The Impact of the Cost of Car Ownership on the Housing Price Gradient in Singapore

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December 26th, 2016

Abstract

This paper examines the extent to which a change in the cost of car ownership affects the house price gradient with respect to distance from the central business district (CBD). Theory suggests that if the cost of car ownership increases, then people will shift towards other modes of transportation, thus reducing house prices farther away from the CBD. However, the cost of car ownership is likely to be endogenous and correlated with various unobserved factors that also contribute to a change in the house price gradient. To obtain causal effects, we exploit a unique feature of Singapore's car registration process. All cars in Singapore must have a Certificate of Entitlement (COE), but the number available is restricted based on the traffic concerns of the government and are allocated through a competitive bidding process. We use the number of COEs available each quarter as an instrument for the price of a COE, as the quota is likely to be correlated with the price of the COE but not the price of housing at various distances from the city center. We find that when the price of a COE increases, the price of housing closer to the city center increases, suggesting that increases in the price of a car cause individuals to increase their willingness to pay to locate closer to the CBD.

Key words: Vehicle ownership restraint; Certificate of Entitlement (COE) price; COE quota; housing price gradient
JEL Codes: D1; R3; R4; R5

1. Introduction

The price distribution of housing throughout a city has been of interest to urban economists since the advent of the monocentric city model (Alonso, 1964; Muth, 1969; Mills, 1967; Wheaton, 1974; Brueckner, 1987). The monocentric city model argues that there are different factors that affect the price of housing relative to distance from the city center. For example, as transportation costs increase, individuals will be willing to pay more to locate closer to the central business district (CBD) so that they do not have to travel as far to work.[1] However, estimating the effect of transportation costs on the urban price gradient is problematic, as the costs are likely correlated with various unobserved factors that contribute to the house price gradient. To address endogeneity concerns, we examine the urban house price gradient in Singapore, as the unique nature of the car registration process allows us to obtain supply-driven, exogenous variation in the price of car ownership to identify a causal relationship.

The city-country of Singapore offers a unique opportunity to study the urban price gradient due to a key feature of its transportation policy aimed at reducing road congestion. To own a car in Singapore, like most countries, you must obtain a registration, known as a Certificate of Entitlement (COE).[2] However, unlike most countries, the government restricts the number of COEs available to curb growth of the number of cars and hence to reduce traffic. To distribute the limited number of COEs, the government allocates the registrations through a competitive on-line bidding process.[3] Therefore, the price of a COE, which is a significant portion of the price of acquiring a car in Singapore, varies over time based on the number of registrations available each auction. The high cost of obtaining a COE is one of the primary reasons that car ownership rates are so low in Singapore (Chu, 2014; 2015).

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[1] Glaeser, Kahn, and Rappaport (2008) found that the poor tend to live in cities due to reliance on public transportation, consistent with predictions from this model.

[2] Singapore also engages in congestion pricing practices. However, since we are not studying congestion specifically in this paper, we do not discuss the details of this policy. For more information on congestion pricing, see Verhoef (2002), Saleh (2007), Larsen, Pilegaard, and Van Ommeren (2008), Eliasson et al. (2009), and De Lara et al. (2013).

[3] We discuss the auction process in detail later in the paper.

We estimate the extent to which house prices throughout Singapore vary with respect to distance from the CBD as transportation costs, specifically the price of a car, change.[4] To obtain causal estimates, we use the number of COEs released by the Land Transport Authority as an exogenous, supply-driven instrument for the price of a car. The number of COEs released each auction is based on the government's desire to reduce congestion and is unlikely to be affected by the future change in house prices throughout the city. Therefore, we use the number of COEs released each quarter as an instrument for the price of a COE and hence the price of a car. Our first stage regressions support the use of the number of COEs as an instrument for the price of a COE.

Using the number of COEs allocated in a given quarter as our instrument, we examine how the price of housing varies with respect to distance from the city center as the price of a COE, and hence the price of a car, changes. To do so, we obtained proprietary information on residential property sales in Singapore from 2002Q2 to 2015Q4. To control for house-specific characteristics other than distance to the city center, we exploit a homogeneity feature of Singapore's private residential market to include "unit" specific fixed effects. This is a viable option because all units within each residential project are homogenous, with the same interior design, the same furnishings, the same major electrics, and the same outdoor facilities. In this context we have high-frequency transaction records for almost identical units in the property sales market (Baltagi and Li, 2015). This feature of the Singaporean private housing market enables us to frequently trace the change in house prices at various distances from the CBD while including "unit" (project) fixed effects.

