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ORIGINAL PAPER

Impacts of self-selection and transit proximity on commute mode choice: evidence from Taipei rapid transit system

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Abstract Debate over how land use and self-selection affect travel behavior continues. Prior research contributes limited empirical evidence to this debate, and characterizing self-selection remains problematic. This empirical research explores the impacts of self-selection and proximity to transit at both residence and workplace. The research hypothesis is self-selection and proximity to transit increase the probability of workers commuting by rapid rail transit. To conduct this research, a station-exit passenger survey was conducted along the Taipei Rapid Transit System. Analysis methods include binomial logit modeling and sensitivity analysis. Research results support the idea that transit proximity to both work and residence increase the probability of transit commuting, but the hypothesis about the impact of self-selection is only partly supported. Policy implications suggest that, on one hand, increasing density around transit stations could realize unfulfilled self-selection; on the other hand, improved quality-of-life characteristics in neighborhoods around station areas may induce residents and companies to relocate to the neighborhood, thereby increasing residents' and workers' probabilities of commuting by transit.

JEL Classification R14

1 Introduction

Compact city and new urbanism land use policies have drawn attention, and even gained popularity, in sustainable development efforts to curtail transportation energy consumption, tailpipe pollution, and land consumption. The attention emerged largely

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as travel behavior was found to be correlated with compact elements of the built environment (Ewing and Cervero 2001; Boarnet and Crane 2001). Recent research attributes (part of) this relationship to self-selection instead of land use per se (Giuliano 1995; Crane 2000; Cervero and Duncan 2002; Krizek 2003a; Jarvis 2003; Handy et al. 2005; Schwanen and Mokhtarian 2005a,b; Levine et al. 2005; Cao et al. 2006). The presence of self-selection emphasizes the importance of a market- or demand-oriented approach (Cervero and Duncan 2002) or reducing the "zoned out" effect (Levine et al. 2005), as opposed to a planning- or supply-oriented approach. Market manipulation or lack of latent demand in sustainable land use casts doubt on the correlation or impact land use has on travel behavior.

However, a few gaps remain in addressing the relationship among self-selection, land use, and travel behavior. First, the variables characterizing self-selection in past research vary. Some research has applied revealed-preference variables such as existing residential location (Cervero and Duncan 2002), and some has applied attitudinal variables (Handy et al. 2005; Cervero 2007). The former has limited capability to predict latent demand, and the latter may generally involve issues of inconsistency of attitude and less reliability. Second, in the complex model of travel behavior, preference for living in or relocating to a place with few barriers to taking transit could be a significant factor in predicting mode choice decision. However, a self-selection variable based on relocation preference—behavior-based, in particular—has rarely been applied in previous research. In addition, limited research has been conducted to address the impacts of self-selection on commute mode choice. Finally, the measurement of fulfilled and unfulfilled self-selection is made possible by the availability of a newly operating mass rapid system, such as in Taipei.

The purposes of this paper are two-fold: (1) to provide insights into the meaning of self-selection, its relationship with transit proximity and land use, and variables characterizing self-selection; and (2) to empirically examine impacts of self-selection and transit proximity on travel behavior, respectively. The hypothesis of this empirical research is transit self-selection (represented by a station-area residential self-selection index, hereafter, SAR self-selection) and transit proximity at both residence and workplace ends (hereafter, residential and workplace transit proximities) increase workers' probability of commuting by transit.[1] If this hypothesis is true, all else being equal, a person characterized by all three—high SAR self-selection and close proximity to transit at both home and workplace ends—is more likely to commute by transit than others.

This paper starts with a literature review on the meanings of self-selection, its relationship to land use and transit proximity, and its impact on travel behavior from an interdisciplinary aspect. The following describes an empirical study to test the research hypothesis. To conduct this empirical research, a station-exit survey was conducted to the rapid rail patronage of the Taipei Rapid Transit System—Taipei

[1] Non-work trips are not included for a few reasons: first, since non-work trips are composed of a variety of trip purposes (e.g., personal business, shopping, and medical appointments), their relationships with self-selection and transit proximity are likely to be different from each other. In addition, many non-home-end destinations of non-work trips are not as easy for riders to pinpoint as workplaces. Also, to collect statistically large enough sample of one particular type of non-work trips would be too costly. As a result, both data collection and analysis for non-work trips are barely feasible for this research.

Metro. Research methods include descriptive statistics, binominal logit modeling, and a sensitivity analysis. Finally, policy implications are developed for land use plans around transit stations.

2 Self-selection, proximity and travel impacts

Informed by prior research and current theory, this section explores self-selection, its relationship to transit proximity and land use, and its impact on travel behavior from different perspectives—behavioral, economic, and statistical.

2.1 Self-selection

Self-selection in the transportation/land-use arena can be defined as mode-specific and/or built-environment-specific preferences. In a narrow sense, it could be defined as preferences to travel by public transit modes and also preferences to live in neighborhoods that can accommodate such travel preferences (Cervero and Duncan 2002; Krizek 2003a,b), such as transit-driven SAR self-selection. In this case, transportation mode choice can be regarded as being partially initiated by travel self-selection, and realized through residential location choice.

Though travel self-selection affects residential self-selection, they are not the same for several reasons. First, travel self-selection is only one of many factors affecting residential location choice, such as housing and neighborhood characteristics (McFadden 1978). Second, travel self-selection is more of an individual behavior, as opposed to a household's joint decision making of residential location (Handy et al. 2006). Finally, travel and residential self-selections may contradict each other—for instance, people with public transit preference may prefer to live in low-density, auto-oriented environments.

The discussion of self-selection in land use and transportation planning stems from the debate over whether land use affects travel behavior—or to be more exact, to what extent land use and self-selection affect travel behavior, respectively. By addressing the self-selection issue, we can begin to understand the dynamics of land use in relation to transportation. And with this understanding, we can begin to predict the extent to which land use policy affects travel behavior, which is particularly important if self-selection per se, or the impact of self-selection, is low in a market. Such knowledge can help determine whether land use policy plays the role of market facilitator (meeting latent demand), planning interventionist (inducing demand), or both (Jarvis 2003; Schwanen and Mokhtarian 2005a; Levine et al. 2005).

