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CAN INCREASED ACCESSIBILITY FROM EMERGING MOBILITY SERVICES CREATE A CAR-LITE FUTURE? EVIDENCE FROM SINGAPORE USING LUTI MICROSIMULATION

A PREPRINT

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ABSTRACT

Emerging mobility services are being increasingly regulated, with several cities testing policy interventions in pilot study areas before a metro-wide implementation. This is motivated by the expectation that increased accessibility from these services might induce households to relinquish private vehicles, and demonstrate the viability of car-lite strategies that could be expanded to metro-wide areas. However well-intended, the increased attractiveness of such test areas might also increase neighborhood attractiveness in ways that cause gentrification. This study uses an agent-based LUTI microsimulation model to examine the effect of accessibility improvements on private mobility holdings, both directly and through the mediating effect of housing choice. A scenario-based design is adopted, wherein different types of market responses to a pilot car-lite policy are modeled through various assumptions of changes in model parameters. Three study areas with different characteristics are chosen to explore the spatial variation in policy effects. Our findings indicate that in-movers are more likely to be higher-income households that have a comparatively higher car ownership rate. Such unintended negative consequences like gentrification can significantly undermine the potential boosts to vehicle-free behavior inside the study area. As a possible step to mitigate such consequences, we suggest that emerging mobility regulation strategies anticipate and address the likely response of the housing market and urban redevelopment opportunities.

Keywords Emerging mobility services · Accessibility · Residential location · Vehicle ownership · Agent-based microsimulation · Land use-transport interaction (LUTI) model

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1 Introduction

Emerging transportation technologies like automated vehicles (AVs), and services like mobility-on-demand (MoD) and micro-mobility, are motivating discussions on the future of cities (Shaheen et al., 2017). Popular media outlets often focus solely on their benefits, such as lower commute costs, higher comfort, and increased accessibility. However, experts hold more nuanced opinions, and have voiced their concerns over social inequity, induced travel demand, and urban sprawl (Milakis et al., 2018). The future of urban mobility is certainly uncertain, but there seems to be a consensus about accessibility benefits resulting from these emerging services, with some going so far as to anticipate a ‘quantum leap in accessibility’ (Meyer et al., 2017). Megacities like Singapore and London are beginning to take a more proactive

approach to planning for uncertain urban mobility futures (Chng et al., 2019). While there are obvious socio-political and contextual differences in their strategies, the common underlying vision is to reduce private car ownership and usage, and create a ‘car-lite’ future¹ with both improved accessibility and fewer privately owned vehicles.

Much ink has been spilt trying to explore the impacts of emerging mobility services, MoD and AVs in particular, on the city. The majority of studies use agent-based simulation approaches to model transport-related behavior, without considering the need to integrate mobility choice with housing choice. The relatively few studies that do consider both decisions are primarily based on travel behavior model estimation, which are useful but not appropriate to understand the impact of real estate market dynamics. Therefore, we construct an approach where we embed disaggregate behavioral choice models for household decisions such as *housing unit choice* (going beyond the simpler residential location choice) and *mobility bundle choice*, and individual decisions such as *employment or education choice*, in an agent-based land use-transport interaction (LUTI) simulator *SimMobility*. Such an approach allows us to explore the detailed dynamics of the housing and mobility markets in tandem.

Fostering car-lite communities for a car-lite future can only happen incrementally over time. As megacities begin to pilot car-lite strategies as test cases, it is timely to understand plausible housing market reactions that might undermine potential benefits of such strategies. To maintain the generalizability of our study, we conceptualize this future through the lens of increased accessibility that most literature seems to agree on, instead of focusing on a specific policy design. There are other complexities that need to be considered, such as the socio-demographic and cultural differences in the proclivity for vehicle availability and use (Carrone and Rich, 2020; Yum, 2019). Considering Singapore as our case study requires the inclusion of an additional contextual consideration, i.e. the national regulation of private mobility holdings. Ownership of private vehicles in Singapore is strongly dependent on income, as there are prohibitively high expenses arising from government policies, such as the requirement of a Certificate of Entitlement (COE²) (Basu and Ferreira, In press, 2020). Such policy instruments can make shared mobility more attractive and affordable than private cars, casting doubt on whether the traditional car ownership paradigm will continue to thrive in the future (Spieser et al., 2014). Indeed, if car-lite strategies fail to be effective in Singapore (which has dense neighborhood designs, reliable and accessible public transport, and high costs of private car ownership), other megacities around the world might have cause for concern.