We find that higher COE premiums are associated with higher house prices for units that are closer to the CBD. Specifically, we find that if the COE premium increases from $10,000 to $40,000, which is how much the premium increased between 2009 and 2010, the price of centrally located

[4] Glaeser and Kahn (2004) argue that the declining cost of a car in the U.S. is one of the main reasons why American cities have become so sprawled. This suggests that the price of a car is important when considering transportation costs.

housing increases by approximately 8.37%. At the same time, we find that this increase in house prices declines with distance from the CBD. For those units that are 10 kilometers away from the city center, the same increase in the COE premium is associated with only a 2.19% increase in house prices. In other words, the percent increase in the price of housing for units 10 kilometers from the CBD is approximately four times less than the price increase of centrally located housing units. This result supports the predictions of the monocentric city model, allowing for alternative modes of transportation (i.e. private or public transportation). Our findings are consistent across various specifications, such as using different time trends as controls, using different definitions of the CBD, restricting the sample to only those units that are sufficiently far from a subway stop that residents are more likely to rely on cars for transportation, and to including different types of COE registrations.

Our results are consistent with the literature on the "negative rent gradient," which has been discussed extensively in the urban economics literature.[5] To estimate the effect of transportation costs on house prices at various distances from the CBD, prior studies have mainly considered time costs and gasoline prices. For instance, Coulson and Engle (1987) and Blake (2016) found that increases in gas prices increased the price of centrally located houses. Anas and Chu (1984) reported that the probability of living in a given neighborhood is decreasing in average travel time and travel cost to the city center. Cortright (2008) showed that house prices fell more in ZIP codes with longer commutes after an increase in gas prices. Molloy and Shan (2010) found that an increase in gasoline prices led to a decrease in new home construction in locations with longer commutes, but found no significant effect on existing house prices. Accounting for both monetary and time costs, Tse and Chan (2003) found evidence of a negative rent gradient using data from Hong Kong, versus the other studies mentioned which focused on the U.S.

[5] Arnott and MacKinnon (1978) also examined these price gradients, allowing for congestion.

We contribute to this literature by examining the effect of a change in the acquisition costs of car ownership on the house price gradient. In the U.S., the car ownership rate is high and usage costs, both monetary and non-monetary, are generally larger than the acquisition costs (Ferdous et al, 2010). However, in jurisdictions where the government institutes traffic control policies, such as Shanghai and Singapore, the per-capita car ownership rate is low (12 cars per 100 people in Singapore) and the cost of acquiring a car is substantially larger than the usage costs (Chu, 2014; 2015). This implies that the acquisition cost of car ownership may affect the housing price gradient through its impact on the demand for a car versus other types of transportation. We expand upon the literature by examining how changes in the acquisition costs of a car affect the price of housing at various locations throughout the city using a model with two modes of transportation. Furthermore, our identification strategy is novel within the urban price gradient literature as we use an exogenous change in the supply of car registrations, which is unlikely to be correlated with other demand factors influencing the house price gradient, as an instrument for the price of a car. While the use of such supply side instruments is becoming increasingly popular in the economics literature, we are the first to utilize this type of instrumental variables approach to estimate the urban price gradient.[6]

The rest of the paper will proceed as follows. Section 2 discusses the institutional details of vehicle ownership and the housing market in Singapore. Our theoretical model is presented in Section 3. Section 4 outlines our identification strategy and we discuss our data in Section 5. Section 6 describes our main results and we show a series of robustness checks in Section 7. We conclude in Section 8.

2. Vehicle Ownership and Residential Property Market in Singapore

[6] These supply-side instruments have become increasing popular since Saiz (2010) created estimates of the elasticity of supply for MSAs in the U.S. These elasticity estimates have been used in the literature to address demand-related endogeneity issues, including Mian and Sufi (2011, 2013) and Cvijanović (2014) who use this measure to explain variation in house price appreciation across MSAs.

2.1 Vehicle Ownership and Costs in Singapore

According to the Economist Intelligence Unit (EIU)'s report in 2016, Singapore retained the title of the most expensive city in the world for the third consecutive year, and the price of owning a car is one of the factors that make the city-country so expensive. The Singaporean government has implemented several policies to reduce traffic and congestion, specifically congestion pricing[7] and vehicle ownership restraint. As a result of these policies, the costs of owning a vehicle in Singapore are extremely high and subsequently the car ownership rate is low (Chu, 2014; 2015).