2.2 Relationship of self-selection with land use and transit proximity

In the debate over the impacts of land use and self-selection on travel behavior (Handy et al. 2005; Cao et al. 2006), the significance of land use cannot be overlooked. First, regardless whether its relationship to transportation is causal or correlated, land use is a necessary tool for the supply of neighborhoods with high transit accessibility. Second, built environment affects neighborhoods' competitiveness and residents' utility—and thus, residents' housing consumption and transportation mode choice, since travel times and costs are different in different settings. Though travel time and cost, rather than the built environment, directly affect travel behavior (Boarnet and Crane 2001), land use is one of the primary policy tools affecting travel time and cost. Third, from an economic point of view, when the supply of housing in station areas increases (e.g., higher density cap) the consumption of housing at this location may increase if the demand is not completely inelastic. This in turn may attract more transit patrons due to more residents living in transit-competitive areas. Finally, if past travel experience affects current travel behavior—for instance, some research finds that immigrants from transit-accessible countries, like Asia and Latin America, tend to ride transit more than Americans do (Cervero 1996)—then perhaps residing in transit-conducive neighborhoods can affect travel self-selection in the long term. That is, land use could affect travel behavior, or the post-decision consolidation (Svenson 1992; Schwanen and Mokhtarian 2007) in psychology.

Transit self-selection may be more directly reflected by preference for transit proximity than by preference for the built-environment of transit-oriented development (TOD)—i.e., high density, mixed-use, and pedestrian-friendly environment. Preference for transit proximity (location factor) is largely driven by transit self-selection, but preference for TOD (land use and urban design factors) may be caused by residential and/or transit self-selection, which may conflict with each other as described above. Transit proximity can be fulfilled by both transportation and land use policies; that is, bringing transit services near home, or providing more housing around transit stations (mostly within 5-min walking distance, or 350–400 m from a station). People self-selecting for both transit proximity and TOD, however, are probably the primary targets that TOD activists aim to serve.

Transit self-selection may lead to SAR self-selection (i.e., transit-driven SAR self-selection in this research) but it is not the only cause of SAR self-selection. SAR self-selection can be driven by at least two factors. One is transit-driven SAR self-selection, including transit preferences of individuals as well as household members, where land use policy can facilitate transit demand by offering residences near transit stations. The other factor is station area characteristic-driven self-selection, including preferences for TOD settings and real estate investment. Preferences for TOD settings are particularly true if the preferred characteristics exist only in station areas. Real estate investment is defined here as the intention of purchasing a residence in the station area for investment returns from expected increased real estate values. The above two factors compose the SAR self-selection. However, another factor that causes people to move into station areas is not due to transit-related reasons, but due to certain location characteristics which happen to exist within a station area. Preferred school districts and other building amenities, for example, characterize non-transit-related relocation in this research.

Theoretically, out of the above three causes for moving into station areas, only individual transit preferences could affect personal transportation mode choice, all else being equal (e.g., *transit proximity*). For example, among people living at the same distance from a transit station, those with individual transit-driven SAR self-selection will be more likely to be transit commuters than those without it. SAR self-selection, partly underpinned by transit-driven SAR self-selection, hence, would also increase the probability of riding transit, but at a smaller magnitude than that of transit-driven SAR self-selection. In addition, station-area characteristic-driven self-selection and non-transit-related characteristic-driven relocation would not affect the probability of riding transit except that their proximity to transit is improved—that is, transit proximity rather than the causes of relocation affects commuting mode.

Failure to relocate to a station area may occur under various conditions. Starting from Alonso's (1964) location theory that workers trade-off between commuting and housing costs, current residential location theory becomes more delicate: consumers seek a dwelling unit that maximizes their utility by weighting a list of residence attributes—tenure, size (Clark et al. 1996), cost (McFadden 1978)—and neighborhood traits—amenities, crime levels, quality of schools (Clark et al. 2006), accessibility to work and non-work activities (Waddell 1993; Weisbrod et al. 1980), and ethnic composition and social network (Scheiner and Kasper 2003)—both contributing to the supply of housing. The attributes of individuals/households compose the demand for residential location, including socioeconomic characteristics like age, household size, number of children, personality/life style (e.g., status seeker, workaholic; Schwanen and Mokhtarian 2007), and attitudes about family, labor, leisure, environment, land use, travel (Salomon and Ben-Akiva 1983), neighborhood image (Bagley and Mokhtarian 2002), number of workers, and life cycle. In economist Makhtarian's residential location theory, the endogenous factors could be regarded as self-selection, partly resulting from attitudes and socioeconomic characteristics (Makhtarian and Cao, 2008). Hence, SAR self-selection, for instance, only one of an array of variables affecting residential location choice, cannot materialize if the characteristics of dwelling unit and neighborhood as a whole in the station area do not maximize consumers' utility.

2.3 Variables and travel impacts of self-selection

Past self-selection related research adopts different variables and methods to represent self-selection, but a few gaps exist in this regard. Cervero and Duncan (2002) dichotomize residents into people with and without (residential) self-selection by their actual residential proximity to the closest rail transit stations—i.e., living within or beyond 1/2 mile from transit stations. This kind of method takes advantage of revealed choice residential location, but it may be unable to estimate unmet housing/neighborhood demand. Some studies apply attitudinal self-selection variables (Schwanen and Mokhtarian 2004; Levine et al. 2005; Handy et al. 2005; Cervero 2007) that can help forecast unmet housing demand of people with self-selection, but may involve issues of inconsistency of attitude and be less reliable. Schwanen and Mokhtarian (2004, 2007) develop six factors to represent residential preference including travel dislike, pro-high-density, and pro-suburban housing which are the results of factor analysis of 32 variables. Levine et al. (2005) apply principle component analysis to a list of attitudinal variables to extract a neighborhood transportation/land use preferences factor, representing the degree to which an individual prefers auto- or transit-/pedestrian-oriented neighborhoods.

Travel self-selection variables could contribute to modeling travel behavior, and differentiating impact of self-selection from land use (as planning interventionist). First, R-squared values in most travel-behavior models seldom exceed .30, suggesting that travel behavior is unpredictable for a significant proportion of the choice (Krizek

2003a). In these models, socio-demographic variables are usually included to represent life-style preferences, such as travel preferences/self-selection—from one point of view preferences being partly genetically coded (McFadden 2001), and from the other point of view possibly affected by socio-demographic status. However, travel self-selection likely is not totally captured by socio-demographic traits but by attitudes also (Mokhtarian and Cao 2008) and by the way they are measured. Secondly, land use characteristics, mixed land use and density, for example, may not only influence travel behavior, but also meet travel preferences. As a result, if travel self-selection is not controlled for when evaluating the impact land use, this impact is likely to be compounded with self-selection.

