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Neighborhood retail amenities and taxi trip behavior: A natural experiment in Singapore

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ABSTRACT

While a small change in land use planning in existing neighborhoods may significantly reduce private vehicle trips, we do not have a great understanding of the magnitude of the project- and shock-based causal change in travel behaviors, especially for the retail purpose. We analyze the impact of newly developed malls on the retail trip behavior of nearby residents for shopping, dining or services. Using the difference-in-differences approach and big data from a major taxi company in Singapore, we find that households residing within 800 m from a new mall are significantly less likely to take taxis to other retail destinations after the mall's opening. This travel behavior change encompasses both intensive (the share of the number of retail trips out of total taxi trips originating from each residential building) and extensive (the share of retail trip distance out of total taxi trip distance) margin responses. We further demonstrate that the magnitude of this retail trip reduction is more significant during PM peak hours and for residential buildings that are located farther from the Central Business District and in less self-sufficient communities. Our research provides suggestive evidence on the significant role of neighborhood retail amenities to the change in mode and destination choices for retail. An important implication is that improving self-sufficiency for suburban neighborhoods could not only enhance the well-being of their residents but also increase aggregate welfare by reducing the level of congestion. This is extremely relevant to residential town planning in both developing and developed countries.

1. Introduction

Retail trips account for a significant portion of daily trips and the average distance traveled for retail activities has significantly increased over time (Land Transport Authority Singapore, 2012; UK Department for Transport, 2015). Although shifting retail trip behaviors is less challenging compared with business and school trips, existing literature tends to focus less on these behaviors when discussing urban planning approaches to reduce vehicle trips and traffic congestion (Pan et al., 2009). At the same time, while smaller-scale change in land use distribution in existing neighborhoods could directly affect residents' travel behaviors, we do not have a great understanding of the magnitude of the project- and shock-based causal change in these behaviors. For example, the provision of a new retail store in residential neighborhoods that used to have no amenities nearby may substantially decrease residents' retail travel costs and, in turn, lead to a change in their choice of the retail destination. If such amenities are provided within a short distance from their homes, residents may choose to walk or cycle instead of drive or take a taxi for their retail.

Our research question focuses on how proximity to newly provided retail amenities changes the retail trip behaviors of surrounding residents. In particular, we investigate the extent to which those who used to travel to retail destinations by taxi change to other travel modes because of the shorter distance and better accessibility to newly opened shopping malls in Singapore. We focus on taxi trips because private vehicle trips including taxis are the main cause of congestion and negative externalities. Private vehicles are a popular mode for retail trips (24.3% of the mode share in Singapore according to the Household Travel Survey [HTS] 2012) and a substantial proportion (42.7%) of taxi trips is used for the retail purpose. Although we do not have direct observations of all private vehicle trips, taxi trips are a good proxy for private car usage. Because taxis are considered a reasonable substitute for private vehicles

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and users of the two modes share similar characteristics (Conway et al., 2018),[1] our analysis could be expanded to patterns of driving for retail. Therefore, we aim to provide a new insight on how a small change in land use planning and the introduction of a new neighborhood mall contribute to reducing vehicle travel.

In doing so, we use the GPS-based taxi-trip data, provided by the largest taxi operator in Singapore, for the period of January 2009 to September 2012. These data allow us to take advantage of the micro big data at the trip level. The Singapore contexts provide a unique opportunity to answer this question as retail shops are distributed across various geographic locations, such as new town areas, and retail trips account for the highest percentage of non-work trips in the country (Land Transport Authority Singapore, 2012). According to the HTS 2012, after excluding trips with respondents' own residence and offices as destinations, shopping and dining are the most dominant travel purposes for working adults aged 25–65 years old (38.4% and 20.3% respectively).[2] Specifically, we use the opening of neighborhood shopping malls as a shock for retail amenities not only because the malls feature retail clustering including eateries, groceries and other shops but also because Singapore consumers show a strong preference for indoor malls as their retail destination.

To estimate the isolated effect of a mall's opening on the share of taxi trips to other retail destinations out of all taxi trips originating from nearby residential buildings, a difference-in-difference (i.e., variations in the distance from new neighborhood malls and the pre/post of a mall opening) is used as the main empirical strategy. The treatment group is composed of residential buildings located within 800 m (walking distance) from a new mall and the unit of analysis is the monthly taxi trips originating from each residential building. As our dependent variable is the share of retail trips out of all taxi trips, we observe patterns of using taxis for a retail purpose relative to general taxi trip patterns. Rather than directly observing a change in travel mode choices, therefore, we are able to examine the probability that people living near newly opened shopping malls reduce taxi trips for the retail purpose controlling for the general tendency of choosing taxi trips.

Analysis results discover that the number of taxi trips to other retail destinations fall by 33 per month, or the share of retail trips out of total taxi trips decreases by 1.4 percentage points for residential buildings within 800 m of the neighborhood malls after those malls open. We also find a similarly significant reduction in the distance traveled to other retail destinations only for residential buildings that are within walking distance to newly opened malls. Interestingly, the magnitude of the retail trip reduction is much more significant during the PM peak hours than off-peak hours, which suggests significant effects on traffic congestion reduction. Finally, our results suggest heterogeneity by location and type of residential buildings. Residential buildings that are located farther from the central business district (CBD) and in less self-sufficient communities are likely to experience a higher reduction in retail trips by taxi after a mall's opening. These results suggest that the level of residents' travel behavior adjustment depends on the existing conditions of the neighborhood.

This study directly contributes to the literature on the role of urban forms to travel behavior. While researchers were interested in diverse aspects of urban forms ranging from density and building shape to streetscape and the proximity to transport facilities (e.g., Appleyard, 1980; Cervero & Duncan, 2008; Pan et al., 2009; Gehl, 2011; Khan et al., 2014), the spatial distribution of different land uses is considered as a key factor influencing travel behaviors. As the land use distribution is directly associated with the actual and perceived costs of the trips, it would influence people's decisions on the mode of travel. Studies in the fields of urban planning and public health report that mixing land uses and increasing the non-residential uses within a neighborhood have a positive relationship with the general probability of walking or cycling (Cervero & Duncan, 2003; Ewing & Cervero, 2010; Hou, 2019; Krizek, 2003; Krizek & Johnson, 2006; Li et al., 2018). Our research differs from them because we examine how the smaller-scale change in land use distribution, such as the opening of a new neighborhood mall, directly affects the shift in the residents' mode of travel for the single purpose of retail. Our focus is on the magnitude of the project- and shock-based behavior change and thus has more meaningful and practical planning implications for established neighborhoods.

Next, our analysis results add insights to the understanding of retail trip behavior. While there is voluminous research on how people choose the mode of travel and destination for retail purposes, existing empirical evidence tends to be based on the non-causal framework as they rely on cross-sectional administrative data or information from a small-scale survey and experiment (e.g., Handy, 1993, 1996; Ibrahim, 2003, 2005; Lovejoy et al., 2013; Meena et al., 2019). To our best knowledge, this is the first study to quantify the casual effect of neighborhood retail amenities on residents' choice of retail trips by examining trip-level taxi trips together with the detailed residential and retail locations across an entire nation. Few studies on the dynamics between retail trip choices and neighborhood retail amenities use land use diversity as a proxy of the accessibility to and availability of these amenities and only observe the average outcomes (Greenwald, 2003; Rajamani et al., 2003). Our research advances them by using a more direct measure of the proximity to a new neighborhood mall, which is the clustered retail amenity, as well as by providing heterogeneous outcomes across times of the day and the location of residential buildings.