To curb the growth of the vehicular population, a vehicle quota system was introduced by the Singaporean government in May 1990 via the Certificate of Entitlement (COE) scheme. Vehicle owners must obtain a COE to purchase a car, but there are a limited number of these registrations available. Therefore, obtaining a COE is conditional on making a successful bid when buying a car. A COE is valid for ten years and individuals have the option to renew at the end of the term but will have to pay a significantly higher road tax premium and obtain a new COE at the current market price.[8] COEs are distributed via five categories of vehicles, and households primarily obtain COEs for their personal cars from categories A and B, but sometimes through category E as this is an open category.[9]

The number of COEs available, known as the COE quota, is determined by the Singaporean government based on three components: the number of vehicles de-registered, the allowable growth rate

[7] While congestion pricing is in effect in Singapore, we do not discuss it in detail as it is not the focus of our analysis. For more information, see Agarwal, Koo, and Sing (2015) and http://www.lta.gov.sg/content/ltaweb/en/roads-and-motoring/managing-traffic-and-congestion/electronic-road-pricing-erp.html.

[8] When the COE for a vehicle is about to expire, the owner can renew it by paying a Prevailing Quota Premium (PQP). There are two options for COE Renewal: (1) revalidate the COE for another 10-year period by paying the PQP; (2) revalidate their COE for another 5-year period by paying half the PQP. For motorcycles and cars, there is no limit to how many times you can renew the COE so long as the COE is renewed for 10 years. However, there will be road tax surcharge applied for vehicles over 10 years old. Details can be found at https://www.lta.gov.sg/content/ltaweb/en/roads-and-motoring/owning-a-vehicle/costs-of-owning-a-vehicle/tax-structure-for-cars.html.

[9] Category A refers to cars up to 1,600cc and maximum power output not exceeding 97kW, Category B refers to cars above 1,600cc or maximum power output above 97kW, Category C refers to goods vehicles and buses, Category D refers to motorcycles, and Category E can be used for any type of vehicle.

as determined by the government, and adjustments to account for changes in the vehicle population.[10] The auction for a COE is held through an online, open-bid process and has been conducted over a three day period, twice a month since April 2002. The number of successful bidders is limited by the number of COEs available in each category in that auction. The price of the COE is increased over the bidding period until the number of bids is less than or equal to the quota for that auction. All successful bidders in the vehicle category pay the same premium, the minimum amount needed to have a successful bid in that auction, regardless of the bid made.[11]

Kochhan et al. (2014) estimate that the total cost, net of the resale value, of a new mid-range car over a seven-year operation period in Singapore is 150,001 Singapore Dollars (SGD) (see Table A2 for the details of this example), with an acquisition cost of 122,144 SGD, an operating costs of 61,530 SGD, and a resale value of 33,673 SGD.[12] In the case that Kochhan et al. (2014) discuss, the COE premium was 63,630 SGD, which was the average 2012 COE bidding results, and accounted for 52.1% of the acquisition cost and 34.6% of the combined acquisition and operating costs. Note that the total operating costs over a seven-year period for a mid-range car is estimated to be less than the price of a COE. This further highlights the importance of considering the impact of the acquisition costs of a personal vehicle in jurisdictions where the government institutes traffic control policies.

2.2 The Residential Property Market in Singapore

Residential properties in Singapore are grouped into three categories: private non-landed properties (including private apartments and condominiums), private landed properties, and public housing, locally

[10] For specific details on the allowable growth rate set, see https://www.mot.gov.sg/About-MOT/Land-Transport/Motoring/Vehicle-Ownership/.

[11] For more information on the auction process, see http://www.lta.gov.sg/content/ltaweb/en/roads-and-motoring/owning-a-vehicle/vehicle-quota-system/certificate-of-entitlement-coe.html. For an example of the bid process, see Appendix Table A1.

[12] Acquisition costs include open market value (OMV), customs duty, goods and services tax, a registration fee, an additional registration fee (ARF), a carbon emission-based vehicle scheme (CEVS), the COE price, and the retailer margin.

known as Housing and Development Board (HDB) flats. Private landed properties are those properties where the owner owns the title to the land. Private non-landed properties are leased from the government through either a 99-year lease or a 999-year lease. HDB flats are low-income properties that are heavily subsidized by the Singaporean government.

For our analysis, we restrict our sample to the private non-landed residential market. We make this restriction for several reasons. First, private residential housing is likely to be affected by any market force that impacts the price of housing, unlike HDB flats which are heavily subsidized by the government. While HDB flats make up the largest portion of the overall housing market in Singapore, approximately 85% of Singaporeans live in HDB flats according to the 2012/13 General Households Expenditure Survey (HES),[13] we exclude these units due to the high subsidy received when purchasing a HDB unit as well as other policies that restrict the demand and supply of these properties.[14]

In addition, compared to other market segments, private non-landed housing units are very homogenous within each residential project. This provides an opportunity to explore price variation of hedonically adjusted units that are essentially the "same." In Singapore, it is uncommon to find repeatedly transacted units that would allow us to explore price variation of the *same unit* over time (Liang, Phillips, and Yu, 2015).[15] As such, it is important to match hedonic characteristics to track price changes of *matched units* over time. Private non-landed housing units within the same housing project are very homogenous in terms of the attributes of the units (Baltagi and Li, 2015).[16] This feature allows us to track the price change of almost identical units in the same project.