This paper explores different scenarios of housing market reactions arising from the implementation of a car-lite policy that increases accessibility in a particular study area (comprised of one or more planning districts) in Singapore. We compare policy impacts across three different study areas to examine the effect of initial neighborhood characteristics on potentially undesirable outcomes such as gentrification and decreasing vehicle-free behavior. The following section outlines the methodology adopted in this study. We discuss the simulation results in light of four different metrics of neighborhood change in Section 3, and conclude this paper by outlining potential policy implications of our findings in the final section.

2 Methodology

This section provides details of the assumed car-lite policy, our agent-based LUTI microsimulation platform (*SimMobility*), the study areas, the hypothesized scenarios, and the simulation framework.

2.1 Car-lite pilot

We assume that the planning agency introduces a car-lite program in a certain neighborhood as a pilot, with an eye towards facilitating and promoting the use of emerging mobility services in lieu of private car ownership and usage. Such programs might involve urban design improvements (e.g., road infrastructure to facilitate high-occupancy vehicle travel, dedicated bus lanes, pickup/dropoff areas, etc.) and/or regulations that prioritize first/last-mile travel not in privately-owned vehicles (e.g., subsidized shared mobility trips to bus/MRT stops, restrictions on privately owned vehicle use, priority for shared mobility pickup/drop-off, etc.). All such programs are likely to be piloted in one or more ‘study areas’ before being rolled out metro-wide. Consequently, we seek to examine the possible housing market dynamics and vehicle availability implications of ‘car-lite pilots’ that enhance accessibility in specific study areas.

We anticipate that the increased accessibility can lead to a positive perception of the study area in two aspects. First, households living outside the study area may want to move in, and enjoy the accessibility benefits, which might lead to an *unintended gentrification side-effect*. Second, households living inside the study area may want to reconsider private

¹<https://www.clc.gov.sg/research-publications/publications/urban-systems-studies/view/creating-liveable-cities-through-car-lite-urban-mobility>

²The COE quota is capped to keep annual vehicle growth rates below 2%. 10-year COEs are made available at monthly auctions with prices ranging from 2,000 to 10,000 USD/year over the past decade.

mobility holdings due to widespread availability of emerging mobility services for trip-making, which might result in *increasing vehicle-free behavior, as intended*.

2.2 SimMobility

Long-term effects of emerging mobility services on transport-land use interactions are co-determined by several exogenous factors, and can be undeniably complex. LUTI models can be useful tools in exploring this research direction, as they integrate location and mobility choices using accessibility. Operationalization of this accessibility link varies widely across applications, ranging from logsum-based accessibilities from only the mode choice model in SWIM (Donnelly et al., 2018) to zone-level accessibility using shortest path-based travel costs in an UrbanSim - MATSim integration (Nicolai and Nagel, 2012). Although the concept of activity-based accessibility (ABA) proposed by Ben-Akiva and Bowman (1998) has gained significant popularity in practice-ready implementation of transportation models, we were unable to find LUTI models that use the full economic information represented through the logsum of an activity-based travel demand model for integration. This is one of the key contributions of *SimMobility* (Simulation of Future Urban Mobility), which is the LUTI model developed by our research group based on the gaps we identified in the literature.

SimMobility is a multi-scale agent-based microsimulation platform that incorporates time-scale dependent behavioral modeling through activity-based frameworks (Adnan and et al., 2016). The *Long-Term (LT)* component involves creation of a synthetic population, followed by household-level residential location and vehicle availability choices, and individual-level job or school location choices, at the temporal scale of days to years (Zhu et al., 2018). The *Medium-Term (MT)* component couples a mesoscopic supply simulator with a microscopic demand simulator that involves mode choice, route choice, and activity-travel pattern generation at the temporal scale of minutes up to a day (Basu and et al., 2018). The LT and MT components are connected through individual-specific ABA measures that are disaggregate utility-based measures of alternative daily activity patterns (*logsums*) generated by MT, which are then used as explanatory variables in LT choice models.