Finally, this study contributes to the literature on land use and town planning, especially for suburban neighborhoods. Originating from the Garden City movement by Ebenezer Howard (1902), satellite new towns have been developed in many countries around the world (He et al., 2020). Although Singapore shows one of the most prominent examples of new town planning that achieved a relatively higher level of self-containment, there are some neighborhoods lacking access to retail amenities. Our research analyzes the extent to which residents in these neighborhoods rely on taxis for retail trips and rigorously tests the importance of retail service provision to altering such reliance. And we note that taxi trips contribute significantly to traffic congestion and air pollution because they occupy the roads like private cars (He et al., 2013). Hence, the implications of proper community planning go beyond the well-being of residents in these community by suggesting that changes in their taxi-trip behavior significantly affect aggregate-level welfare.

2. Backgrounds

2.1. The relation of urban forms to travel behavior

An emerging question in the urban planning literature has been how to plan neighborhoods to reduce vehicle trips and traffic congestion. To investigate how to shift people's travel choices from automobiles to non-motorized modes such as walking and cycling, scholars have explored diverse aspects related with the built environment and urban forms (Appleyard, 1980; Gehl, 2011; Khan et al., 2014; Pan et al., 2009). Many studies considered the distribution of different land uses as a main factor that could change travel behavior. The job-housing balance at the regional level is known to shorten commuting distances and durations (Giuliano & Small, 1993; Frank & Pivo, 1994; Sun et al., 1998). At the

[1] In the Singapore context, we find that the proportion of private vehicle trips over all trip modes moves consistently with the proportion of taxi trips out of private vehicle trips, suggesting the close association of choices for taxis and private cars.

[2] This may not be the case in other countries. For example, in the US, people travel more for social and recreational purposes than for shopping (2009 National Household Travel Survey).

neighborhood level, researchers focus on how mixing residential and non-residential, uses such as retail shops, impacts the travel patterns of residents. Cervero and Duncan (2008) report that job-housing balance yields a more significant reduction in travels than the accessibility to retail shops. Other studies demonstrate a positive relationship between mixed land uses with the probability of inducing people to use non-motorized travel modes such as walking and cycling (Cervero & Duncan, 2003; Ewing & Cervero, 2010; Hou, 2019; Krizek, 2003; Krizek & Johnson, 2006; Li et al., 2018).

Krizek and Johnson (2006) is the closest to our study in a sense that they estimate the relationship between the distance to neighborhood retail establishments and individual travel modes. Using the trip diary data of 1635 individuals in the Twin Cities of Minneapolis and St. Paul, Minnesota, they find that only individuals residing within 200 m of a retail establishment are likely to increase the probability of walking compared with those who have no retail establishment within 600 m of their residences. As their analyses do not specify the purpose of trips, however, the results do not suggest whether the proximity to retail establishments influences the general mode of travel or the retail trips specifically.

2.2. Travel destination and mode choices for retail purposes

As retail trips are considered inessential trips, accessibility in terms of travel time is a main determinant for the individual choice of retail destination (Kitamura & Kermanshah, 1984; Koppelman & Hauser, 1978; Landau et al., 1982; Recker & Kostyniuk, 1978; Timmermans, 1996). In modelling the retail destination choice, therefore, it is common to use travel time constraints to restrict alternative choice sets (e.g. Thill & Horowitz, 2002). Building on this framework, Huang and Levinson (2015) suggest that people are likely to choose a retail destination with shorter travel time and with more walkable opportunities. In line with this evidence, we hypothesize that there is a high probability for residents to switch their retail destination from retail establishments requiring automobile trips to new neighborhood malls within walking distance.

Few studies examine the direct role of the urban environment to travel mode choices for retail trips, and they offer solid foundations for our research. For example, Rajamani et al. (2003) demonstrate that the land use diversity index has a significant, positive association with the probability to choose walking for non-work trips. Etminani-Ghasrodashti and Ardeshiri (2016) also find that residents in neighborhoods with more mixed use tend to use non-motorized modes for their non-work trips. We could treat the opening of a mall as a small-scale change in the land use mix and expect the similar increase in the probability of walking or cycling. Jiao, Moudon, and Drewnowski (2016) and Lovejoy et al. (2013) suggest that the probability of driving decreases when stores are clustered and when retail destinations become closer to homes. This provides good motivation for our empirical approach using the neighborhood mall as a clustered retail amenity as well as our hypothesis that the distance to a newly opened mall affects the change in taxi trips for retail.

2.3. Singapore's contexts

As a well-known retail destination, Singapore presents a wide array of retail amenities in both the downtown and suburban areas (Henderson, Chee, Mun, & Lee, 2011). While retail facilities were concentrated in the CBD before the 1960s, public housing programs initiated by the government agency, the Housing Development Board (HDB), have led to suburban new towns and provided a planned hierarchy of retail services in these towns.[3] People make retail trips not only to purchase necessities or acquire product information but also do so as a weekly family ritual in Singapore (Chua, 2003). Also, because most women work, it is common to dine out frequently. Almost two thirds dine out at least four times a week (Health Promotion Board Singapore, 2010). For their retail activities, Singapore residents show strong preference for indoor, air-conditioned shopping malls that incorporate fringe services such as banks as well as recreational and entertainment components such as cinemas (Davies, 2012; Ibrahim & Ng, 2002).[4] As of August 2020, there are 171 shopping malls in Singapore, which is significantly more than the 65 in New York City.[5] There is also evidence that Singapore residents are willing to pay the premium for housing units that are closer to shopping malls. Deng et al. (2012) suggest that the proximity to shopping malls leads to a significant increase in housing prices in Singapore.

According to the Household Travel Survey (HTS) 2012 by the Land Transport Authority, 63% of Singapore commuters use public transport for their daily trips. Among the public transport modes, taxi ridership accounts for 14–15% of all trips by public transportation over the period of 2009–2012 compared to the 16–17% ridership for light rail transit (Singapore Statistics). Despite the increasing trend in public transport usage, many people still prefer private vehicle trips and this preference is strong especially for retail trips. For all trips with retail locations as either the origin or destination, 24.3% were by private vehicles including taxis (HTS 2012). Taxis are considered an ideal substitute that incur much lower costs.[6] In fact, people perceive taxis to meet the similar level of travel qualities to the private car, including 'travel time', 'suitability' and 'practicality' (Ibrahim, 2005). As a result of the strong taxi demand, about 28,000 taxis and 99,000 licensed taxi drivers provide more than 1 million taxi trips daily in Singapore. In particular, when shoppers have to carry many things from retail, they are likely to choose taxis over other public transport modes. For all taxi trips, 42.7% were with retail locations as either the origin or destination and 16% involved trips from and to shopping malls (HTS 2012).

One major reason that shopping malls in Singapore could play an important role in retail trip behaviors, especially long-distance trips by taxis, is because these malls provide a wide range of services. An ordinary shopping mall in Singapore offers not just restaurants and branded stores, but also banks, supermarkets, drug stores, clinics, gyms, preschools, even enrichment classes.[7,8] As such, whenever a new neighborhood mall is constructed, nearby residents naturally shift many of their retail trips to this closer mall. And some of their previous travel

[3] Still, most large-scale malls are located in city centers. For example, Orchard Road, which is the principal shopping belt in the CBD area, has more than 30 malls.

