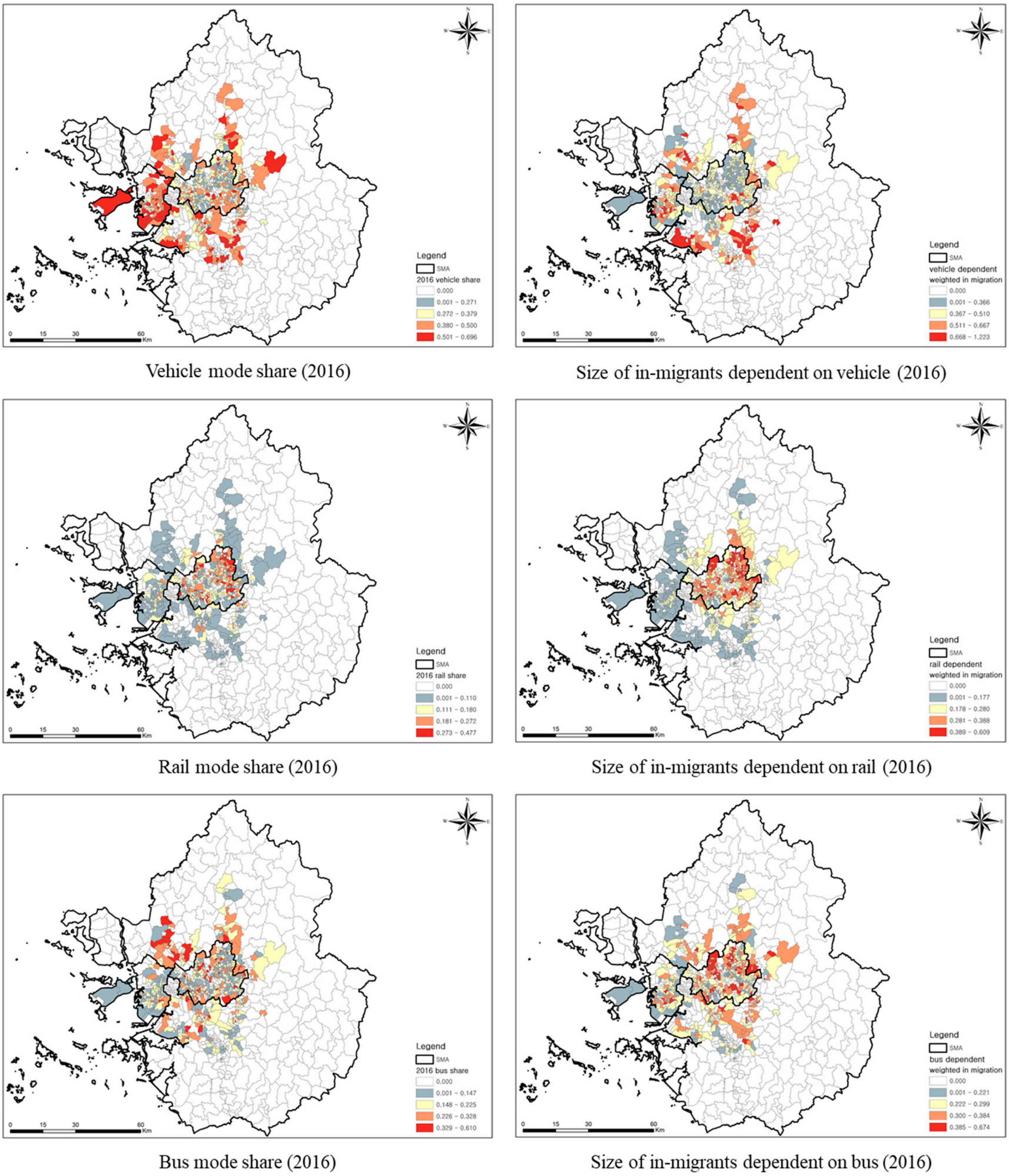

Figure 3. Mode share in 2016 (**left**) and the size of in-migrants dependent on vehicle, rail, and bus (**right**) within the SMA.

4.3. Model Results for Overall Trips and Commuting Trips

To examine the influence of in-migration on each travel mode in each neighborhood mode share in the future, we conducted six linear regression models accounting for socio-demographics and built environments. Table 2 shows the results of three models for all trips, and Table 3 shows the results of three models of commuting trips. The travel mode share of vehicles in 2016 was negatively associated with the size of in-migrants who may use rail transit in the past neighborhoods (ρ = −0.230 for all trips, ρ = −0.289 for commute trips). On the other hand, the mode share of rail in 2016 had positive associations with the size of in-migrants dependent on rail (ρ = 0.392 for all trips, ρ = 0.506 for commute trips), and negative associations with the size of migrants dependent on busses (ρ = −0.304 for all trips, ρ = −0.377 for commute trips). The results indicated that the mode share of busses in 2016 had positive associations with the size of in-migrants dependent on busses (ρ = 0.354 for all trips, ρ= 0.363 for commute trips), and negative associations with the size of in-migrants dependent on rail (ρ = −0.168 for all trips, ρ = −0.152 for commute trips). The overall model fit for the bus mode share was relatively low, ranging from 0.129 to 0.136.