A fixed number of households are awakened every day (in the simulation) based on pre-computed probabilities specific to the household type and current tenure status, which were estimated from a survey of recent movers in Singapore. The awakened households then select a choice set of 30 available units based on a screening model, in addition to the unit in which they currently reside. The screening model predicts the probabilities for every combination of planning region and unit type, leading to about 40 alternatives. For each unit in the choice set, the hedonic price model predicts the asking price and the WTP model predicts the WTP of that household for that unit, following which the expected consumer surplus (ECS) is calculated. The household finally bids on the unit with the maximum ECS, provided the ECS for that unit is larger than that for their current unit.

The seller evaluates all bids at the end of each day, and decides whether to sell or hold out. Feedback loops are included, wherein sellers may raise the asking price if the unit is perceived to be in demand, or lower the price if the unit does not attract bids for several days. Following a successful bid, the household moves into the new unit and reconsiders their mobility holdings based on their new location. Our vehicle availability model considers household mobility holdings, which could include vehicles that are privately owned, rented, or simply available for use. Six categories of mobility holdings are constructed based on the combination of different types of vehicles that fall within a particular bundle, with the first category indicating ‘*no private vehicle availability*’ (Basu, 2019). The size of this ‘vehicle-free’ group is used to characterize the extent to which a neighborhood is ‘car-lite’.

The hedonic and WTP models are estimated using real estate transaction data, and include household-level ABA measures aggregated at the TAZ level (i.e. TAZ-averaged logsums) as explanatory variables. There are 1,169 TAZs in Singapore, with an average of about 1,700 households living in each TAZ. The vehicle availability model, on the other hand, uses alternative-specific household-level logsums. In addition to these logsums, we also include a subset of the 5D measures proposed by Ewing and Cervero (2010), such as population and job densities, land use diversity, and distances to different urban amenities such as transit, shopping malls, and schools. Interested readers may refer to Zhu et al. (2018) for a more detailed description of the modeling framework.

2.3 Study areas

There are 55 planning districts in Singapore, among which we choose four districts grouped into three separate study areas where the car-lite pilot could be introduced (see Figure 1). Descriptive statistics of the study areas are presented in Table 1. Our choice of Toa Payoh is motivated by considering a plausible albeit somewhat extreme case, i.e. a study area neither in the CBD nor in the periphery, and which is already more vehicle-free than Singapore on average. Therefore, we expect a muted effect of the policy on both residential mobility (due to lower vacancy rate) and private mobility holdings (due to higher initial vehicle-free share). On the other hand, Pasir Ris has a greater share of vehicles

than the whole of Singapore on average, but a larger vacancy rate than Toa Payoh. Finally, we combine the districts of Punggol and Sengkang to create our third study area. The population here is almost double that of the other two study areas, while the vacancy rate is almost double that of Singapore. However, the vehicle-free market share is closer to the national average, compared to Pasir Ris.