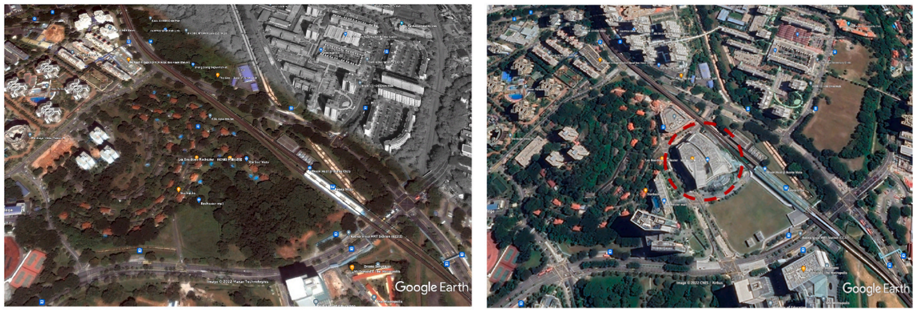
[4] This is in line with Bloch et al. (1994) that malls are considered not only as shopping destinations but also as places for entertainment and social interactions.

[5] Source: Wikipedia. The population of Singapore and New York City are 5.7 million and 8.4 million, respectively. E-commerce challenges are less relevant to our study period of January 2009–September 2012.

[6] Due to the extremely high costs of car ownership from the implementation of the Vehicle Quota System (VQS) and Electronic Road Pricing (ERP), only 46% of households own cars in Singapore. The main purpose for these measures is to mitigate road traffic congestion. Still, in 2015, Singapore was ranked 38th in a global index which measures the severity of traffic congestion on roads during peak hours by TomTom. Drivers in Singapore spend 33% more time stuck in traffic across the day, and up to 65% more time during the evening peak. This adds up to 126 h of extra travel time a year (www.tomtom.com).

[7] Refer to https://web.archive.org/web/20210620190917/https://www.nex.com.sg/Directory/Category for the list of available services at a typical mall in Singapore.

[8] Although estimating consumer demand for the different types of malls is beyond the scope of our research, we looked into the difference in directories of shopping malls in our sample and find that the diversity of these directories is the dominant factor in attracting taxi traffic, which is a proxy of consumer demand.



(a) Pre-construction (b) Post-construction

Fig. 1. The aerial views of pre- and post-construction of the new shopping mall in the One North neighborhood, Singapore.

modes to retail destinations would have been by taxis. Another reason why a newly constructed shopping mall could effectively reduce longer-distance retail trips is the way they are constructed. In Singapore, a shopping mall is usually a multi-story, high-density development that occupies a block, thus making it a compact origin and destination node. A typical example of this design can be seen in Fig. 1, in which we present the pre- and post-construction satellite images of the surrounding area of a new shopping mall in Singapore.

3. Data and methods

3.1. Data

This study utilizes data from several sources. The first is a dataset on taxi trips. Our taxi-trip data is provided by the largest taxi operator in Singapore, covering periods from January 2009 to September 2012. The market share of this taxi company is around 50–60% (in terms of the number of taxis), and the monthly ridership is around 11–12 million trips. Due to its dominant market position, the trip data it provides can thus be viewed as a representative sample of actual taxi trips in Singapore. We focus on the period of 2009–2012 because it is before the entry of ride-hailing, food delivery, and logistics services technology companies which are likely to involve more complicated travel choices and potential confounding issues.[9] For each taxi trip, we have the following two categories of details: (1) the GPS coordinates and time-stamps of the trip origin and destination, and (2) the distance, duration, and charged fare of the trip. From the spatiotemporal information of the trip, we could further derive the closest postal codes associated with the GPS coordinates of the trip origin and destination.[10] This is a crucial step, as it allows us to associate the origin and the destination of a trip to postal codes.

The second data are the land use information of each postal code. The postal code system utilized in Singapore is unique in that each postal code is associated with a building and unique XY coordinates. Because of this, we could easily determine the land use (e.g. residential, retail, etc.) of the origin and destination postal codes. We determine the land use of each postal code mainly based on the 2008 Master Plan, which is the statutory land use plan in Singapore (https://www.ura.gov.sg/Corporate/Planning/Master-Plan) and official property database including the Urban Redevelopment Authority's (URA) REALIS portal and the Housing Development Board's[11] resale transaction database. For some ambiguous cases, usually because of the mixed land use of a particular building, we rely on Google Street View and PropertyGuru (an online property platform) to determine the most appropriate land use for the building. This postal code system also allows us to identify the exact location of shopping malls as all malls in Singapore can be uniquely identified by their postal codes. By combining the land use information with the above taxi-trip data by postal codes, we could then determine the time-dependent taxi-trip flows between any pair of postal codes. Note that we focus on trip flows originating from residential postal codes.

Finally, although we focus on the share of retail trips out of all taxi trips so the general tendency for choosing a taxis as a travel mode are less relevant to our analyses, we consider the potential that other modes influence this share.[12] For public transportation accessibility, we collect the distance from each residential postal code to the nearest subway station for each month.[13] To account for the driving option, we collect the vehicle ownership rate at the neighborhood level and calculate the road-based distance of each residential building to the shopping mall opened during our study period. The road-based distance is also a better proxy for the walking distance than the straight-line distance used in most previous studies.[14] Based on these distances, two binary variables are generated: (1) whether the nearest shopping mall is located within 800 m and (2) whether the nearest shopping mall is located within 1500 m. The distance criteria are determined following the gradient of taxi trips to retail destinations by distance to the nearest shopping mall,

[9] Ride-hailing, food delivery, and logistics services technology companies entered Singapore after our research period (e.g., Uber in late 2012 and Grab in 2013), so they should not affect our analyses.

[10] The mapping from a GPS coordinate to the closest postal code is achieved by using the official API service from OneMap, which is an open platform provided by the Singapore Land Authority.

[11] The Housing and Development Board refers to the statutory board of the Ministry of National Development that is responsible for public housing as well as public housing itself in Singapore.

[12] Our main interest is the extent to which those who used to travel to a retail destination by taxis change to other modes after a mall opening. While we do not exactly know which travel modes they change to because of data limitations, we are able to observe the probability that people living near newly opened shopping malls reduce taxi trips for the retail purpose controlling for the general tendency of choosing taxi trips. Our concern is that other travel modes affect the share of retail trips out of all taxi trips, which could be potentially confounded with the opening of shopping malls. For example, if a lot of new subway stations open near new shopping mall areas, some taxi riders may switch to subway for their trips, including both retail and non-retail trips. Similarly, if the road conditions are significantly improved because of the opening of shopping malls, some taxi riders may switch to driving.

[13] We also collect the distances from each residential postal code to the CBD and the nearest expressway.

[14] The real walking distance could be between the road-based distance and the straight-line distance as some take shortcuts that are only possible for walkers.

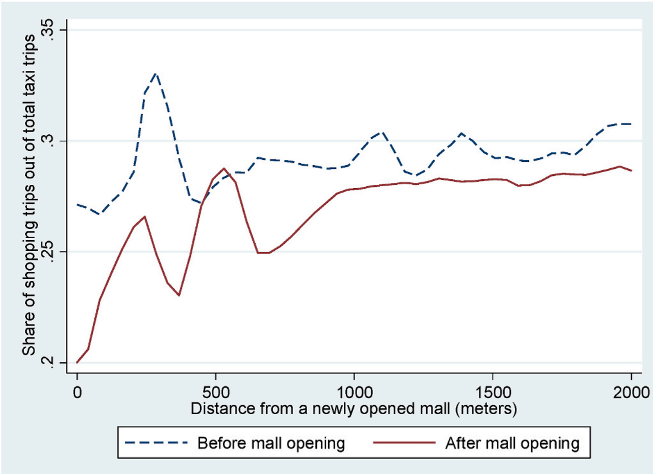


Fig. 2. Gradient of taxi trips to retail destinations by distance from the nearest mall.
Note: This is based on the results from local polynomial regressions of the share of retail trips out of total taxi trips on the distance from shopping malls.

which suggests that after the opening of a new neighborhood shopping mall, the share of trips to other retail destinations out of total taxi trips decreases significantly within 800 m of the mall (see Fig. 2).[15] This 800-m cutoff is also considered as the walkable distance and the extent of the perceived neighborhood boundary in the urban planning literature (Moudon et al., 2006).