A few past studies have examined the dissonance between preferred and actual residential neighborhood types, but only limited research has addressed the impact of self-selection on travel behavior. First, current evidence on the dissonance of preferred and actual neighborhoods varies. A comparative study of commuters living in transit- and automobile-oriented communities in the San Francisco Bay Area found that a quarter of residents lived in mismatched neighborhoods, of which more were automobile-oriented individuals preferring to live in lower-density neighborhoods (Schwanen and Mokhtarian 2004), possibly implying oversupply of transit-oriented neighborhoods. Evidence from a comparative study of more transit-oriented Boston and less transit-oriented Atlanta showed that a larger portion of Bostonians lived in preferred neighborhoods than did Atlantans (Levine et al. 2005). The above studies show no uniform degrees of mismatched residential self-selection in different neighborhood or city settings, which might imply needs for deregulation of land use policy to allow market forces to work, in particular for TOD environments. Second, evidence is found that both self-selection and land use factors affect travel behavior (Cao et al. 2006). Furthermore, in the San Francisco Bay Area, land use factors were found to have stronger impact on travel distance than neighborhood built-environment preference (Schwanen and Mokhtarian 2005a,b). Finally, evidently mismatched higher-density-oriented individuals are likely to travel unsustainably via automobiles due to limited transit services in lower-density settings (Schwanen and Mokhtarian 2005a,b).

3 Modern rail transit systems in Taiwan

Taiwan is one of the densest countries in the world, although it is relatively small in terms of population and land area.[2] Taiwan has had a conventional rail system for more than a century, but its first rapid rail transit system, Taipei Metro, did not begin operation until 1996, serving the Taipei metropolitan area,[3] with a population over 6.3 million and a population density of 9,649 persons per square kilometer (25,106 persons per square mile) in 2004 (Executive Yuan of Taiwan Government 2005), compared

[2] In 2004, the 36,000-square-kilometer Taiwan had a population of 22.6 million (Executive Yuan of Taiwan Government 2005), only about eight million less than that of Canada (United Nations 2006a). Taiwan's population density was 628 persons per square kilometer (or 1,608 persons per square mile) (Executive Yuan of Taiwan Government 2005), which was about twice that of Japan and United Kingdom, and 15 times that of the U.S. (United Nations 2006b).

[3] The Taipei metropolitan area is composed of Taipei City and Taipei County in this paper.

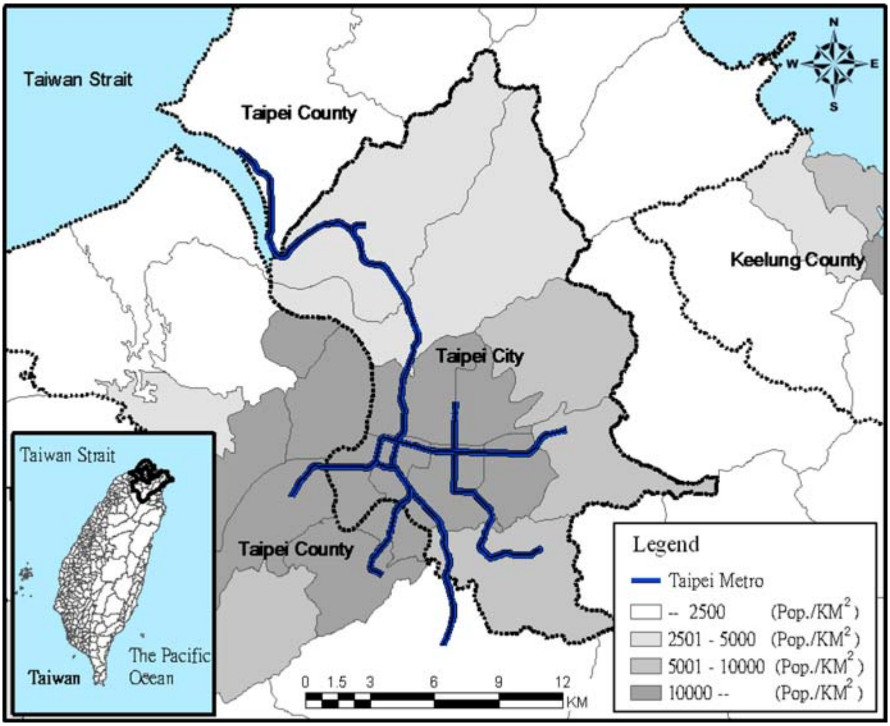

Fig. 1 Network of Taipei Rapid Transit System-2008

to 24,448 of Paris, 13,333 of Tokyo, and 10,292 of New York (Wikipedia 2006). Taipei Metro presently boasts eight routes, totaling 74.4 km (Fig. 1), though during the station-exit survey period in 2004, it comprised only 67 kilometers (Taipei Rapid Transit Corporation 2008). In 2006, it served about a million riders per day (Taipei Rapid Transit Corporation 2006). The system is scheduled for completion in 2021, at which time it will extend approximately 230 km and serve 3.6 million riders per day. The other two modern rail transit systems are the recently-opened (2007) 345-km Taiwan High Speed Rail, connecting most of the large cities in West Taiwan, and a newly opened (2008) rapid transit system in Kaohsiung (Kaohsiung City Government 2006), the second largest city in Taiwan.

4 Methods

For this research, adult passengers riding the Taipei Metro were selected for the case study; [4] consequently, the research findings are limited to rapid transit riders. It is unreliable to draw implications for the general public based on the findings derived

[4] A better survey population would be the residents of Taipei metropolitan area, for which mail or telephone surveys could be adopted. However, both of those survey methods were beyond the budget of this research due to extremely low response rates for mail survey in Taiwan, and the nature of the questionnaires was not appropriate for a phone survey.

from Taipei Metro riders in terms of distribution of various SAR self-selection groups (refer to Sect. 5.1), and relative importance of SAR self-selection to transit proximity in affecting mode choice. However, this sample, though not representative of the general public, can still contribute in a conservative way. First, among transit riders, unmet market needs for living in station areas are reasonably expected to be lower than unmet needs among the general public at large. Second, if transit proximity and SAR self-selection statistically affect use of the Taipei Metro for current riders, then the research hypothesis and related policies will work for at least this portion of the general public. Finally, it is composed of unmet demand of current riders, who can be prioritized targets of TOD projects.

Twelve years into the Taipei Metro's operation since 1996, this study provides an opportunity to gauge the degree of riders' SAR self-selection from a *quasi-revealed-preference* angle, represented by the actual response to the new rapid rail transit system, which will be elaborated in detail below. A station-exit passenger survey with a general questionnaire was conducted in September 2004, for which multi-stage cluster sampling was applied. The survey was conducted in each selected station during three time periods: weekday peak hours, weekday off-peak hours, and the weekend of the same week.[5]In addition, due to an expected statistically small sample size of SAR self-selection riders collected from the general survey, another version of the questionnaire was specifically designed to solicit information from only those riders with SAR self-selection.[6] The number of valid questionnaires collected for the general (hereafter, general sample) and self-selection (hereafter, self-selection sample) questionnaires are 469 and 94, respectively. The pooled sample is weighted to reflect the distribution of Taipei Metro passengers egressing at each station for the same month, as well as the proportions of the six SAR self-selection groups (whose definitions are addressed in detail later in this section) in the general sample.