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[13] The HES collects detailed information on the expenditures of households in Singapore. HES 2012/13 was the tenth in the series conducted by the Singapore Department of Statistics from October 2012 to September 2013.

[14] For more information on the policies and the nature of the subsidy for HDB housing flats in Singapore, see: https://lkyspp.nus.edu.sg/wp-content/uploads/2014/11/Public-Housing-in-Singapore.pdf

[15] This is especially true for landed private properties. These units make up a very small portion of the market, less than 5%, and are not frequently transacted. Given that we do not have many repeat sales of comparable properties for this segment of the market, we exclude the landed market from our analysis.

[16] Guntermann, Liu, and Nowak (2016) also argue that nearby properties are likely to have similar attributes in the U.S. and a nearest neighbor model can be used to increase the number of observations in a repeat sales model.

3. Theoretical Model

Consider first the standard downward sloping bid-rent function from the monocentric city model, as shown in Figure 1. Many factors may cause this bid-rent function to shift, including a change in the cost of purchasing a car. If the cost of acquiring a car changes, there will be a parallel shift in the bid-rent function due to the change in the fixed costs of car ownership. For example, suppose that the purchase price of a car decreases, then this would cause a parallel shift outwards as indicated by the arrow in Figure 1.

However, the model in Figure 1 assumes cars are the only means of transportation. In many cases, like in Singapore, alternative modes of transportation (i.e. the subway or bus) are popular options. Therefore, individuals who live the closest to the city center, where the subway system is the most extensive, do not need a car and will be willing to pay more for housing. Those individuals farther from the CBD, where public transportation is not as extensive and amenities are not as nearby, may not be willing to spend as much on housing because they are more likely to need to purchase a car for daily transportation.[17] Therefore, when there are two modes of transportation we will have two bid-rent functions, as shown in Figure 2, and the price of housing at various distances from the CBD will be determined by the outer envelope of the two bid-rents.

Now, suppose that we see the same decrease in the price of acquiring a car that shifts the bid-rent function for private transportation outwards. In this situation, we see that there will be a change in the portion of individuals who rely on public versus private transportation. Specifically, those individuals who live at a distance between X^1 and X^2 from the city center will switch from using public

[17] Independent of the intention to drive to work, which in the standard assumption of the monocentric city model, individuals may also use cars for other types of trips, such as shopping or taking the kids to school. This will also affect the willingness to pay for a car at various points in the city. As transportation is needed to access amenities, a car may make these other errands easier especially in more distant areas where amenities are more likely to be scattered.

transportation to car ownership. Given this change in the mode of transportation used by some residents, we have a new outer envelope of the bid-rent function and hence will observe a change in both the level and slope of the observed house prices throughout the city.

4. Identification Strategy

We estimate how changes in the price of a car, driven by variation in the cost of a COE, affect the price of housing. Furthermore, we consider how this effect varies based on the distance of the housing project from the CBD to estimate the house price gradient. To do so, we start with the following specification:

$$P_{i,t} = \beta_1 COEP_t + \beta_2 DD_i \times COEP_t + \beta_3 PPI_t + \gamma_i + u_{i,t} \quad (1)$$

where the dependent variable, $P_{i,t}$, is the median area-adjusted house price in housing project i in quarter t. $COEP_t$ is the average COE premium in quarter t. We focus on COEs in categories A and B to calculate $COEP_t$ based on the quarterly COE premium weighted by the quarterly COE quota in each category.[18] DD_i represents the distance (in kilometers) between project i and the city center, which we define as the Raffles Place MRT station.[19] We also include the price index for the national non-landed private housing market, PPI_t, to control for the national trend in house prices.[20] Individual project fixed effects, γ_i, are included to control for project-specific characteristics that could affect the price of housing, including the amenities in the unit as well as the distance to the city center. We include

[18] Categories A and B are the primary categories for personal vehicles. As a robustness check, we include Category E which can be used for any type of vehicle.
[19] The Raffles Place MRT stop is considered the CBD in Singapore because it is directly beneath the center of the financial district . As a robustness check, we use the City Hall MRT stop as the city center, which is considered the closest to the political center of Singapore.
[20] For more information on the creation of house price indices, see Bailey, Muth, and Nourse (1963) and Case and Shiller (1987, 1988).

different time trend controls across specifications, such as a yearly time trend, year-by-quarter fixed effects, and a planning-area specific linear time trend.[21]

If we estimate equation (1) using OLS, β_1 captures the overall price response of residential properties with respect to changes in the price of the COE (also known as the COE premium). β_2 captures the house price response with respect to changes in the COE premium relative to a given project's distance from the CBD. This coefficient is an estimate of the urban price gradient, where the effect of the COE premium on house prices varies based on how far the unit is from the CBD.