3.2. Samples

Table 1 provides summary statistics for two primary samples of monthly taxi trips originating from residential postal codes during our study period. The first sample is created by dropping all residential buildings that already had a shopping mall within 1500 m before January 2009 or more than one shopping mall within 1500 m during the study period (column 1). In other words, this sample is composed of residential buildings that were never near any shopping mall (comparison group) and those that were near only one shopping mall that opened during our study period (treatment group). Following Kim and Lee (2018) and Lee (2021), this restriction is to ensure that being located close to multiple shopping malls does not obscure the treatment effect. The first sample contains 9133 residential buildings and 359,068 monthly taxi records over 40 months.

The second sample is created by dropping all residential postal codes in the first sample that are located farther than 1500 m from the shopping malls that opened during our study period (column 2). By doing so, each newly opened shopping mall creates a “mall area" with the average area of about 7 square kilometers and the sample consists of 1164 residential buildings.[16] This mall area is based on the location rather than an administrative boundary, so it may better control for neighborhood characteristics. As the size of the mall area–based sample is significantly smaller than the first sample, and the postal sector fixed effects should effectively control for spatial confounding, analyses using the second sample are reported as supplementary results to those from the first sample.

The subsample of the treatment group I is composed of residential buildings located within 800 m of a newly opened shopping mall (column 3). There are 153 residential buildings and 6120 monthly obser-

Table 1
Summary statistics.

	(1)		(2)		(3)	
	Cleaned full sample of residential postal codes * month (January 2009–September 2012)		Subsample of postal codes within 1500 m from newly opened mall * month (Mall Areas)		Subsample of postal codes within 800 m from newly opened mall * month (Treatment Group I)	
Number of observations	359,068		46,546		6120	
Number of residential postal codes	9133		1164		153	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Taxi trips per 1 month *originated from each residential building*						
Total number of taxi trips	325.344	533.123	381.607	559.73	386.979	560.439
Total number of trips to retail destination	95.986	158.335	110.496	165.291	111.957	174.798
Share of number of retail trips out of total trips	0.288	0.111	0.285	0.1	0.28	0.083
Total distance traveled to retail destination (km)	936.741	1386.465	1045.76	1437.130	1069.935	1484.466
Share of retail trip distance out of total trip distancev	0.28	0.114	0.28	0.102	0.279	0.086
Total number of trips to mall	21.574	31.92	25.348	32.108	24.371	34.924
Share of number of mall trips out of total retail trips	0.078	0.065	0.076	0.055	0.071	0.045
Location characteristics						
Distance to the closest subway station (m)	1633.211	893.101	1426.539	807.606	1413.081	932.103
Distance to the CBD (m)	11,716.54	4591.265	11,094.61	3794.992	11,070.39	3282.347
Distance to the closest expressway (m)	1007.02	814.808	991.79	601.669	1336.956	610.767
Other characteristics						
Car ownership per population (proxied from survey)	0.132	0.096	0.117	0.06	0.105	0.025
Within 800 m from a shopping mall newly opened between 2009 and 2012	0.017	0.129	0.131	0.338	1	0
Between 800 and 1500 m from newly-opened mall	0.113	0.316	0.869	0.338		

Note 1: The unit of analysis is the monthly taxi trip record originated from each residential building.

[15] Regarding the two peaks after a mall opening, we found that more than 95% of these residential blocks coincide with the blocks that had a substantially higher share of retail trips out of total taxi trips even before a mall opening. This suggests sticky behavior of some residents who still take taxis to other retail destinations even after new neighborhood shopping malls are opened. Nevertheless, the share of retail trips out of total taxi trips has decreased even in these blocks (Figs. 2 and 4) and these peaks become smoother as more months pass after the mall’s opening time (Fig. 4).

[16] There are 80 postal sectors based on the first two-digit of the unique six-digit postal code system in Singapore. The size of residential postal sectors varies between 0.1 and 3 km^2. We use the postal sector fixed effects for analyses with the full sample.

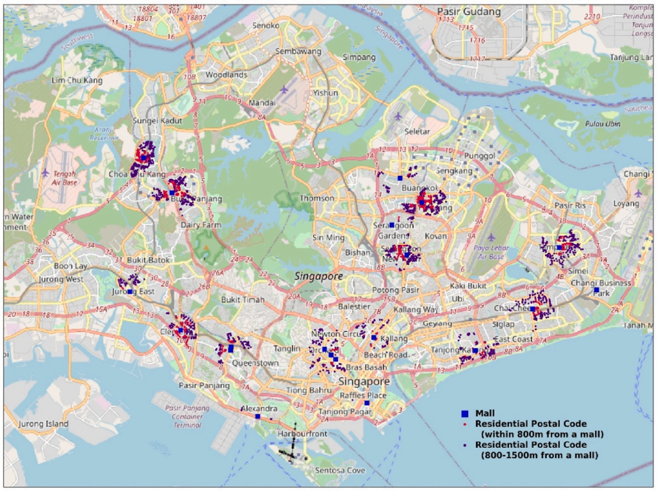


Fig. 3. Spatial distribution of newly opened shopping malls between 2009 and 2012 and residential postal codes.

vations under this category. Fig. 3 exhibits the mapped locations of 20 shopping malls that opened between January 2009 and September 2012 (blue squares) and residential buildings (dots) for the cleaned full sample. The buildings with red dots are located within 800 m from each mall, and belong to the treatment group. The buildings with purple dots are located between 800 and 1500 m, and are used as treatment group II for the analysis using the first sample as well as the comparison group for the analysis using the second sample (i.e. mall area).

According to Table 1, both the number and distance of taxi trips to retail destinations originating from residential postal codes that are closer to newly opened shopping malls (columns 2 and 3) appear to be higher than the average number and distance of taxi trips to retail destinations (column 1). Areas that are closer to shopping malls also show a larger number of non-retail trips. These results imply that new shopping malls are likely to be located in areas with higher and denser residential population, which makes sense from the developers' mall-location choice. Alternatively, as these areas have lower car-ownership rates (columns 2 and 3) compared to the national average (column 1), residents in these areas may rely more on taxis than other transport modes. In any event, the important fact is that the shares of the number and distance of retail trips out of total taxi trips originating from these areas (columns 2 and 3) are not larger than the national average (column 1). This suggests that the taxi travel patterns of residents in the treatment and comparison groups do not significantly differ from those in other areas of Singapore. More importantly, there is little heterogeneity in most attributes between the mall areas (column 2) and treatment group I (column 3) and this ensures random distribution of the new shopping mall location within the mall areas.

3.3. Empirical methodology

A simple cross-sectional model that uses the distance of a residential building to the nearest shopping mall to estimate the relationship between the proximity to the neighborhood mall and taxi trips f to retail destinations would be as follows:

$$Log(T_{ijt}) = \beta D_{ijt}^{800} + X_i'\gamma + \varphi_t + \alpha_j + \varepsilon_{ijt} \tag{1}$$

where T_{ijt} is the share of the number (or distance) of taxi trips to retail destinations out of the total number (or distance) of taxi trips originating from the residential building i in postal sector j in month t, D_{ijt}^{800} is a binary indicator of whether any shopping mall is located within 800 m of residential building i. Note that we observe the taxi trips for a retail purpose relative to all taxi trips instead of the raw number or distance of taxi trips to retail destinations. X is a control vector of location-specific characteristics, including the distance to the closest subway station, CBD and the closest expressway. Because our taxi data do not have socio-demographic information, which may influence the tendency to use taxi for a retail purpose relative to use taxis in general, we include spatial and temporal controls, such as postal sector fixed effects (φ_j) and year-month fixed effects (α_t). These controls help increase the probability that the treatment effect is as exogenous as possible. ε_{ijt} is an *i.i.d.* error term. Standard errors are clustered at the postal sector level j (Cameron and Miller, 2015).