Secondary data includes the number of Taipei Metro's monthly passengers for the survey month (Taipei County Government 2004), and the number of residents by a neighborhood-level administrative unit—"Li" in Taiwan (Taipei City Government 2004 ; Taipei County Government 2004). Analysis methods are composed of geographic information systems (GIS), descriptive analysis, binomial logit model, and sensitivity analysis.

To measure riders' levels of transit self-selection based on their behavior is a challenge, and eventually a SAR self-selection index is adopted for this research.[7] Three questions of the questionnaires are employed to measure levels of SAR self-selection in two phases. One question was designed to single out riders' relocation behavior

[5] All stations were selected except for three major transfer stations, for which we did not obtain permission from Taipei Rapid Transit Cooperation. Additionally, to avoid intentional interviewer bias of picking certain passengers, the third passenger exiting gates were approached for the survey whenever interviewers began to conduct a survey or resumed from a previous survey.

[6] This questionnaire contained the same questions as the above general version except that the SAR self-selection question was moved to the very beginning as a screening question. Only those riders with SAR self-selection were surveyed for this questionnaire.

[7] The challenge faced includes: behavior-based transit self-selection indicators are simply hard to develop; and transit-driven SAR self-selection is easily entangled with other SAR self-selection causes as described above.

only for purposes of "living closer to Taipei Metro stations" in response to Taipei Metro's construction begun in 1988. The "relocation behaviors" in question are (1) talked with realtors, or house owners; (2) collected housing information; (3) intended to move, but took no direct action, and (4) had none of the above, representing possibly different levels of SAR self-selection behavior/interest, in a high-to-low order. The other two questions were intended to solicit information on location of a person's current residence, and the year the person moved to the current residence.

In phase one, riders are characterized into 12 types based on the above four degrees of relocating behavior/interest, and whether they were original station-area (defined as 400 m radius from a Taipei Metro station) residents (i.e., moving into station areas before 1988), new station-area residents (i.e., moving into after 1988), or non-station-area residents (Table 1). The arbitrarily-defined station areas, allows this research to identify and measure the unmet demand of TOD, such as types C, F, and I. Of the new station-area residents showing only such interest as collecting housing information (i.e., type E), no action for moving closer (i.e., type H), or no SAR self-selection (i.e., type K), their reasons for moving closer can be regarded as non-transit-related characteristics since none of above three (non)actions constitutes the sufficient precondition of moving behavior (as opposed to talking with realtors/house owners) for purposes of living closer to transit stations.

In phase two, the 12 types of riders are further classified into 6 types in order to distinguish different levels of SAR self-selection:

Group1: *Success SAR self-selection group* is composed of those who moved into the station area only for purposes of living closer to Taipei Metro stations (i.e., type B of Table 1).[8]

Group2: *Talking-with-realtors group* is composed of those who were interested in moving closer to a Taipei Metro station, but at most, only met with realtors or housing owners (i.e., types A and C).

Group3: *Collecting-housing-information group* is composed of those who were interested in moving closer to a Taipei Metro station, but at most, collected only housing information (i.e., types D, E, and F).

Group4: *No-action SAR self-selection group* is composed of those who were interested to move near a Taipei Metro station, but took no direct action of any sort (i.e., types G, H, and I).

Groups 2 through 4 include not only non-station-area residents but also station-area residents; original station-area residents might still (arbitrarily) show interest in moving closer as a response to the expansion of the Taipei Metro even though their

[8] Success SAR self-selection group is defined as those new station-area residents reporting talking with realtors or house owners, which is a sufficient precondition of relocating behavior for purposes of living closer to transit stations per se; the other three (i.e., collecting housing information, being intended to move near to a Taipei Metro station, but taking no direct action of any sort, and having none of the above) are not sufficient preconditions of moving behavior. Hence new SA residents reporting only any of these three non-sufficient behaviors are regarded as moving into for non-transit-driven reasons. However, it cannot be ruled out that those moving into station areas for non-transit-related-characteristics-driven causes may also reported talking with realtors or house owners (i.e., group 2). Hence they are misclassified in this group, which may lead to underestimated of impact of transit-driven-residential self-selection on commuting by Taipei Metro.

Table 1 Definitions and proportions of station-area residential self-selection types

Reported station-area residential self-selection behavior/ interest	Current station-area (SA) residents			Total
	Original SA residents	New SA residents (moving into after 1988)	Non-SA residents	
Talked with realtors, or house owners	Type A: 9 (2.1%)(Group 2)[a]	Type B: 25 (5.4%)(Group 1)	Type C: 31 (6.9%)(Group 2)	65 (14.5%)
Collected housing information	Type D: 6 (1.3%)(Group 3)	Type E: 7 (1.5%)(Group 3)	Type F: 25 (5.4%)(Group 3)	38 (8.2%)
Was intended to move, but took no direct action of any sort	Type G: 5 (1.2%)(Group 4)	Type H: 18 (4.0%)(Group 4)	Type I: 113 (24.7%)(Group 4)	136 (29.9%)
Had none of the above actions	Type J: 31 (6.9%)(Group 6)	Type K: 41 (9.1%)(Group 5)	Type L: 143 (31.5%)(Group 5)	215 (47.5%)
Total	51 (11.5%)	91 (20.0%)	312 (68.5%)	455 (100%)

$N = 455$; Weighted to reflect the distribution of Taipei Metro passengers egressing at each station
[a] The group information indicates the SAR self-selection group of this type, as shown in Table 2

Table 2 Taipei Metro patrons, by station-area residential self-selection

Types of Taipei Metro patrons, by station-area residential self-selection	Percentage
Group 1: Success SAR self-selection group	5.4
Group 2: Talking-with-realtors group	9.0
Group 3: Collecting-housing-information group	8.2
Group 4: No-action SAR self-selection group	29.9
Group 5: No-SAR self-selection group	40.6
Group 6: Unclear-SAR self-selection group	6.9
Total	100.0

$N = 455$ (Weighted general sample)

current locations were regarded as within station areas already by this research (also see footnote 8).

Group:5 *No-SAR self-selection group* is composed of those who showed no interest in moving near a Taipei Metro station among non-original station area riders (i.e., types K and L) (for original riders, see definition of Group 6 below).