Table 2. OLS models in the case of overall trips among adults aged 30–59.

Variable	Vehicle Share in 2016		Rail Share in 2016		Bus Share in 2016	
Size of in-migrant dependent on each mode type						
vehicle	0.0694		−0.0518		−0.064	
rail	−0.2303	***	0.3923	***	−0.1684	***
bus	−0.0087		−0.3042	***	0.3539	***
Socio-demographics						
vehicle ownership	0.5189	***	−0.1105	***	−0.1402	***
male	0.4289	***	0.1739	**	−0.0156	
Built environments						
pop density	−0.0384		0.8243	**	−1.063	**
entropy	0.0182		0.015		−0.0062	
4-way intersections	0.0485		−0.0309		−0.033	
distance to CBDs	0.0024	***	−0.0005		−0.001	.
subway density	−0.2614		1.9154		−1.8829	
bus density	−1.2358	*	−0.0812		0.9403	.
(Intercept)	−0.2906	***	0.1338	**	0.3187	***
Obs.	590		590		590	
R-squared	0.5402		0.3656		0.1287	

$p < 0.001$ '***'; $p < 0.01$ '**'; $p < 0.05$ '*', $p < 0.1$ '.'

Table 3. OLS models under the case of commute trips among adults aged 30–59.

Variable	Vehicle Share in 2016		Rail Share in 2016		Bus Share in 2016	
Size of in-migrant dependent on each mode type						
vehicle	0.0414		−0.0741	·	−0.0639	
rail	−0.2886	***	0.506	***	−0.1517	**
bus	0.0552		−0.3765	***	0.3633	***
Socio-demographics						
vehicle ownership	0.5591	***	−0.1076	**	−0.1604	***
male	0.3153	***	0.0813		−0.1355	.
Built environments						
pop density	0.0252		1.1016	**	−1.3626	***
entropy	0.0159		0.0215		−0.0186	
4-way intersections	0.032		−0.036		−0.0395	
distance to CBDs	0.0034	***	−0.0008		−0.0019	**
subway density	0.0534		2.9651	.	−2.0989	
bus density	−1.1793.	.	−0.1968		1.3800	*
(Intercept)	−0.2247	***	0.2126	***	0.4400	***
Obs.	545		545		545	
R-squared	0.5074		0.3717		0.1356	

$p < 0.001$ '***'; $p < 0.01$ '**'; $p < 0.05$ '*', $p < 0.1$ '.'.

In general, we can find two common aspects across multiple models. First, in-migrants' travel mode choices in the past are strongly linked to the travel mode share even after relocations. The travel mode share of private vehicles was not associated with the number of in-migrants dependent on private vehicles in the past, but it had a negative relationship with past mobility dependence on rail. Second, the values of model coefficients imply that such connections between the two were stronger for commuting trips, which might be due to the repetitive nature of commuting trips. The frequently performed behavior may strengthen and establish habitual behavior [23]. Thus, the models for habitualized commuting trips tend to show a strong influence of past travel behavior on present travel modes.

The influence of the socio-demographic and built environment variables generally met our expectations. Higher car ownership was associated with a higher mode share for vehicles and a lower share for public transit. The proportion of males has a positive association with the share of both vehicle and rail use, and we speculated that it might be related to the fact of gender difference in travel length [53]. Men generally travel longer distances and, therefore, are more likely to choose vehicles and rail systems. Distance to CBD is the most influential built environment factor to explain the vehicle mode share, while other built environment variables showed relatively weak associations. We further discuss these findings in the latter part. Meanwhile, population density is the most influential environmental factor associated with public transportation modes. We discuss this finding further in the discussion part.

4.4. Model Results for Forced and Voluntary Relocation

We compared the present travel mode share results after forced and voluntary relocations to distinguish the influence of residential self-selection and habitual behavior. Tables 4 and 5 show the results of forced and voluntary relation models. Overall, the associations between the size of in-migrants dependent on each travel mode and the present travel mode share were consistent with the findings of Tables 2 and 3. However, in terms of the strength of the relationship, forced and voluntary relocation models showed different results. The regression coefficients of the two models commonly suggest that the past mobility dependence on the present travel share has a larger effect in voluntary relocation (Table 5) than forced relocation (Table 4).