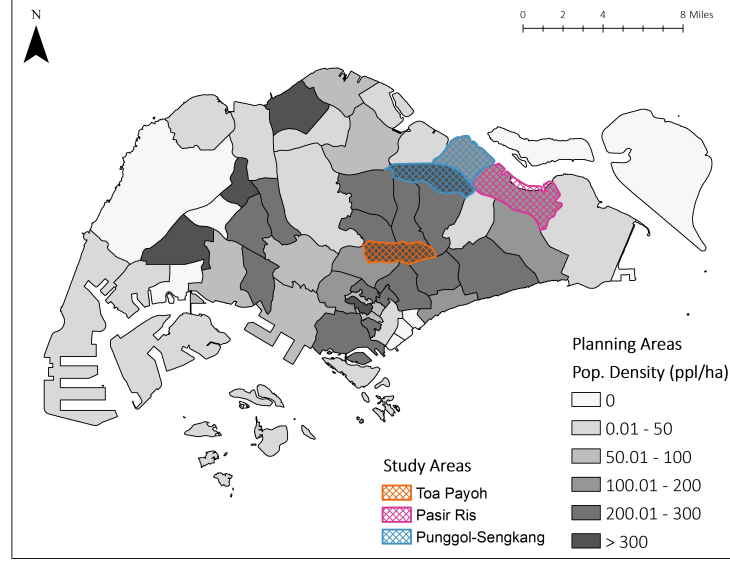


Figure 1: Study areas for the car-lite pilot in Singapore

Table 1: Description of study areas in Singapore

Study Area (SA)	HHs ^a	Units	Vacancy rate (%)	Vehicle-free HHs (%)	Workers who live in this SA ^b	Workers who live and work in this SA (%)
Toa Payoh	44,028	45,715	3.69	67.02	59,776	2.07
Pasir Ris	39,293	41,103	4.40	42.25	71,502	0.88
Punggol & Sengkang	68,694	78,817	13.14	45.15	121,945	0.37
Singapore	1,148,066	1,235,833	7.10	54.11	1,940,076	1.96

^a We consider only households whose head is a Singapore citizen or Permanent Resident.

^b Workers from only these “citizen” households are considered.

2.4 Scenario design

To examine the impact of this policy on the housing and mobility choices of households, we adopt a scenario-based approach:

- **Baseline:** The baseline run simulates the long-term evolution of Singapore, assuming that the car-lite pilot was never introduced. All parameters in the LT models are held constant and equal to the estimated values for the year (2012) for which the synthetic population and behavioral parameters were calibrated.
- **Scenario I (Minimal effect):** The car-lite pilot is now introduced in the study area, which results in the screening model doubling the likelihood that housing units in the study area are included in a household’s choice set. Apart from this awareness about the introduction of the policy, there are no other housing market effects in this scenario.

- **Scenario II (Buyer valuation increases):** In addition to the awareness change in the previous scenario, we hypothesize that the policy leads to an increase in housing demand inside the study area. The increased demand is captured through the willingness-to-pay (WTP) model whereby potential buyers increase their WTP for a housing unit in the study area to the extent that the accessibility improvements are valued by the buyer's household. This scenario can be thought of as a *short-run market reaction*, where only consumers have reacted to the car-lite policy. Empirically, we increase the ABA values for households living *or* working in the study area by 0.5 times the standard deviation of TAZ-averaged logsums. For the households that both live *and* work inside, the augmentation is doubled and set to 1.0 times the standard deviation.
- **Scenario III (Both buyer & seller valuations increase):** We construct this scenario as a representation of the *longer-run market reaction*, where both consumers and suppliers have reacted to the policy. In this scenario, the market has had enough time to respond to the increased demand through an increase in the asking price of units in the study area, which is captured through an enhancement of the accessibility parameter in the hedonic price model that estimates the market price of housing bundles. The ABA values in the hedonic model are enhanced for housing units inside the study area in the same way as the WTP adjustments described for Scenario II.

2.5 Simulation framework

All households with citizens and permanent residents in the synthetic population (approximately 1.15 million households) in the base year (2012) are considered to be eligible for the daily bidding process. We use the aforementioned bid-auction housing model to simulate housing market transactions for a one-year simulation period. At the end of this period, we identify households who had successful bids along with their new residential locations. These households reevaluate their vehicle availability using dynamically calculated ABA measures (i.e., logsums) based on their new residential location. We assume that increased accessibility will cause the 'vehicle-free' ABA of households residing in the study area to increase by half the average difference between the 'vehicle-free' ABA and the 'privately owned car' ABA. This signifies that accessibility improvements from emerging mobility services have halved the accessibility gap between being car-less and owning a car (on average). Finally, we obtain a new study area population at the end of the simulation period in 2013 comprising (a) *in-mover* households that lived outside the study area in 2012 and moved inside during the simulation, and (b) *out-mover* households that lived inside the study area in 2012 but moved outside during the simulation, and (c) *non-mover* households that lived inside the study area in 2012 and did not change their residence during the simulation.