Group:6 *Unclear-SAR self-selection group* is composed of existing station-area riders showing no interest of moving closer (i.e., type J). The degree of SAR self-selection of this group cannot be measured since showing no interest could be due to the fact that they live close enough already and do not have interest in moving closer.

The above constitutes a quasi-revealed-preference SAR self-selection variable measured by both behaviors (i.e., moving, talking with realtors, collecting housing information) and attitude (i.e., group 4). The behaviors of moving, talking with realtors, collecting housing information, and taking no direct action may reflect different levels of moving preference. However, it cannot be ruled out that groups 1 through 4 might be of the same level of SAR self-selection since their behavioral difference might merely reflect their self-consciousness of financial capability of purchasing housing near a transit station.

Based on the above definitions, SAR self-selection, in this case, is a mix of transit-driven SAR self-selections of individuals and household members, and station-area characteristic-driven self-selection of preferences for TOD settings and real estate investment. Theoretically, only *individual transit-driven SAR self-selection* out of these factors would have impacts on transit mode choice (also see footnote 1), given transit proximity and else being equal. Due to this mix of factors, affecting and not affecting transit mode choice, the impact of transit self-selection, being represented by SAR self-selection, on transit mode choice would be underestimated.

5 Characteristics of Taipei metro patrons and trips

This section first introduces the basic characteristics of Taipei Metro patrons and latent demand of housing within station areas. It then cross-analyzes one self-selection variable against others. The final part addresses patrons' commuting behavior.

5.1 Socio-economic characteristics and latent demand

Among the Taipei Metro adult riders, females were more than males (56% vs. 44%). Riders' mean age was 42 years. Approximately 80% had a college degree or higher. Three-quarters were employed, either part-time or full-time. About two-thirds had an automobile driver's license, and about 60% had a moped driver's license. Per household, the mean ownership of automobiles and mopeds were 1.05 and 1.38, respectively. More than 70% of those surveyed owned their homes.

Of the Taipei Metro adult riders, some 20 % moved into station areas after 1988 when the construction started; however, only 5.4% (i.e., type B) out of 20% were considered as SAR self-selection driven (Table 1); the rest (types E, H, and K) were regarded as non-transit-related characteristic-driven new residents. Some 70% lived outside of station areas.

Table 1 also reveals information on fulfilled and latent demands for living within the Taipei Metro station areas. Putting aside preferences for housing style and housing tenure, those living outside of station areas and showing certain degrees of interest in relocating closer to transit stations can be regarded, in a broad sense, as the latent demand for station area housing—that is, types C, F and I, altogether accounting for 37% of all riders. Due to the sample's composition of only Taipei Metro patrons, the quantity of overall latent demand for living within station areas is reasonably expected to be higher than just this proportion of the riders. The demand for station-area housing by current station-area residents may be regarded as being fulfilled due to their already high transit proximity, regardless of their reported SAR self selection.

Of those six SAR self-selection groups, the largest groups comprised the two rider groups with the possibly least levels of SAR self-selection, i.e., no-SAR self-selection group (41%), and no-action self-selection group (30%) (Table 2). The two groups with intermediate levels of SAR self-selection—those who only talked to realtors or collected housing information—accounted for less than 10% each.

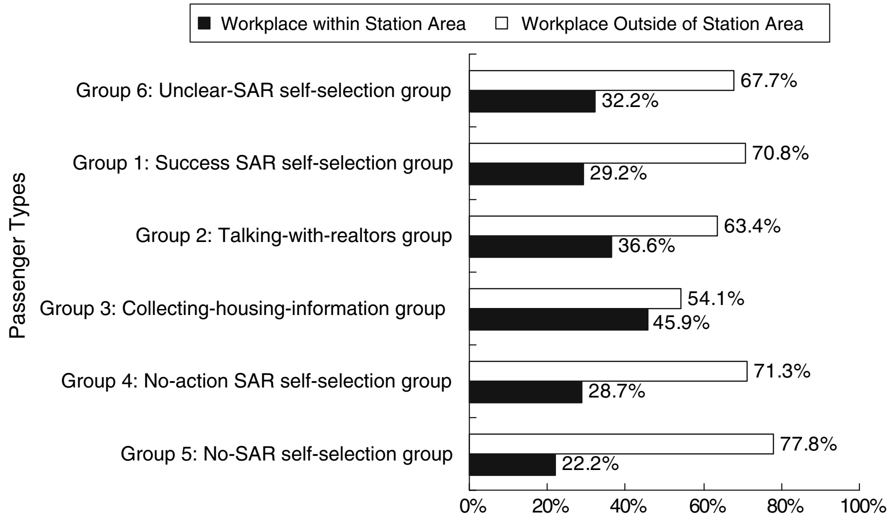

Fig. 2 Riders' workplace transit proximity to Taipei Metro stations, by station-area residential self-selection

5.2 Cross-analysis

The median distances from riders' residence and workplace to the closest Taipei Metro station were 943 and 563 m, respectively. Fig. 2 shows that the *proportion of workplaces located within station areas* (hereafter, workplace transit-proximity index) was less than 40% for all SAR self-selection groups, except for collecting-housing-information group. Based on this index, Fig. 2 may also indicate that no specific relationship can be observed between SAR self-selection and workplace transit proximity.

Insufficient affordable housing near Taipei Metro stations seems to hinder riders with SAR self-selection from purchasing or moving closer to the station area. Among groups 2 through 4 with a certain degree of self-selection, the higher their financial capability (personal income and residence ownership), the higher was their degree of SAR self-selection (Figs. 3, 4); in addition, the success SAR self-selection group had the highest income. New station-area residents had lower rates of home ownership (64.5 %) than the original residents (80.6%), implying station area housing might be not very affordable.

5.3 Commuting characteristics

Table 3 reveals descriptive statistics about Taipei Metro patrons' primary commute modes, broken down by residential transit-proximity and SAR self-selection. First, it was probably not surprising that Taipei Metro was the primary commute mode for all six groups of Taipei Metro riders. Second, interestingly, shares of commute mode by Taipei Metro of groups 1 through 5 were very much in the high-to-low order.