However, there may be reverse causality present which would cause OLS estimates to be biased. For example, it is likely that housing farther away from the CBD and cars are complementary goods, as individuals with farther commutes are more likely to rely on personal vehicles for transportation.[22] Therefore, if the price of housing farther from the CBD increases due to an unobserved local shock, then this would decrease the demand for personal vehicles and drive down COE premiums. Since both of these effects are expected to have a negative relationship, our estimated average effect will be somewhere in between these two slopes, which suggests that we could have an upward or downward bias, depending on which effect is stronger.[23]

[21] There are 55 urban planning areas in Singapore, spanning five regions. Each planning area has a population of about 150,000 people and is served by a town center and several neighborhood commercial/shopping centers. More details can be found at http://www.ura.gov.sg/uramaps/?config=config_preopen.xml&preopen=Planning Boundaries&pbIndex=1.

[22] Based on data released by the Department of Statistics in Singapore, the proportion of resident working persons aged 15 years and over using a car to commute to work is the lowest in CBD area. This proportion generally increases as the distance to CBD increases, except for three spikes in car usage rate in areas concentrated with high income residents living in private condos and landed properties. For more information, see https://www.singstat.gov.sg/docs/default-source/default-document-library/publications/publications_and_papers/cop2010/census_2010_release3/cop2010sr3.pdf

[23] Specifically, we argue that housing prices for units farther away from the CBD can be negatively explained by COE premiums, $P_{far} = -aCOEP + u_1$, where $a > 0$. However, due to potential reverse causality issues, the following causation may also exist: $COEP = -bP_{far} + u_2$, where $b > 0$. In identifying the first equation, we may suffer from an omitted variable bias where the sign of the bias depends on $COV(COEP, u_1)$. Note that $COEP = -b(-aCOEP + u_1) + u_2$. We have $COEP = \frac{b}{ab-1}u_1 + \frac{1}{1-ab}u_2$, where $COV(COEP, u_1) > 0$ if $a > \frac{1}{b}$ and $COV(COEP, u_1) < 0$ if $a < \frac{1}{b}$. That is, the estimated coefficient of -a will be biased upwards (less negative) if the slope of the key equation is steeper and is biased downwards (more negative) if the slope of the key equation is flatter.

To address this concern and obtain causal effects, we instrument for the COE premium using the number of COEs available (also known as the COE quota), announced by the Land Transport Authority. The COE quota measures the supply of COEs in a given quarter, which is likely to be correlated with the price of the COE. However, the COEs are allocated by the government based on concerns about congestion and traffic in Singapore from past statistics, not expected house price appreciation throughout the city-country.[24] Therefore, we believe that the COE quota is a valid instrument for the COE premium.

To show that the price of the COE and the COE quota are correlated, in Figure 3 we plot the relationship between the COE premium and quota for vehicles in categories A, B, and E. As we see in this figure, these variables are highly negatively correlated, suggesting that as the number of COEs available increases, the COE premium decreases. We therefore can use the COE quota ($COEQ_t$) as an instrument for the COE premium ($COEP_t$), where we will use $COEQ_t$ and $DD_i \times COEQ_t$ to instrument for $COEP_t$ and $DD_i \times COEP_t$ in equation (1).

5. Data

To conduct our analysis, we rely on three datasets. The first dataset is transaction-level price data for all private residential transactions in Singapore from the Real Estate Information System (REALIS) maintained by the Urban Redevelopment Authority of Singapore (URA).[25] The REALIS database provides proprietary information on the universe of all residential property sales since January 1, 1995.[26] The data contains information on the transaction date, transaction price, unit attributes (project identity,

[24] One possible concern may be that traffic is a disamentiy, and since traffic tends to be concentrated in the CBD in many cities there may be a problem with our instrument. However, unlike most American and European cities, the Singaporean government is cognizant of traffic related issues and has implemented various policies to curb traffic congestion. The COE quota system and congestion pricing have been especially effective in ensuring good traffic conditions in Singapore. For more information on what has been done by the government in Singapore to curb congestion, see https://www.lta.gov.sg/content/ltaweb/en/roads-and-motoring/managing-traffic-and-congestion.html.
[25] https://spring.ura.gov.sg/lad/ore/login/index.cfm
[26] Sales are logged with the Singapore Land Authority (SLA) by the purchasers' lawyers shortly after the property is sold.

building block, floor level, and living area), and project attributes (project size, location by postal district, completion date, and land title).