Table 4. OLS models under the case of forced residential relocation.

Variable	Vehicle Share in 2016		Rail Share in 2016		Bus Share in 2016	
Size of in-migrant dependent on each mode type						
vehicle	0.108	*	−0.0743	.	−0.0796	
rail	−0.2459	***	0.5441	***	−0.2582	***
bus	−0.0284		−0.3898	***	0.5075	***
Socio-demographics						
vehicle ownership	0.5227	***	−0.1167	***	−0.1403	***
male	0.4152	***	0.1656	**	−0.0209	
Built environments						
pop density	−0.2514		0.5847	*	−0.9881	**
entropy	0.0164		0.0134		−0.0036	
4-way intersections	0.0356		−0.0141		−0.0253	
distance to CBDs	0.0026	***	−0.0009	.	−0.0011	*
subway density	−0.4747		2.1418	.	−1.5875	
bus density	−1.1578	*	−0.0207		0.864	.
(Intercept)	−0.297	***	0.143	***	0.3189	***
Obs.	590		590		590	
R-squared	0.5322		0.3554		0.1428	

$p < 0.001$ '***'; $p < 0.01$ '**'; $p < 0.05$ '*', $p < 0.1$ '.'.

Table 5. OLS models under the case of voluntary residential relocation.

Variable	Vehicle Share in 2016		Rail Share in 2016		Bus Share in 2016	
Size of in-migrant dependent on each mode type						
vehicle	0.1472		−0.1416		−0.2425	*
rail	−0.7013	***	1.4203	***	−0.6724	***
bus	0.111		−0.9933	***	1.0755	***
Socio-demographics						
vehicle ownership	0.5299	***	−0.1269	***	−0.1291	***
male	0.4057	***	0.1741	**	−0.0168	
Built environments						
pop density	−0.3273		0.6939	**	−0.9526	**
entropy	0.0175		0.014		−0.0029	
4-way intersections	0.0556		−0.0333		−0.02	
distance to CBDs	0.0027	***	−0.0007		−0.0012	*
subway density	−0.3973		1.7229		−1.2344	
bus density	−1.1925	*	−0.1787		1.0143	*
(Intercept)	−0.2952	***	0.1396	***	0.3269	***
Obs.	590		590		590	
R-squared	0.5334		0.3539		0.1129	

$p < 0.001$ '***'; $p < 0.01$ '**'; $p < 0.05$ '*'.

In voluntary relocation models (Table 5), the size of in-migrants who may use rail transit in the past neighborhoods was strongly associated with the present share of private vehicles (ρ = −0.701) and busses (ρ = −0.672). At the same time, it has moderately negative associations with private vehicle (ρ = −0.246) and bus transit share (ρ = −0.258) in forced relation models. Similarly, the size of in-migrants who may use bus transit in the past neighborhoods had a more significant effect on the mode share of busses in the voluntary relocation model (ρ = 1.08) than in the forced relocation models (0.508). These results are not surprising since the voluntary relocation models account for the effect of both residential self-selection and habitual behavior. Those who voluntarily move are more likely to persist or strengthen their previous travel patterns since their selected environments may provide conducive conditions. In contrast, for those who forcedly move, the new residential environment may not provide an advantageous situation for maintaining past travel patterns. Therefore, we suppose that the forced relocation models more clearly present the sole influence of past habitual behavior on the present travel patterns.

5. Discussion

Consistent with the finding of a previous study [54], our findings demonstrated that current travel behavior is generally associated with the past behavior (e.g., travel habits), than the new type of built environments after residential relocation. However, unlike our expectation, the past vehicle dependency did not represent significant effects on the current travel behavior. A strong correlation between the past vehicle dependency and the distance to CBDs (Corr = 0.449) may explain the result. Figure 3 showed that the number of in-migrants dependent on vehicles tended to be higher in suburban areas or on the periphery of the metropolitan regions, while, within the boundary of Seoul, the size was small. Indeed, the distance to CBDs was the most dominant built environment factor that explains the present vehicle dependency.

In contrast with the predominant debate in the previous literature [1,55], other built environment variables related to density, land use and connectivity were not shown to have a clear association with current mode share. According to the results of Eom and Cho's empirical study [56] in the SMA, South Korea, the built environment characteristics, such as gross density and land-use mixture, have a non-linear relationship with individual travel mode choice in contrast to the well-established theory on the influence of the built environment. Specifically, the study explained that the negative association between population density and private vehicle mode selection was significantly reduced at an intensity beyond 9132–16,101 persons/km^2. In the context of the selected study neighborhoods with a high-development density (mean of population density is approximately 21,000 persons/km^2) and highly mixed land use (mean of entropy variable is 0.686), the manifest influence of the built environment on travel mode share was not shown.