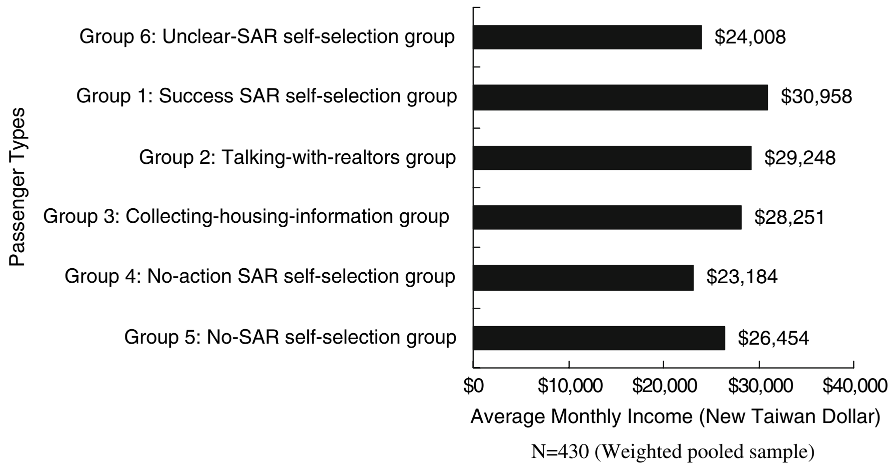

Fig. 3 Average income of Taipei Metro patrons, by station-area residential self-selection

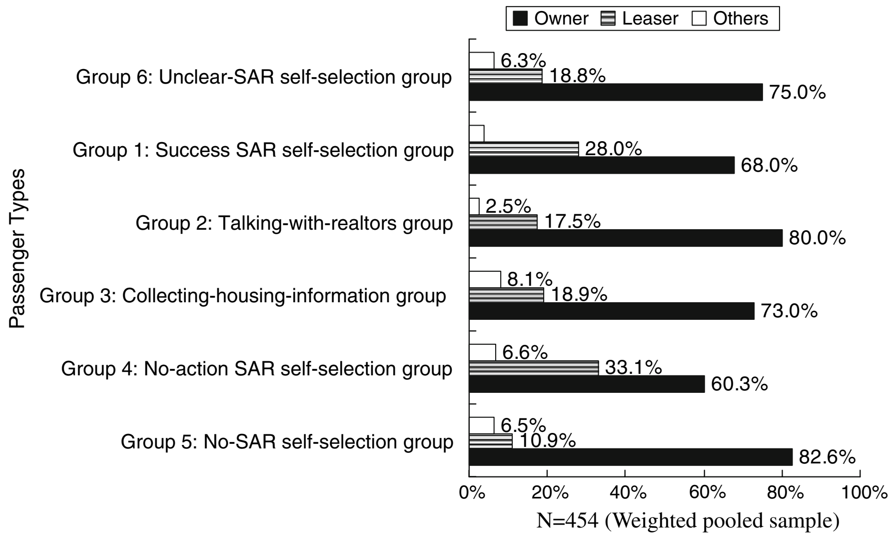

Fig. 4 Housing tenure of Taipei Metro patrons, by station-area residential self-selection

This result would agree with the hypothesis that SAR self-selection positively affects commuting by transit, if the degrees of SAR self-selection are also in this order as discussed earlier in Sect. 4. However, note that the exact transit-driven SAR self-selection of these groups cannot be measured, and also this analysis does not control for residential and workplace transit-proximities. Next, the proportion of commuting by public transit (Taipei Metro plus bus) of the success SAR self-selection group was highest (85%), and in contrast, no self-selection group was generally lower than the SAR self-selection groups, except for group 3.

Table 3 Commute mode of Taipei Metro patrons, by station-area residential self-selection and residential proximity to Taipei Metro stations

Types of Taipei Metro patrons		Commute mode in (%)						
		Taipei Metro	Buses	Autos	Mopeds/ Biking	Walking	Others	Total
Group 6: Unclear-SAR self-selection group	Living within station areas only	63	0	16	11	11	0	100
Group 1: Success SAR self-selection group		74	11	0	5	11	0	100
Group 2: Talking-with-realtors group	Living within or outside of station areas	46	30	6	6	12	0	100
Group 3: Collecting-housing-information group		38	15	12	18	18	0	100
Group 4: No-action SAR self-selection group		44	23	6	17	10	0	100
Group 5: No-SAR self-selection group		36	23	9	19	11	3	100

* Pearson Chi-square test: 0.198 (two-sided)
$N = 333$ (Weighted pooled sample)

6 Predictive models of commute mode choice

This section presents a binomial logit model of Taipei Metro riders' commute mode choice, which attempts to predict whether a person commutes via Taipei Metro or by another mode (refer to footnote 1). The findings of this model also serve to examine the research hypothesis—namely, that SAR self-selection, representing a certain degree of transit self-selection, and transit proximities at both residence and workplace ends increases probability of commuting by transit.

Following are details about the development of the binomial logit model. Only employed Taipei Metro patrons were selected, and the unclear-SAR self-selection group (i.e., group 6) was excluded from the modeling since the degree of their SAR self-selection could not be measured. The sample was categorized into Taipei Metro riders and other modes, as the dependent variable. Three primary independent variables to examine were: SAR self-selection, residential transit-proximity, and workplace transit-proximity. Four dummy variables were developed to represent groups 1 through 4, with group 5—the no-SAR self-selection group—as the base level (Table 4). In order to distinguish the impacts of SAR self-selection from transit-proximity, a few versions of transit-proximity variables were tested, including a dummy variable characterizing proximity status within and outside of station areas; finally, straight-line distance was adopted due to its statistical significance in the modeling. Control variables included personal and household socioeconomic variables (e.g., age, gender, education, driver's license, moped and auto ownerships, household size, life cycle, household income, and residence tenure), commute length, population densities at both residence and workplace ends, and transportation benefits from work (Table 4).

Table 4 Variables applied in developing Taipei Metro patrons' binomial logit models: commuting by rapid rail

Variable	Alternative variable(s)
SAR self-selection	
Group 1: Success SAR self-selection group (1/0)	
Group 2: Talking-with-realtors group (1/0)	
Group 3: Collecting-housing-information group (1/0)	
Group 4: No-action SAR self-selection group (1/0)	
Transit proximity	
Straight-Line Distance from Workplace to the Closest Taipei Metro Station (m)	Workplace Located within Station Area (1/0)
Straight-Line Distance from Residence to the Closest Taipei Metro Station (m)	Residence Located within Station Area (1/0)
Socio-economic characteristics	
Age (Year)	<=40 Years Old (1/0)
Female (1/0)	
Schooling:	Schooling (Years)
College (1/0)	
Graduate School (1/0)	
Full-time Worker (1/0)	
Moped driver's license (1/0)	
Auto driver's license (1/0)	No moped and auto driver's license (1/0)
Household size	
Life cycle:	
Household composed of >= 65 Year-Old Adults Only (1/0)	
Household composed of 18–64 Year-Old Adults Only (1/0)	
Household composed of 18–64 Year-Old Adults and Children (1/0)	
Household composed of 18–64 and >= 65 Year-Old Adults (1/0)	
Household composed of Three Generations (1/0)	
Single-parent household (1/0)	
Mean household monthly income	
No. of household members employed	
No. of mopeds owned by household	No. of household-owned mopeds per adult
	No. of household-owned mopeds per worker
No. of autos owned by household	No. of household-owned autos per adult
	No. of household-owned autos per worker
Residence tenure (1 = Owned; 0 = Others)	