We aggregate the house price data to the project-quarter level. To do so, we compute the median floor-area-adjusted transaction price for all the units transacted within the same project in that quarter.[27] As discussed above, there are not many repeated house sales in Singapore. Therefore, we rely on the area-adjusted median price within a project to determine the average sale price of a unit within the building, as the units within the same project are very homogenous. We exclude transactions that took place under an en bloc sales (collective sales) agreement as they are not conducted in a standard market and thus may bias our results.[28]

The second dataset we utilize contains the COE bidding results from April 2002 to December 2015, which is publicly available from the Land Transport Authority.[29] This data contains the COE quota each auction, the number of successful bids, the number of bids received, and the COE premium for each vehicle category in each auction. To calculate the quarterly COE premium, we weight the COE premium in categories A and B by the number of successful bids in each category in each auction. We then take the average of all auctions that happened in a quarter to obtain the quarterly COE premium. The quarterly COE quota is calculated in the same manner.

The third dataset we use is the distance from each property to the city center, obtained from MapInfo, a GIS software developer. We first match the postal code of each building in the REALIS dataset with the postal code in MapInfo, and from this we obtain the distance from each building to the

[27] To calculate the area-adjusted price, we first divide the transaction price by its corresponding floor area. We then take the median of the area-adjusted price among all the transactions within a quarter for a particular project. We only keep records of projects that have at least three transactions each quarter to reduce the amount of noise in our estimates.
[28] En bloc sales refer to the sale of all the units within a housing development to a single party or a consortium/joint venture. The price of housing bought through an en bloc sale is usually higher than the market price.
[29] https://www.lta.gov.sg/content/dam/ltaweb/corp/PublicationsResearch/files/FactsandFigures/COE_Result_2005_2009.pdf and http://www.lta.gov.sg/content/dam/ltaweb/corp/PublicationsResearch/files/FactsandFigures/COE_Result_2010_2013.pdf

141 MRT stations in Singapore.[30] We calculate the distance from each project to the Raffles Place MRT station to determine the distance from each building to the CBD.[31] If a project has multiple buildings, we use the average distance from each building within a project to the city center as the distance measure for that project.[32] We also gather information on the distance to the closest MRT station. In one of our robustness checks, we restrict the sample to those properties that are more than 1,000 meters away from the closest MRT station. To determine the closest MRT station, we base our calculations on all 2015 proposed and existing stations. We use both proposed and existing MRT stations as there may be anticipatory effects of future subway stops on house prices. We combine these three data sets to create a panel data set of 2,543 projects from 2002Q2 to 2015Q4.

Table 1 provides summary statistics for the area-adjusted median house price, the COE premium, the COE quota, and the distance to the city center for the 43,073 observations in our sample. The average COE premium over our sample period is 38,826 SGD, which is almost four times the average of the area-adjusted median house price of 10,677 SGD. We see in Table 1 that there is a large amount of variation in the COE premiums during our sample period, ranging from 3,590 SGD to 83,425 SGD. The quarterly COE quota ranges from 3,894 to 24,503, with an average of 12,525 registrations. The average distance to the city center is approximately 7,000 meters if we use Raffles Place MRT station as the city center and is 6,470 meters if we use the City Hall MRT stop as the city center. Some properties are only 380 meters from the CBD, while the farthest units are 18,580 meters away.

6. Main Results

We begin our analysis by estimating equation (1), which gives us the effect of the COE price on the housing price gradient using a simple OLS regression. Results are presented in Table 2. Column (1)

[30] Since Singapore is a small city-country, each building has a unique postal code.
[31] As a robustness check, we use the City Hall MRT station as the city center, using the same type of distance calculation.
[32] The buildings within a project are relatively close to one another, so distance does not vary much from building to building.

provides our baseline specification, which includes project fixed effects. In column (2) we include the property index for the private non-landed housing market to capture the market trend in house prices. In column (3) we add an annual time trend. Column (4) includes year-quarter fixed effects, and column (5) adds a planning area[33] specific linear time trend. T-statistics are reported in parentheses below each coefficient, which are calculated using standard errors clustered at the project level.

Looking at Table 2, we see that a higher COE premium is associated with a higher median price in a given private residential project. We also see that as the distance from the CBD increases, a higher COE premium is associated with a lower private non-landed housing price. This is consistent with results in the literature regarding the urban price gradient – that as the price of transportation (i.e. a car) increases, individuals will pay more for housing closer to the CBD (Coulson and Engle, 1987; Anas and Chu, 1984; Cortright, 2008; Molloy and Shan, 2010; Bradley, 2016).