However, it is possible that the opening of neighborhood shopping malls is correlated with unobserved location characteristics and with a temporal market trend. Cross-sectional regressions cannot avoid being subject to the problem of unobserved spatial heterogeneity and an omitted variable bias. For example, if some unobserved negative attributes already exist at or near the location of a shopping mall, those factors would reduce taxi trips to retail destinations around this location right before the shopping mall is opened. As the main goal of this analysis is to estimate the isolated, causal effect of the opening of a shopping mall on nearby residents' taxi-trip behavior for retail, a difference-in-differences (DID) using the full sample (see Table 1, column 1) is employed as the main empirical strategy as follows:

$$Log(T_{ijt}) = \left(\beta D_{ijt}^{800} + \delta D_{ijt}^{1500}\right) + \left(\theta D_{ijt}^{800} + \lambda D_{ijt}^{1500}\right) \times Post_{it} + X_i'\gamma + \varphi_t + \alpha_j + \varepsilon_{ijt} \tag{2}$$

The main difference of this DID equation from Equation (1) is the inclusion of the interaction between the distance of residential postal codes to the nearest shopping mall and *Post*, a binary indicator of the retail taxi trips originating from the residential postal code i in month t occurring 1 month after the opening month of the nearest shopping mall. θ and λ pick up the opening effect of the shopping mall within 800 m and between 800 and 1500 m on taxi trips to retail destinations, respectively. D_{ijt}^{1500} is a binary indicator of whether a shopping mall is located within 800 and 1500 m (i.e., outside the treatment area but within the 1500 m) of residential building i. The interaction term between D_{ijt}^{1500} with *Post* is added to estimate counterfactual treatment effects by using the units that are located slightly farther away from the shopping mall. As mentioned earlier, the subsample located within 1500 m from a newly opened shopping mall (mall area) is based on the location of each mall. The dependent variable for the DID model using this subsample is T_{ikt}, with mall area k and mall-area-by-year fixed effects (δ_{ky}) are included, and standard errors are clustered at the mall area level. Other variables are the same as those used for Equations (1) and (2).

Fig. 4. Gradient of taxi trips to retail destinations by distance from shopping malls: 6–18 months before and after the mall opening.

Table 2
Cross-sectional regression results.

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	Cleaned full sample	Cleaned full sample	Subsample of Mall Areas	Cleaned full sample	Cleaned full sample	Subsample of Mall Areas
	Number of retail trips	Share of the number of retail trips out of total taxi trips		Distance to retail destinations	Share of retail trip distance out of total taxi trip distance	
Within 800 m from newly opened mall	18.5107	−0.0044	−0.0028	152.8658	−0.0042	−0.0042
	(13.3864)	(0.0041)	(0.005)	(127.3092)	(0.003)	(0.0053)
Between 800 and 1500 m from newly opened mall	10.8446	−0.0006		104.1363	0.0002	
	(9.4175)	(0.0027)		(79.7881)	(0.0029)	
Constant	328.992***	0.3557***	0.3479***	1256.778	0.1521***	0.1467***
	(9.5992)	(0.0042)	(0.0077)	(83.6019)	(0.0048)	(0.0077)
Observations	359,068	359,068	46,546	359,068	359,068	46,546
R-squared	0.085	0.124	0.144	0.046	0.027	0.043
Distances to MRT, CBD, and expressways	Yes	Yes	Yes	Yes	Yes	Yes
Car Ownership Rate	Yes	Yes	Yes	Yes	Yes	Yes
Year-Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Postal Sector FE	Yes	Yes	NO	Yes	Yes	NO
Mall area-year FE	NO	NO	Yes	NO	NO	Yes

Note 1: Standard errors clustered at the postal sector level are reported in parentheses.
*Note 2: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.*

The underlying assumption imposed by our DID model is that residential buildings in the treatment and comparison groups have parallel trends of taxi-trip behaviors for retail. Fig. 4 validates this by showing that retail-trip gradients do not evolve much prior to mall openings. Six months after an opening, there is a drop in retail trips by taxi only for residential buildings within 800 m.

4. Results

4.1. The impact of a neighborhood shopping mall opening on taxi trips to retail destinations

Table 2 presents estimates of the cross-section model presented in Equation (1). The analysis results from this specification show the difference between taxi trips to retail destinations originating from residential buildings within 800 m of newly opened malls and those from other residences in Singapore. The average difference in the number of monthly retail trips is about 18.5 when we include all controls, including the year-month fixed effects, but it is not statistically significant (column 1). When changing the dependent variable to the share of the number of monthly retail trips, the average difference is less than 0.01 and statistically insignificant for both the full sample (column 2) and subsample of residential buildings within 1500 m of new malls (column 3). Similarly, we do not find any substantial difference in terms of the taxi-trip distance to retail destinations by the distance of residential buildings to new malls (columns 4–6). Taxi trips to retail destinations originating from residences between 800 and 1500 m of newly opened malls are also not significantly different from those from other residential buildings (columns 1, 2, 4 and 5). These results suggest that households residing near the location of new malls (treatment group) do not take taxis to retail destinations more or less significantly than other households (comparison group). As these regressions do not take into account the temporal variation of the mall opening, they support no pre-trend.

As the main quasi-experimental treatment of this analysis is being located within 800 m of new malls, the treatment effect is estimated after these malls open using the DID specification in Equation (2). Results using the full sample shown in Table 3 demonstrate that a mall opening within 800 m causes a significant reduction in the number of taxi trips to other retail destinations (columns 1 and 2). Prior to a mall opening, the number of taxi trips to retail destinations originating from these residential buildings was not significantly different from that of trips from other residences with similar locational attributes that did not have any new malls nearby and in the same postal sector and year-month (columns 1 and 2). However, after a new mall opens, each residential building located within 800 m of the mall originates 33 fewer taxi trips to other retail destinations per month on average, compared to the number of trips from the same buildings before a mall opening (columns 1). As a result, the share of the number of retail trips out of total taxi trips also decreases by 1 percentage point and the reduction is statistically significant at the 5% level with the p-value of 0.0222 (column 2).

For residential buildings located between 800 and 1500 m, the estimated reduction in taxi trips to retail destinations after new malls open was close to zero compared to the pre-opening period (columns 1 and 2). This is statistically insignificant and negligible compared to the 33-trip decrease or 1 percentage point decrease in the share of retail trips out of total taxi trips originating from residential buildings within 800 m. Hence, the treatment effect of the mall opening on taxi-trip behaviors for retail is highly significant for households that reside within the 10-min walking distance to the location of the mall and dissipates beyond this distance. This 800 m is a longer distance than the 200-m cutoff that Krizek and Johnson (2006) found to be significant for increasing the probability of walking. Although our data do not allow us to investigate the travel mode changes of individual households, we could infer that people in Singapore are willing to walk a longer distance than those in the U.S., or some households in Singapore choose other modes such as cycling to travel to a neighborhood mall.[17]

A potential concern of these results based on the full sample is that the relationship between taxi-trip behaviors for retail are systematically different within and outside the mall areas. To address this concern, the treatment effect is re-estimated using the subsample of residential postal codes located within 1500 m of the new malls. Results suggest that after the neighborhood mall opens, individuals residing within 800 m from the mall reduce their taxi trips to other retail destinations significantly and, in turn, the share of retail trips out of total taxi trips decreases by about 1.4 percentage points and it is significant at 1% even after clustering standard errors at the mall area level (column 3). As this is consistent with results in columns 1 and 2 while the magnitude of the retail-trip reduction becomes slightly larger, it demonstrates that using

[17] According to the statistics reported by the Land Transport Authority, 70% of commuters in Singapore use the subway within a radius of 800 m or about a 10-min walking distance.