From transportation planners' perspective, the influence of past habitual behaviors could be one of the barriers to the use of public transit or non-motorized travel since people are reluctant to change their past travel habits. Verplanken et al. [23] proposed that a disruption, such as residential relocation [57], which removes the cues automatically triggering behaviors, obliges people to revert to deliberate decision-making. Furthermore, Bamberg [58] suggested that residential relocations can be considered a "window of opportunity" for behavioral change, offering new transport opportunities. Therefore, shortly after residential relocations, providing information or subsidies of alternative travel modes could weaken the past mobility-related habits on the present travel mode choice since their travel behavior is not fully established according to the new residential environment. Moreover, these interventions, shortly after residential relocation, could be more effective for those who move involuntarily than voluntarily. For those who have a reasonable degree of control over when and where they relocate, it might be easier to persist in their car-dependent travel behavior by self-selecting to live in a car-dependent neighborhood.

The other insight for policymakers is that the built environment factors considered in this study showed a relatively weak influence on travel behavior within the context of the SMA with a high level of density and land-use mixture and a well-connected transit system. Meanwhile, the habitual behavior and travel-related attitudes (i.e., residential self-selection) established in the past have a notable impact on travel mode share even after residential relocation. Although the present study did not use a truly experimental approach to explore the effects of interventions on changes in sustainable travel attitudes, the results of this study support the effectiveness of soft intervention strategies rather than modifications of the physical environment to encourage sustainable travel behavior. For instance, employers could provide their employees who are forced to move in the process of workplace relocation with incentives, such as free transit cards and reduced parking availability [46], to encourage the use of public transportation for commute trips [59].

It should be acknowledged that the present analysis has several limitations. First, while the current study presented the possibility that the travel mode share is associated with the past travel behavior, we could not theoretically explain how long the impact of the past could last after the residential move and whether the influence will weaken or become stronger over time. Moreover, the analyses conducted do not reveal variances between the neighborhoods with different spatial and demographic characteristics. For instance, neighborhoods with varying mode shares in the target year might be differently influenced by the in-flows of mobility dependences due to the pre-determined mobility dependence in the neighborhoods. For these reasons, we could not firmly establish a generalized finding, and therefore, these theoretical limitations need to be addressed in future research. For instance, we expect that the findings may be generalized by extending the tempo-spatial ambit field of analysis or clustering [60], accounting for individual and context variances and sensitivity analysis [61].

Second, our results may not directly represent the impacts of past mobility dependence after residential relocation on individual mode choice, instead using proxy variables representing the share of migrants from the past neighborhood and mode share in a target year. Furthermore, it is difficult to obtain enough amounts of sample size given the aggregated model, and thereby, we could not confirm the findings we reported. However, a previous study, based on a questionnaire on travel behavior before and after the relocation, revealed that the perception of urban mobility cultures as a shared knowledge, even in city-level, could explain the travel behavior of individuals [26]. In this light, our findings on change in mode share might represent the difference in individual mode choices. Considering these methodological issues, we recommend conducting surveys tailored to the particular requirements of researching key events and further investigating panel data from a life-span perspective. However, conducting such surveys seems to be an exception given the high cost and time expenditures required [11].

6. Conclusions

The present study empirically investigated how travel mode dependence in the past neighborhood persists even after residential relocation from the perspective of residential self-selection and habitual behavior. The findings suggested that the migrants who have pre-determined mobility-related preferences or attitudes might have a noticeable effect on travel mode choice at the neighborhood level. In particular, the comparison between forced and voluntary relocation models showed that the influence of past travel behavior on the present travel pattern tends to be strengthened by the effect of self-selection. This finding, therefore, supports the previous explorations on the effect of movers who chose post-move locations due to the accessibility of places and the public transport options (i.e., residential self-selection) on transport mode choice behavior [26,54,62]. Last, but not least, we tried to identify the separate effect of habitual behavior in the forced relocation model. We found that habitual travel patterns can affect the travel patterns in new neighborhoods even after controlling for the effect of self-selection.

Our findings challenge the assumption that travel choices are affected solely by the built environment, pointing out the role of residents' pre-established habitual behavior related to the past mobility dependence even after residential relocation. Habits toward the old mode did not disappear in our study, suggesting that there could be a propensity to persist in old mobility-related behaviors even after a context change. This result might provide an impetus for the ideas about impacts of residential context change and persistence of old habit on travel mode choice in the future for a sustainable mobility intervention. In this line of questioning, we believe that drawing and relying on interdisciplinary knowledge from sociology, psychology, and geography ultimately allows for an integrated and comprehensive understanding of the underlying rationales of travel behavior change over time.

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