However, as discussed above, there may be a reverse causality issue that would cause OLS estimates to be biased. To address this endogeneity issue and obtain unbiased coefficient estimates, we instrument for the COE premium with the COE quota released each quarter. Our first stage IV results are presented in Table 3a. As we see in this table, the signs are as expected and are highly significant, indicating that we have a valid instrument.

Table 3b presents the second stage coefficients from our IV regression. Across all specifications, we find consistent evidence of an urban price gradient. Note that these coefficients are larger than the OLS estimates produced in Table 2, indicating that the OLS coefficients have an upward bias. Based on the coefficient estimates in column (3) and the mean of the area-adjusted median house price, we find that if the COE premium increases by 30,000 SGD, which is how much the premium increased between 2009 and 2010, then the price of centrally located private non-landed housing increases by approximately 8.37%. However, for units that are 10 kilometers from the city center, the same increase

[33] There are 30 planning areas are in our sample, out of the 55 in Singapore.

in the COE premium is associated with only a 2.19% increase in house prices. In other words, the percent increase in the price of units 10 kilometers from the CBD is approximately four times less than the price increase of centrally located housing. The impact on the housing price gradient is consistent even after we adopt the richest controls in column (5), although in this case the fixed effects make us unable to identify the relationship between COE premium and house prices independent of distance.

7. Robustness Checks

To show that the results presented above are robust, we perform three additional tests.[34] First, in Table 4 we restrict our sample to projects that are more than 1,000 meters from the closest MRT station,[35] as these are the areas where individuals are the most likely to use a car for transportation. As we see in Table 4, when we restrict our sample to these units, we continue to find that as the price of a COE increases, individuals are willing to pay more for housing that is located closer to the city center.

In Table 5 we use an alternative definition of the CBD. In our initial regressions, we used the distance to the Raffles Place MRT station to calculate the distance between a housing project and the CBD because Raffles Place is the subway stop that is directly beneath the financial center of Singapore. To show that our results are not driven by our definition of the CBD, in Table 5 we use the City Hall MRT station as the city center to calculate our distance measures. The City Hall MRT stop is located close to Parliament and the Supreme Court and is considered to be the center of political activity in Singapore. As we see in Table 5, our results are robust to this alternative definition of the CBD.

Finally, in Table 6 we include vehicle categories A, B, and E to calculate the COE premium and quota. The majority of private vehicles use a COE from category A or B, as these categories are for

[34] Our sample changes slightly with each robustness check. We show in Appendix Tables A3, A4, and A5 the first stage results for each model. In all three models, our instrument continues to be strong.
[35] More than a 1,000 meter walking distance is often considered far and inconvenient to access public transportation hubs given the hot and humid weather conditions of Singapore.

personal vehicles. However, category E may be used for any type of vehicle, so it is possible that the price of a COE from category E is relevant. As we see in Table 6, our results are consistent when we include this category of COEs. Overall, our results are consistent across various specifications, suggesting that as the price of a COE increases, residents living in the non-landed, private property housing market in Singapore are willing to pay more to live closer to the CBD.

8. Conclusions

We estimate the house price gradient with regards to changes in the price of transportation, specifically the price of registering a car, in Singapore. Simply estimating the effect of the price of a car on house prices may suffer from a reverse causality issue, specifically if car ownership and housing farther from the city center are complementary goods. To address this concern, we focus on Singapore, which has a unique feature to its car registration process that allows us to obtain causal estimates. The Singaporean government, in an effort to curb traffic and congestion, requires all cars to have a Certificate of Entitlement (COE), which is a significant portion of the cost of acquiring a car and is one of the reasons the car ownership rate is low in Singapore. These COE registrations are rationed by the government based on growth and traffic concerns. Therefore, the COE quota is likely to be correlated with the COE price, and hence the price of a car, but uncorrelated with the price of housing, allowing us to use an instrumental variables strategy to obtain causal effects.

When we estimate the effect of the COE premium on house prices, we find that as the price of a COE increases, the price of housing farther from the CBD decreases. This is consistent with the predictions from the monocentric city model that allows for two modes of transportation. As the price of transportation increases, individuals will be willing to pay more to locate closer to the CBD, hence increasing house prices closer to the city center. We find that if the price of a COE increases by 30,000

SGD, then the percent increase in the price of housing for units 10 kilometers from the CBD is approximately four times less than the price increase of centrally located housing units. Overall, our findings suggest that the urban house price gradient responses to changes in the price of purchasing a car in Singapore. Policy makers need to be cognizant of the unintended consequences that traffic control policies, such as restricting the number of car registrations, have on residential house prices.