Table 3
Effect of neighborhood mall openings on taxi trips to retail destination (Difference-in-difference regression results).

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	Cleaned full sample	Cleaned full sample	Subsample of Mall Areas	Cleaned full sample	Cleaned full sample	Subsample of Mall Areas
	Number of retail trips	Share of the number of retail trips out of total taxi trips		Distance to retail destinations	Share of retail trip distance out of total taxi trip distance	
Within 800 m from newly opened mall	23.1752	−0.0048	−0.0010	206.0464	−0.0031	−0.0028
	(13.4788)	(0.0046)	(0.0045)	(119.5305)	(0.003)	(0.0052)
Within 800 m from newly opened mall & trips made 1 month after mall openings	−33.0979**	−0.0101**	−0.0142***	−354.7235***	−0.0114**	−0.011**
	(12.8581)	(0.0046)	(0.0035)	(115.526)	(0.0054)	(0.0053)
Between 800 and 1500 m from newly opened mall	11.323	−0.0026		109.5551	−0.0001	
	(9.7736)	(0.0029)		(81.87469)	(0.0034)	
Between 800 and 1500 m from newly opened mall & trips made 1 month after mall openings	−0.1931	0.002		19.56641	−0.0013	
	(10.0363)	(0.0019)		(88.88411)	(0.0041)	
Observations	359,068	359,068	46,546	359,068	359,068	46,546
R-squared	0.085	0.125	0.145	0.046	0.027	0.043
Distances to MRT, CBD, and expressways	Yes	Yes	Yes	Yes	Yes	Yes
Car Ownership Rate	Yes	Yes	Yes	Yes	Yes	Yes
Year-Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Postal Sector FE	Yes	Yes	NO	Yes	Yes	NO
Mall area-year FE	NO	NO	Yes	NO	NO	Yes

Note 1: Standard errors clustered at the postal sector level (for Columns 1, 2, 4 and 5) and the Mall Area level (for Columns 3 and 6) are reported in parentheses.
Note 2: ***p < 0.01, **p < 0.05, *p < 0.1.

additional residential postal codes outside of mall areas does not lead to statistical bias.

While the reduction in the number of taxi trips to retail destinations accounts for intensive margin responses to a mall opening, the distance traveled to other retail destinations by taxi indicates extensive margin changes in travel behaviors. Results in Table 3 show that a mall opening reduces the taxi-trip distance for retail (columns 4 and 5). After a neighborhood mall opens, individuals in each residential building within 800 m of the mall decrease their taxi trips to other retail destinations by about 355 km per month on average, compared to the distance from the same building before a mall opening (column 4). The share of the retail-trip distance out of total taxi-trip distance also decreases by 1.1 percentage points (column 5). When using the tightly bounded subsample of the mall areas, this 1.1 percentage point decrease remains consistent (column 6), which is about a 4% reduction of taxi trips to retail destinations.[18]

Another potential concern is that the change in taxi-travel behavior that we observe might come from a retail-trip reduction right before new malls open. Hence, a falsification test is performed using false dates of mall openings that are 6 months and 1 year before the actual opening. As shown in Appendix 1, the regression results reveal no evidence that retail trips in treatment areas closer to new malls were experiencing a significant downward trend before the actual mall opening. An additional robustness test is done by adding a series of interactions of 12 time dummies (i.e., −36 to −30 months, −30 to −24 months… +24 to +30 months, +30 to +36 months) to Equation (2). Appendix 2 reports no significant change in taxi-trip patterns for retail is found before a mall opening for the treatment group within 800 m of neighborhood malls. The retail trip reduction in terms of both the number and distance appears to begin only after 6 months of a mall opening and remain significant up to 3 years afterward.

We interpret our results aggregated at the residential building level as suggestive evidence of changes to individuals' travel behavior. They suggest the important role of neighborhood retail service provision to the residents' retail travel patterns. When a new neighborhood mall opens, residents who used to take taxis to other retail establishments for retail are likely to choose the new mall over others as their retail destination. And when this new mall is located within walking distance, residents may switch their travel mode from taxis to walking or cycling. This confirms the external validity of existing evidence on the effect of the proximity to retail establishments on the choice of non-motorized travel modes (Cervero & Duncan, 2003; Krizek & Johnson, 2006) in the high-density environment. Further, we suggest that travel behavior change induced by new malls would be particularly significant in cities where a lot of retail activities happen in indoor malls. For example, the trips to shopping malls account for about 23% out of total retail trips (or 8% of total taxi trips) in Singapore. The back-of-the-envelope calculation based on the above results suggest that the 20 malls that opened in Singapore between January 2009 and September 2012 reduced 5049 taxi trips to retail destinations and 54,315 km traveled on the road per month.

4.2. Mall treatment effects during different times

Results shown above are the average monthly effect of a new mall opening on taxi-trip behaviors for retail. There is evidence that many retail trips occur during peak hours and add even more congestion on the road (Kim et al., 1994). If new neighborhood shopping malls can reduce retail-trip demand by taxis during peak hours, they may play a more significant role to mitigating congestion.[19] To test this, we create new dependent variables by calculating the shares of the number/distance of retail trips out of total taxi trips generated from each residential building during the PM peak hours on weekdays (5 p.m.–midnight), off-peak hours on weekdays (10 a.m.–5 p.m.), and weekends and estimate mall treatment effects during these time periods.

Table 4 suggests that the extent to which the mall opening reduces retail trips is largest during the PM peak hours. The new neighborhood malls within 800 m lead to a reduction in the share of the number of retail trips out of total taxi trips by 18.5 percentage points during the 5 p.m.–midnight (column 1) period while the reduction is only 3.36 and 2.62 percentage points during off-peak hours and weekends, respectively (columns 2 and 3). Results on the distance traveled to other retail

[18] The average share of shopping-trip distance out of total taxi-trip distance is 0.279 (Table 1).

[19] One concern is potential reverse causality that congestion may affect the level of demand for taxi trips. Because our dependent variable is not the raw number of taxi trips but the share of retail trips out of total taxi trips, we think reverse causality is less likely unless traffic congestion has a disproportionate impact on taxi trips for retail purposes compared to other taxi trips.

Table 4
Mall treatment effects on taxi trips during different time periods.

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	During PM peak hours (5 p.m.–midnight)	During off-peak hours (10 a.m.–5 p.m.)	During weekends	During PM peak hours (5 p.m.–midnight)	During off-peak hours (10 a.m.–5 p.m.)	During weekends
	Share of no. retail trips out of total taxi trips			Share of retail trip distance out of total taxi trip distance		
Within 800 m of a newly opened mall	0.0528 (0.0548)	−0.0006 (0.0075)	0.0011 (0.0071)	−0.1162 (0.0754)	−0.0715 (0.0432)	0.0032 (0.0065)
Within 800 m of a newly opened mall & trips made 1 month after mall openings	−0.1851*** (0.0544)	−0.0336*** (0.0074)	−0.0262*** (0.0063)	−0.2101*** (0.0691)	0.0231 (0.0329)	−0.0269*** (0.0076)
Between 800 and 1500 m of a newly opened mall	−0.0165 (0.0189)	0.0017 (0.0058)	0.0008 (0.0037)	−0.0235 (0.0804)	−0.0369 (0.0228)	0.0041 (0.0035)
Between 800 and 1500 m of a newly opened mall & trips made 1 month after mall openings	−0.0049 (0.0124)	−0.0015 (0.0054)	0.0021 (0.0028)	−0.1923 (0.0811)	−0.0177 (0.0222)	−0.0002 (0.0054)
Observations	359,068	359,068	359,068	359,068	359,068	359,068
R-squared	0.015	0.047	0.056	0.004	0.001	0.017
Distances to MRT, CBD, and expressways	Yes	Yes	Yes	Yes	Yes	Yes
Car Ownership Rate	Yes	Yes	Yes	Yes	Yes	Yes
Year-Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Postal Sector FEv	Yes	Yes	Yes	Yes	Yes	Yes

Note 1: Standard errors clustered at the postal sector level are reported in parentheses.
Note 2: ***p < 0.01, **p < 0.05, *p < 0.1.

destinations consistently report the most significant post–mall opening effect during the PM peak hours. Individuals in residential building within 800 m of a new mall decrease the trip distance to other retail destinations out of their total taxi-trip distances by about 21 percentage points (column 4). This contrasts to the null effect during the off-peak hours (column 5) and a 2.7 percentage point reduction during weekends (column 6).