A burn-in simulation of one year was conducted first to achieve a quasi-equilibrium of the housing market under baseline conditions with no change in population or available housing units. We then conducted five simulation runs using the 'burned-in' synthetic population for a one-year period, i.e. from 2012 to 2013, for every combination of study area and scenario mentioned in the previous section (i.e. $5 \times 3 \times 4 = 60$ simulations in total).

3 Results

The impacts of the car-lite policy on the study area are measured through four metrics of neighborhood change, according to which the following sub-sections are organized. First, we look at residential mobility and migration, as measured by the change in the population of the study area over time. Second, the gentrification of the study area is measured through the mean household income of mover cohorts. Third, we examine the transitions in vehicle availability for the mover cohorts. Finally, the total policy impact is measured through the change in vehicle availability for the entire study area. We present bar plots that show the mean values for these metrics, with the standard deviations across the five runs represented through error bars.

3.1 Residential mobility

Net migration effects in the three scenarios, relative to the original population, are reported in Figure 2a. The fraction of resident households in each study area who moved during the one-year simulations are shown in Figure 2b. We notice that the net in-migration in Scenario I is not significantly different from the baseline, which is consistent with our assumption of increasing only the likelihood of including study area units in the choice sets of potential bidders (which does not directly affect choice probability). Demand-side market effects through increased buyer valuation in Scenario II serve to further increase in-migration. However, supply-side effects in Scenario III dampen the in-migration, as fewer households are able to afford the higher market prices of units inside the study area. This dampening effect can be strong enough in areas like Toa Payoh and Punggol-Sengkang that the net in-migration effect becomes negative, and results in a decrease in the study area population. The significantly steep decrease from Scenario II to III in Punggol-Sengkang

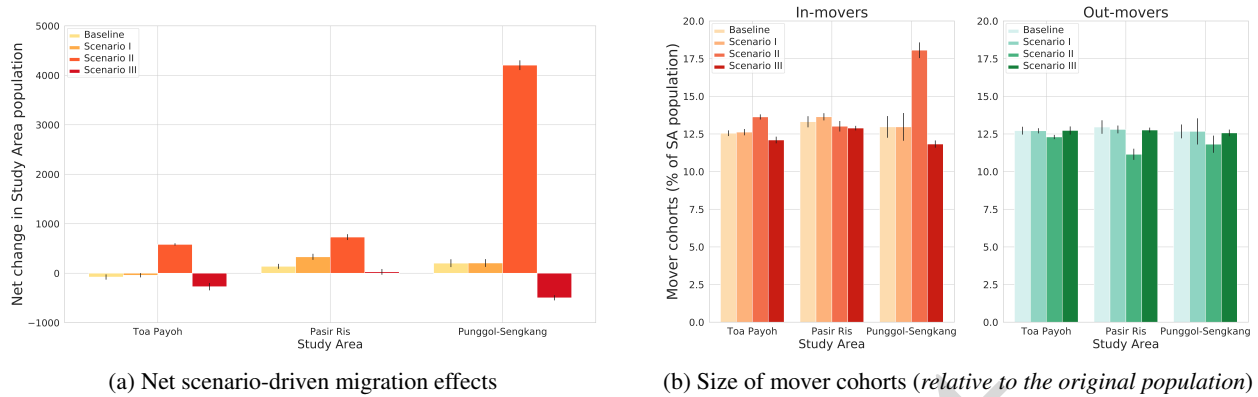


Figure 2: Residential mobility in the study area

highlights the importance of considering spatial variations in policy impacts that may arise from the differences in initial characteristics of the study areas.

3.2 Gentrification

In-movers are found to be similar to the original households for the baseline (except in Pasir Ris), and awareness effects in Scenario I do not cause any significant changes (as expected). However, the additional market effects, which cause further changes in the relative attractiveness of the study areas, result in increased income differences between in- and out-movers (see Figure 3). Out-movers are quite similar to the original study area population, with market effects in Scenarios II and III affecting displacement of slightly lower-income households. This is because market effects cause asking prices of housing units to increase in the study area in response to improved accessibility. However, different households can value the increased accessibility to different extents, based on socio-demographics and current vehicle availability.