Table 4 continued

Variable	Alternative variable(s)
Transportation characteristics:	
Alternative transportation for commuting (1/0)	
Free or discounted parking at work (1/0)	Any transportation benefits from work (1/0)
Company car (1/0)	
Neighborhood/location characteristics:	
Population density	
Employment density	
Straight-line distance from workplace to residence (m)	

Table 5 presents a binomial logit model, in which the impacts of SAR self-selection and residential and workplace transit-proximities on commute mode partly support the research hypothesis. The model has predictive powers with goodness of fit of 31.6% and can correctly predict 74.9% of patrons' commute modes. Controlling for several personal and household demographic variables and straight-line commute distance, higher level residential and workplace transit-proximities (i.e., closer to transit stations) significantly increase the probability of commuting by Taipei Metro.

Riders with the highest level of SAR self-selection (i.e., success SAR self-selection of group 1) have a higher probability of commuting by Taipei Metro than riders with no SAR self-selection (i.e., group 5). However, riders with lower levels of SAR self-selection (i.e., groups 2 through 4) statistically have the same probability as those with no SAR self-selection (i.e., group 5). In sum, all else being equal, those with the strongest transit self-selection, defined by successfully moving into station areas, have a higher probability of being a Taipei Metro commuter than those showing only interest or no interest in moving closer to transit stations. Comparing the coefficients of residential and workplace transit-proximities with that of "success SAR self-selection" shows that the impact on commuting by Taipei Metro of switching from no or lower levels of SAR self-selection to "success SAR self-selection" is the same as moving one's workplace 1,747 m, or one's residence 2397 m closer to a transit station.[9] By computing the ratio of incremental change in the R^2 value for the binomial logit model of commuting by rapid rail, when "success SAR self-selection" is added to a system containing all other variables, to the incremental change when "success SAR self-selection" and residence proximity are added together, the proportion of the effect of "success SAR self-selection," rather than due to the effect of residence proximity is obtained (a method proposed by Mokhtarian and Cao 2008); the result shows that "success SAR self-selection" contributes 21% of the total effect of "success SAR self-selection" and residential transit proximity on affecting commuting by rapid rail.

[9] Dividing the coefficient of "Group 1: Success SAR self-selection group" by the coefficients of workplace and residence proximities equals −1,747 and −2,397, respectively.

Table 5 Taipei Metro patrons' binomial logit model: probability of commuting by rapid rail

Variables	Coefficient (B)	Standard error	Significance.	Odds ratio [exp(B)]
SAR self-selection				
Group 1: Success SAR self-selection group (1/0)	1.11469	0.56854	0.0499	3.04864
Transit proximity				
Straight-line distance from workplace to the closest Taipei Metro station (m)	−0.000638	0.000165	0.001	0.9382 (100 m)[a]
Straight-Line distance from residence to the closest Taipei Metro station (m)	−0.000465	0.000126	0.002	0.9546 (100 m)[b]
Socio-Economic characteristics				
Female (1 = Female; 0 = Male)	0.62404	0.32337	0.054	1.86644
No Moped and Auto Driver's License (1 = No Driver's License; 0 = Otherwise)	1.63666	1.02071	0.109	5.13800
Female[a] (No Moped and Auto Driver's License) (1 = Female with No Driver's License; 0 = Otherwise)	−2.22077	1.11238	0.046	0.10853
No. of Autos per Adult (Household)	0.80646	0.40941	0.049	2.23996
Others				
Straight-Line Distance from Workplace to Residence (m)	0.000227	0.000041	0.000	1.0230 (100 m)[c]
Constant	−1.42233	0.37415	0.001	0.24115
Summary statistics				
Number of cases	326[d]			
$-2L(c)$: Log likelihood function value, constant-only model	368.2			
$-2L(B)$: Log likelihood function value, parameterized model	295.6			
Model Chi-square (probability): $-2[L(c) - L(B)]$	72.5 (0.0000)			
Goodness of fit (Nagelkerke R^2)	0.316			
% of Cases correctly predicted (Relative to "Flip of a Coin")	74.9%			

[a] Odds ratio (100 m farther) = exp (100×Beta) = exp (100× −0.000638) = 0.9382
[b] Odds ratio (100 m farther) = exp (100×Beta) = exp (100× −0.000465) = 0.9546
[c] Odds ratio (100 m farther) = exp (100×Beta) = exp (100×0.000227) = 1.0230
[d] Weighted pooled sample

Further, the magnitude of odds ratios show the difference of the actual odds of commuting by Taipei Metro due to the different status of independent variables. The odds ratio of "success SAR self-selection" is 3.05 (Table 5), meaning that, all else being equal, the odds of commuting by Taipei Metro (i.e., the probability of commuting by Taipei Metro divided by the probability of not commuting by Taipei Metro) for passengers who have moved into station areas for transit self-selection are some 3.05

times the odds for riders showing only lower interest or no interest in moving closer to transit stations for transit purposes. By the same token, workplace and residence being 100 m farther from the station, the odds of Metro commuting are 93.82 and 95.46%, respectively, of the odds in the base case. Transit's proximity to a person's workplace more greatly affects the decision to commute by Taipei Metro than its proximity to the residence.

The model results also reveal that several residential location and socio-economic characteristics are associated with commuting by Taipei Metro. First of all, the signs of coefficients and odds ratios show that the farther patrons live away from workplace, the more likely they will take Taipei Metro to work (Table 5). Women, and patrons without auto or moped driver's licenses are more likely to ride the Taipei Metro to work. Interestingly, a woman without a driver's license lowers the odds of commuting by rapid rail, which is opposite to expectations. The reason for this phenomenon could be that women commute not only by rapid rail, but also by bus. Buses might not be highly regarded by men who do not possess driver's licenses. This argument is somewhat supported by the fact that 40.8 and 30.6% of women without driver's licenses commuted by bus and rapid rail transit, respectively, as opposed to less than 5 and 77.8%, respectively, of men without driver's licenses. Finally, more automobiles per adult increase the odds of taking Taipei Metro to work, the reason for which, however, is not clear; it might be that the Taipei Metro is more a commute mode of the middle class, which tends to own more automobiles.