These results suggest that new shopping malls could have positive externality to traffic reduction, especially if locating them close to residential buildings that generated many taxi trips to retail destinations. And this reduction appears to be greater in PM peak hours, during which traffic congestion is most serious (see Footnote 6). Although this study does not directly estimate the traffic-reduction effect during different times, we argue that the effect during peak hours could be even more significant than what we observe from regression results. Traffic congestion happens if the sum of different types of vehicular trips, such as commuting, retail, and other trips, reaches beyond the road's maximum traffic capacity (Bhat & Steed, 2002). As commuting trips are likely to consume most of this capacity and leave the roads quite congested during peak hours, therefore, the traffic-reduction effect caused by mall openings would be even more notable. With respect to the less significant reduction during weekday non-peak hours and weekends, we believe that consumption habits are the main reason.[20] Visiting larger shopping centers in downtown that feature retail agglomeration is a popular activity on weekends in Singapore. Our results imply that retail trip behaviors to such shopping centers are less likely to change when people have more time for leisure activities and when there is less traffic congestion.

4.3. Heterogeneous mall effects by residential buildings

As the location of residential buildings within a city is an important determinant of travel modes and retail destinations, it could possibly influence the magnitude of the mall-opening treatment effect on retail-trip behaviors of nearby households. For example, the magnitude of taxi-trip reduction for retail may depend on the proximity of residential buildings to a main retail agglomeration and the community environment for these buildings. Table 5 presents significant heterogeneous mall-opening effects between the bottom 33% and top 33% in terms of the distance to downtown. First, residential buildings in the top 33% of the distance to downtown experience an approximately 1.2 percentage point reduction in the share of the number of retail trips out of total taxi trips after a shopping mall opens within an 800-m boundary (column 2). Conversely, the result suggests that residential buildings in the bottom 33% do not experience any significant reduction in retail trips (column 1).

Based on the descriptive statistics of two subsamples shown in Appendix 3, we find that residents living closer to downtown travel a shorter distance but more frequently to retail destinations by taxi compared to those living farther away.[21] Hence, the above regression results suggest that those who used to have to travel longer distance for retail are more likely to be willing to adjust their travel behavior after they find new neighborhood malls within walking distance. We also find that the level of accessibility to non-mall retail amenities is far higher for areas that are closer to downtown than suburban locations.[22] Hence, we interpret our regression results in Table 5 as evidence that those residing relatively close to other retail amenities even before a mall opening have lower incentives to change their retail travel habits.

Another potential variation in mall-opening effects could come from the planned features of broader towns that residential buildings belong to. As mentioned in the previous section, the majority of public-housing buildings in Singapore are located in suburban areas called new towns.[23] HDB has been responsible for public-housing development and followed the principles of self-containment and full-service provision to residents including retail shops in town centers and neighborhood centers. Hence,

[20] With respect to the number of trips to existing malls constructed before 2009, we find that residents within 800 m of newly opened malls reduced 34% of their taxi trips to the existing malls during weekday peak hours. On the other hand, the number of trips to existing malls during weekday non-peak hours decreased by only 25% and remained almost the same during weekends.

[21] We believe that the difference in travel frequency is related with the fact that residents closer to downtown have higher purchasing power and lower accessibility to a subway station.

[22] Residential buildings in the bottom third of the distance to downtown have 49.5 non-mall retail amenities within 800 m while residential buildings in the top third have only 6.3. Residential buildings in the bottom third of the distance to downtown have 118.8 non-mall retail amenities within 1500 m while residential buildings in the top third have only 11.5.

[23] The land size of new towns ranges from 3.84 to 13.09 km^2 and cover up to more than 70,000 housing units.

Table 5
Heterogeneous mall effects by location and type of residential buildings.

VARIABLES	(1)	(2)	(3)	(4)
	Subsample of residential buildings in the bottom third of the distance to downtown	Subsample of residential buildings in the top third of the distance to downtown	Subsample of public housing buildings	Subsample of condominium buildings
	Share of no. retail trips out of total taxi trips			
Within 800 m of a newly opened mall	−0.0069	−0.0035	−0.0044	0.0064
	(0.0089)	(0.0015)	(0.0039)	(0.0164)
Within 800 m of a newly opened mall & trips made 1 month after mall openings	0.005	−0.0119***	−0.0083*	−0.0239**
	(0.0053)	(0.0025)	(0.0044)	(0.0103)
Between 800 and 1500 m of a newly opened mall	−0.0093	−0.0075	−0.0041	0.0091
	(0.0075)	(0.0018)	(0.003)	(0.0068)
Between 800 and 1500 m of a newly opened mall & trips made 1 month after mall openings	0.0025	0.0035	0.0027	0.0106
	(0.0098)	(0.0021)	(0.0023)	(0.0056)
Observations	120,396	121,966	273,842	85,226
R-squared	0.069	0.037	0.107	0.117
Distances to MRT, CBD, and expresswaysv	Yes	Yes	Yes	Yes
Car Ownership Rate	Yes	Yes	Yes	Yes
Year-Month FE	Yes	Yes	Yes	Yes
Postal Sector FE	Yes	Yes	Yes	Yes

Note 1: Standard errors clustered at the postal sector level are reported in parentheses.
Note 2: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

even though public-housing buildings do not have any shopping malls nearby, they are likely to have retail establishments for daily needs including food courts and grocery stores in a proximate distance. In contrast, private housing, referred to as condominiums, is usually designed as purely residential purposes on a much smaller scale. Table 5 reports stratified results for the subsamples of public housing and condominium buildings. While condominiums within 800 m of new shopping malls experience about a 2.4 percentage point drop in the share of the number of retail trips out of total taxi trips after a mall opening (column 4), public-housing buildings experience less than a 1 percentage point reduction (column 3).[24] This suggests that residents in condominiums are more sensitive to a new retail amenity provision within a short distance of their residence and are more likely to change their retail-trip behaviors than those in public housing.

These results suggest that the role of expanded retail amenities to taxi-trip behaviors for retail is more significant if these amenities are provided in suburban locations and near residential areas without existing retail establishments in a proximate distance. At the same time, they indicate the importance of proper town planning, especially retail service provision to residents within a walking distance, efficient distribution of retail trips, and mitigation of traffic congestion. The urban planning literature tends to highlight minimizing commuting and school trips for the goal of well-planned self-sufficiency in suburban new towns (Hamilton & Röell, 1982; He et al., 2020; Hui & Lam, 2005). Our findings add suggestive evidence on the positive externality of proper town planning linked with less wasteful retail trips, such as welfare gains from the reduced congestion and air pollution at the aggregate-level.