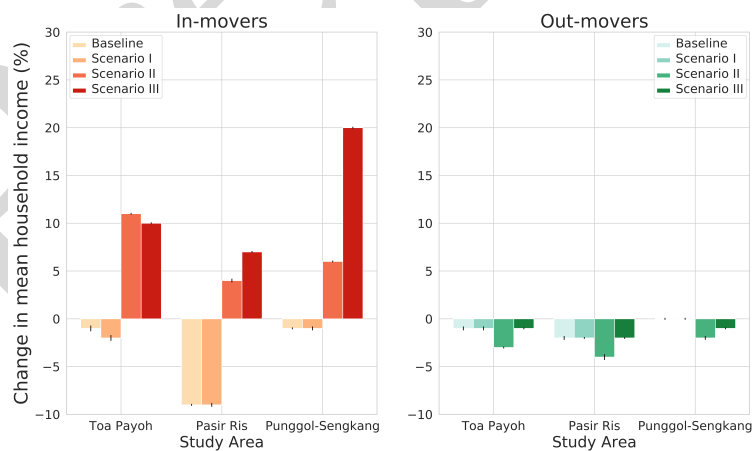


Figure 3: Change in the mean household income of movers (relative to the original mean household income of the study area)

Relatively higher-income households who valued the augmented study-area accessibility could then outbid others when bidding for the units. This causes in-movers to be 5-20% higher-income on average with the inclusion of market effects, which induces gentrification in all study areas. The effect of higher initial vacancy rate in mitigating gentrification is demonstrated through the relative similarity of the mean household income of in-movers and out-movers for Punggol-Sengkang, at least until market effects set in.

3.3 Vehicle-free transitions for movers

In-movers are less prone to vehicle-free behavioral shifts, as is evidenced by their lower vehicle-free shares (compared to out-movers) in Figure 4. We find that in-movers are more vehicle-free than out-movers for the baseline and Scenario I, but this trend switches with the inclusion of market effects. The initial characteristics of the study area can be quite important, as tight housing markets in Toa Payoh and Pasir Ris experience significantly high decreases in the vehicle-free market share in Scenarios II and III (compared to the baseline and Scenario I). Upon further examining in-mover households, we are able to confirm our hypothesis that a sizeable proportion of higher-income car-owning households does not perceive the pilot to provide sufficient accessibility gains that warrant a shift to a vehicle-free lifestyle. However, on average, in-movers are always more vehicle-free than the original study area population, which validates the intention of the car-lite policy.

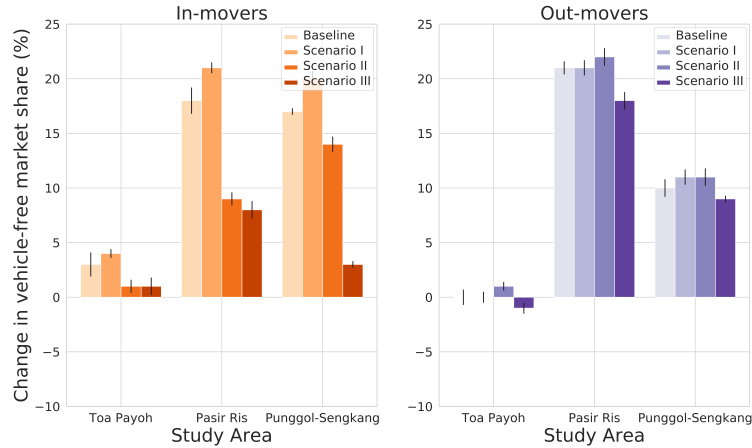


Figure 4: Change in the vehicle-free market shares of movers (*relative to the original study area share*)

Punggol & Sengkang, whose vehicle-free market share was closer to the national average, witnesses a significantly increased vehicle-free share for in-movers in the baseline. While that still remains positive, a drastic decrease can be noticed when market effects set in during Scenarios II and III. On the other hand, the vehicle-free share for out-movers is always higher than the original study area population (and in-movers with market effects), which leads us to conclude that the car-lite pilot impact on the study area can be positive only if the vehicle-free transitions of in-movers are sufficiently high enough to overshadow the gentrification side-effect.