7 Sensitivity analysis

One way to examine the marginal influences of SAR self-selection and workplace and residential transit-proximities is to conduct a sensitivity analysis based on the scenario of "typical passenger" with the only variations being among these three variables. Other than these variations, median and modal values are input into mode-choice models of all the scenarios. The "typical passenger" is a female rider with an automobile or moped driver's license, 0.33 automobiles per adult in the household, residing 943 m from the closest Taipei Metro station and without interest in moving closer to the station, with the workplace 563 and 5,602 m from the closest Taipei Metro station and home, respectively.

Table 6 presents results of a variety of scenarios with variations in SAR self-selection and workplace and residential transit-proximities. Table 6 shows that the "typical passenger" has a 48.1% probability of commuting by Taipei Metro. If the same passenger has different degrees of SAR self-selection, such as talking with realtors/house owners (i.e., group 2), collecting housing information (i.e., group 3), or having no-action at all (i.e., group 4), the probability stays the same (Scenario A1) (Table 6a). However, if the "typical passenger" whose SAR self-selection is changed into the strongest level of "success SAR self-selection" (i.e., group 1)(the home transit-proximity is improved to the 400 m at the station area border too due to the definition of this group), the probability increases significantly to 78.8% (Scenario A2), (Table 6a). Table 6b shows that if a "typical passenger's" workplace is relocated from 563 to 100 m from the station (Scenario B2) the probability rises from 48.1

Table 6 Sensitivity analysis: probabilities of commuting by Taipei Metro

A "Typical passengers" and scenarios with variation in station-area residential self-selection			
Scenario	"Typical passenger" (SAR self-selection: Group 5—No-SAR self-selection group)	Scenario A1: With variation in SAR self-selection (SAR self-selection: group 2, 3, or 4)	
Probability	48.1%	48.1%	
Scenario	Scenario A2: with variation in SAR self-selection (SAR self-selection: group 1—Success SAR self-selection group; home transit-proximity = 400 m)		
Probability	78.8%		
B Scenarios with variation in workplace transit-proximity			
Scenario	"Typical passenger" (Workplace transit-proximity: 563 m)	Scenarios with Variation in Workplace Transit-Proximity Scenario B1: 1,000 m from station	Scenario B2: 100 m from station
Probability	48.1%	41.7%	56.0%
C Scenarios with variation in residential transit-proximity			
Scenario	"Typical passenger" (Residential transit-proximity: 943 m)	Scenarios with variation in residential transit-proximity Scenario C1: 1,500 m from	Scenario C2: 100 m from
Probability	48.1%	Station 42.2%	station 58.3%
D Scenarios with variations in workplace transit-proximity, and residential transit-proximity			
Scenario	Scenario D1: Workplace transit-proximity: 1,000 m Residential transit-proximity: 1,500 m	Scenario D2: Workplace transit-proximity: 400 m Residential transit-proximity: 400 m	Scenario D3: Workplace transit-proximity:100 m Residential transit-proximity: 100 m
Probability	35.6 %	57.5%	65.3%

to 56.0%. Table 6c shows that if a "typical passenger's" residence is relocated from 943 to 100 m from the station (Scenario C2) the probability rises to 58.3%. Finally, if a "typical passenger's" workplace and residence are relocated to 1,000 and 1,500 m (Scenario D1) from the station, the probability significantly decreases to 35.6%. However, if the workplace and residence of this passenger are both relocated to 100 m from the station, the probability rises considerably to 65.3% (Scenario D3).

8 Conclusions and policy implications

The research hypothesis is partly supported by this empirical research that living and working closer to rapid rail transit stations (i.e., residential and workplace transit-proximities) increase the probability of their riding rapid transit to work. In addition, the effect of bringing workplaces nearer to transit stations is better than locating residences nearer. Certainly, locating both residences and workplaces closer to transit works best. Also, riders with high levels of preference for living closer to rapid rail transit stations (i.e., station-area residential self-selection, which to a certain degree is initiated by transit self-selection), and characterized as successfully moving closer to transit stations for no other reason that to live closer, have a higher probability of commuting by rapid transit to work than people with no preference for living closer. However, riders with lower levels of station-area residential self-selection (showing certain levels of interest only, rather than successful relocating behavior) statistically have merely the same probability as those with no preference. The research findings, however, are limited to transit riders, probably one of the most promising groups for TOD projects, and to metropolitan areas where density are higher and mixed land use are more common. Besides, the effect of transit self-selection on commuting by rapid transit could be underestimated due to the limit on the methods of characterizing and measuring it.

In the continuing debate over whether self-selection or land use affects travel behavior, the findings of this research imply transit proximity affects commuting by rapid transit; however, only strong self-selection statistically affects commute mode choice. For those riders with certain levels of self-selection, land use policy that allows them to move closer to transit stations results in increasing transit proximity and hence probability of their riding transit to work, no matter whether self-selection affects the probability or not. If they move closer to transit stations, their SAR self-selection is realized, indicating that market facilitation of land use works in terms of meeting the demand for housing location. Nevertheless, riders with no transit self-selection who live closer to a transit station also have a higher probability of riding transit to work; this indicates that transit-proximity alone, as a result of land use or transit policy, affects travel behavior. This suggests that planning that employs effective land use policy works.

The degree of transit proximity can be improved through both transportation and land use policies, which will face varying levels of popularity or resistance in different cities and countries. Construction of rail transit can bring transit services to residences or companies located near transit stations; increasing densities near existing transit stations can allow people with transit self-selection to move into it to realize their self-selection; additionally, providing quality neighborhood services and amenities in the station areas are also essential for attracting companies and residents, in particular those with no preference for relocating closer to transit stations. However, constructing a new transit line or system is likely to be less financially feasible than implementing land use densification policies. For example, even though mass rapid transit is welcomed in the high-density, multimillion-population Taichung metropolitan area of Taiwan, the area is still struggling financially to develop its rapid rail transit network. Densification may be more welcomed by housing owners and developers than residents in Taiwan. Owners and developers may benefit from densification in terms of overall real estate value, but residents may suffer from overcrowded settings. Besides, under-supply of station area housing due to density cap may lead to increasing housing prices in station areas, which in turn may lead to issues of gentrification and low transit-accessibility for low-income transit-reliant population.

Finally, implementing densification policies to meet the latent demand of people with transit self-selection and, thus, increase rapid rail transit use and consume less land, we suggest that two avenues of research should be explored. The first effort should be to examine degree of commitment to living in denser settings. If people who highly commit to live in denser settings can be identified, the feasibility of densification can be examined. The other effort is to reduce the negative impacts of denser settings through urban design and/or housing policy, such as lowering building-coverage ratio, but increasing floor-area ratio, and creating more affordable housing. If the 101-floor Taipei Sky-Scraper 101 can exist in Taipei, other far-shorter buildings could be considered in the future for sustainability purposes.

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