5. Conclusion

This study analyzes the causal impact of newly developed malls on the taxi-trip behavior of nearby residents. We reveal that residential buildings within 800 m of recently opened neighborhood malls experience a significant drop in taxi trips to other retail destinations. The number of trips fall by 33 per month or the share of retail trips out of total taxi trips decreases by 1.4 percentage points. We also find a similarly significant reduction in the distance traveled to other retail destinations only for residential buildings that are within walking distance (800 m) of newly opened malls. Based on the mean monthly taxi trips to retail destinations in Singapore, these results, based on 20 newly opened malls in Singapore, translate into the reduction of 5049 taxi trips and 54,315 km traveled per 1 month.

Given that retail trips account for the highest percentage of non-work trips and a substantial proportion (42.7%) of taxi trips in Singapore, our findings suggest that providing a new shopping mall with clustered stores within a proximate dsitance from many residents could be an effective way to reduce daily travel distances, particularly taxi trips, to farther retail destinations. At the same time, residents are likely to switch to non-motorized travel modes such as walking or cycling for their retail activities. As a result, these residents could save their travel costs while enjoying a similar level of retail amenities. This strategy is a smaller-scale change compared to increasing land use diversity as a whole and could be used even for established neighborhoods.

Our results also suggest that the substitution of retail destinations in closer neighborhood malls and the change to non-motorized travel modes may reduce taxi-travel demand more substantially during PM peak hours compared to other times. Therefore, the decline in taxi trips to retail destinations caused by the opening of new neighborhood malls is expected to have a non-trivial impact on congested roads, even at the margin, because the impact of one additional taxi on a congested network is not linear but exponential. The outcome of congestion reduction, including positive externalities like the mitigation of air pollution, would be significant and, in turn, enhance public welfare at the aggregate level.

Finally, we report that residents in neighborhoods that are farther from the CBD and in less self-sufficient communities are more likely to adjust their taxi-trip behaviors for retail after a mall opening. These results echo the importance of self-sufficiency for suburban neighborhoods and the role of proper town planning. In particular, in achieving self-sufficiency, town planners should search for strategies to improve retail service provision within walking distance to homes in addition to job-housing balance.

Author statement

Kwan Ok Lee: Conceptualization, Econometric analyses, Writing - Original draft preparation, reviewing and editing, Shih-Fen Cheng: Data curation, Writing - reviewing, All the authors read and approved the

[24] Note that the retail trip patterns by taxis do not vary much between two subsamples (Appendix 3).

final manuscript.

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Appendix 1. Falsification Test

	(1)	(2)
	Cleaned full sample	Cleaned full sample
	6 months prior to actual mall opening	1 year prior to actual mall opening
VARIABLES	Share of no. of retail trips out of total taxi trips	
Within 800 m of a newly opened mall	−0.0033	−0.0019
	(0.0063)	(0.0066)
Within 800 m of a newly opened mall & trips made 1 month after mall opening	−0.0069	−0.0082
	(0.0057)	(0.0053)
Between 800 and 1500 m of a newly opened mall	−0.004	−0.0047
	(0.0036)	(0.004)
Between 800 and 1500 m of a newly opened mall & trips made 1 month after mall opening	0.0015	0.0022
	(0.004)	(0.0046)
Observations	359,068	359,068
R-squared	0.1247	0.1247
Distances to MRT, CBD, and Expressways	Yes	Yes
Car Ownership Rate	Yes	Yes
Year-Month FE	Yes	Yes
Postal Sector FE	Yes	Yes

Note 1: Standard errors clustered at the town level are reported in parentheses.
Note 2: ***p < 0.01, **p < 0.05, *p < 0.1.

Appendix 2. Difference-in-Differences Model Results: Taxi-trip Trends Over Time

		(1)	(2)
VARIABLES		Number of retail trips	Distance to retail destinations
Within 800 m of a newly opened mall		29.7793	251.876
		(17.9571)	(191.6237)
Trips during __ month(s) *before* mall openings			
	30 to 36	31.9977	264.7433
		(34.3121)	(312.5933)
	24 to 30	15.4475	128.0709
		(25.9534)	(247.7982)
	18 to 24	−2.1066	−2.4525
		(23.5268)	(224.0038)
Within 800 m of a newly opened mall	12 to 18	−14.4391	−95.6131
		(22.0942)	(201.956)
	6 to 12	−21.0831	−145.0747
		(19.3599)	(184.2906)
	0 to 6	−16.3446	−105.4538
		(18.83)	(172.4477)
Trips during __ month(s) *after* mall openings			
	0 to 6	−9.8519	−84.79102
		(22.1294)	(190.1904)
	6 to 12	−41.7623**	−333.8887*
		(18.7311)	(169.2605)
	12 to 18	−44.2513**	−368.3387**
		(18.6714)	(169.6521)
Within 800 m of a newly opened mall	18 to 24	−43.7666**	−345.4633**
		(19.0746)	(165.56)
	24 to 30	−27.5194*	−286.108*
		(16.8163)	(149.4308)
	30 to 36	−35.6179**	−404.2203**
		(16.1486)	(151.4146)
Observations		359,068	359,068
R-squared		0.0852	0.0466
Distances to MRT, CBD, and expressways		Yes	Yes
Car Ownership Rate		Yes	Yes
Year-Month FE		Yes	Yes
Postal Sector FE		Yes	Yes

Note 1: Standard errors clustered at the postal sector level are reported in parentheses.
Note 2: ***p < 0.01, **p < 0.05, *p < 0.1.
Note 3: The regression models do include the variables between 800 and 1500 m but results are omitted for better illustration.

Appendix 3. Summary Statistics for Subsamples in Table 5

	(1) Subsample of residential buildings in the bottom third of the distance to downtown		(2) Subsample of residential buildings in the top third of the distance to downtown		(3) Subsample of public housing buildings		(4) Subsample of condominium buildings	
Number of observations	120,396		121,966		273,842		85,226	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Taxi trips per 1 month *originated from each residential building*								
Total number of taxi trips	378.620	666.43	230.838	391.065	217.955	440.623	345.378	549.237
Total number of trips to retail destination	128.251	216.159	60.893	101.456	69.587	142.178	98.832	158.356
Share of the number of retail trips out of total trips	0.330	0.117	0.265	0.148	0.3	0.174	0.28	0.098
Total distance traveled to retail destination (km)	899.274	1521.142	729.764	1145.307	603.342	1149.095	990.430	1411.893
Share of retail trip distance out of total trip distance	0.269	0.115	0.276	0.156	0.275	0.175	0.280	0.104
Total number of trips to mall	26.18	40.994	14.09	22.436	16.730	31.232	21.271	30.596
Share of the number of mall trips out of total retail trips	0.251	0.218	0.289	0.331	0.281	0.283	0.284	0.301
Location characteristics								
Distance to the closest subway station (m)	1811.415	976.571	1622.027	1016.478	2126.788	1224.548	1448.897	713.109
Distance to the CBD (m)	6313.575	2106.223	16,652.14	1600.2	9483.382	4010.054	2370.55	4561.135
Distance to the closest expressway (m)	860.059	675.789	1237.028	1032.362	999.89	723.894	1004.017	839.592
Other characteristics								
Car ownership per population (proxied from survey)	0.165	0.131	0.125	0.074	0.201	0.131	0.101	0.04
Within 800 m of a shopping mall opened between 2009 and 2012	0.017	0.128	0.011	0.104	0.009	0.094	0.021	0.142
Between 800 and 1500 m of a newly opened mall	0.107	0.309	0.072	0.258	0.09	0.286	0.116	0.32

Note 1: The unit of analysis is the monthly taxi trip record originated from each residential building.

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