3.4 Net vehicle-free transitions in study area

The vehicle-free market shares in the study areas for the baseline and three scenarios are summarized in Figure 5, while comparing them to the original market shares in the study areas in 2012. Toa Payoh, which was originally more vehicle-free than Singapore, experiences a decrease in the vehicle-free share in the baseline scenario where the car-lite policy was not introduced. However, the increased accessibility of the study area causes significantly positive vehicle-free transitions among non-movers, which cause the overall policy impact in Scenario I to be quite high. Unfortunately, gentrification side-effects manifest themselves through higher-income and less vehicle-free in-movers, who reduce the positive impact by almost half. This is despite in-movers forming only about 12.5% of the study area population on average. We find that the trend of about 50% decrease in the positive policy impact due to market effects is consistent across all study areas.

4 Conclusion

How will the market for private vehicles get affected when automated, on-demand, and shared mobility services become ubiquitous? This study attempts to address this research question by using the agent-based land use-transport interaction (LUTI) microsimulation model *SimMobility* to examine the effect of accessibility improvements on private mobility holdings, considering the mediating effect of residential relocation. A scenario-based design is adopted, wherein different types of market responses to a car-lite pilot are modeled through various assumptions of changes in model parameters to capture the effects of accessibility improvements.

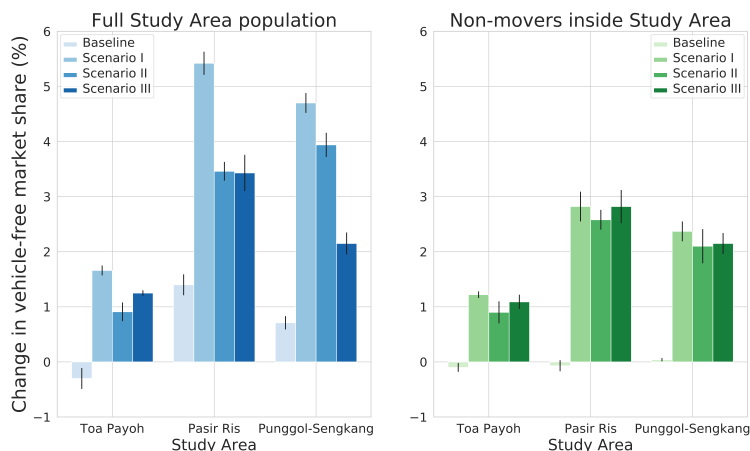


Figure 5: Change in the study area vehicle-free market share (*relative to the original share*)

Our findings indicate that in-movers tend to significantly undermine the positive impacts of the car-lite pilot on the study area. The in-movers are more likely to be higher-income households that displace lower-income households, thereby gentrifying the study area in the long-term. Higher-income households are more likely to own cars, and are found to be less likely to give up their private mobility holdings and transition to a vehicle-free lifestyle. Consequently, the increase in vehicle-free behavior of the study area is cut by half when housing market effects are also considered. While the net impact still remains positive for the three study areas we considered, it is plausible that other study areas might not fare so well.

We also notice spatial differences in policy effects across the study areas. If the housing market is relatively open to begin with (i.e., has a reasonably high vacancy rate like Punggol & Sengkang), the study area can experience a significantly high vehicle-free transition as in-movers may not be as car-dependent as in other study areas. However, the impact is moderate in tight markets like Toa Payoh, which becomes significantly reduced by strong gentrification side-effects wherein in-movers are less vehicle-free and higher-income due to higher competition for such study areas. Keeping the mediating effect of housing choices in mind, coordinated affordable housing policies that increase housing stock in tight markets and make them relatively more attractive to lower-income households are worth exploring in future research efforts.

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