Acknowledgements

We would like to thank David Albouy, Yanying Chen, Adam Nowak and seminar participants at the University of Alabama, the University of Kentucky, Florida Gulf Coast University, the ERSA annual meetings, the WEAI conference, and the AREUEA International meetings for their comments and suggestions. All remaining errors are our own.

References

Agarwal, S., Koo, K.M. and Sing, T.F., 2015. Impact of electronic road pricing on real estate prices in Singapore. *Journal of Urban Economics*, 90, pp.50-59.

Alonso, William. 1964. Location and land use. Harvard University Press.

Anas, A. and Chu, C., 1984. Discrete choice models and the housing price and travel to work elasticities of location demand. *Journal of Urban Economics*, 15(1), pp.107-123.

Arnott, R., MacKinnon, J.G., 1978. Market and shadow land rents with congestion. *American Economic Review* 68, 588 – 600.

Bailey, M.J., Muth, R.F. and Nourse, H.O., 1963. A regression method for real estate price index construction. *Journal of the American Statistical Association*, 58(304), pp.933-942.

Baltagi, B.H. and Li, J., 2015. Cointegration of matched home purchase and rental price indexes – Evidence from Singapore. *Regional Science and Urban Economics*, 55, pp. 80-88.

Blake, T.B. 2016. Commuting costs and geographic sorting in the housing market. *Real Estate Economics*.

Brueckner, Jan K. 1987. The structure of urban equilibria: a unified treatment of the Muth-Mills model. In Handbook of Regional and Urban Economics. Vol II ed E.S. Mills. North-Holland.

Case, K.E. and Shiller, R.J., 1987. Prices of single family homes since 1970: New indexes for four cities (No. w2393). National Bureau of Economic Research.

Case, K.E. and Shiller, R.J., 1988. The efficiency of the market for single-family homes (No. w2506). National Bureau of Economic Research.

Coulson, N.E. and Engle, R.F., 1987. Transportation costs and the rent gradient. *Journal of Urban Economics*, 21(3), pp.287-297.

Chu, S., 2014. Mitigating supply and price volatilities in Singapore's vehicle quota system. *Transportation* 41 (5), 1119 – 1134.

Chu, S., 2015. Car restraint policies and mileage in Singapore. *Transportation Research Part A: Policy and Practice*, 77, pp.404-412.

Cortright, J. 2008. Driven to the Brink: How the Gas Price Spike Popped the Housing Bubble and Devalued the Suburbs. CEOs for Cities White Paper.

Cvijanović, D., 2014. Real Estate Prices and Firm Capital Structure. *Review of Financial Studies* 27, 2690-2735

De Lara, M.D., Palma, A.D., Kilani, M., Piperno, S., 2013. Congestion pricing and long term urban form: application to Paris region. *Regional Science and Urban Economics* 43, 282 – 295.

Eliasson, J., Hultkrantz, L., Rosqvist, L.S., 2009. Editorial. *Transportation Research Part A: Policy and Practice*, 43 (3), 237 – 239.

Ferdous, N., Pinjari, A. R., Bhat, C. R., & Pendyala, R. M., 2010. A comprehensive analysis of household transportation expenditures relative to other goods and services: an application to United States consumer expenditure data. *Transportation*, 37(3), 363-390.

Glaeser, E. and Kahn, M. (2004) "Sprawl and Urban Growth," in J. Vernon Henderson and Jacques-Fran cois Thisse (eds.), *Handbook of Urban and Regional Economics, Vol. IV*. New York: North-Holland, pp. 2481–2527.

Glaeser, E.L., Kahn, M.E. and Rappaport, J., 2008. Why do the poor live in cities? The role of public transportation. *Journal of Urban Economics*, 63(1), pp.1-24.

Guntermann, K.L., Liu, C., and Nowak, A.D., 2016. Price Indexes for Short Horizons, Thin Markets or Smaller Cities. *Journal of Real Estate Research* 38(1), pp. 93-127.

Larsen, M.M., Pilegaard, N. and Van Ommeren, J., 2008. Congestion and residential moving behaviour. *Regional Science and Urban Economics* 38(4), pp.378-387.

Jiang, L., Phillips, P.C.B., Yu, J., 2015. New methodology for constructing real estate price indices applied to the Singapore residential market. Journal of Banking & Finance 61, Supplement 2, S121-S131

Kochhan, R., Lim, J., Knackfuß, S., Gleyzes, D. and Lienkamp, M., 2014. Total Cost of Ownership and Willingness-to-Pay for Private Mobility in Singapore. In Sustainable Automotive Technologies 2013 (pp. 251-261). Springer International Publishing.

Mian, A., Sufi, A., 2011. House Prices, Home Equity-Based Borrowing, and the US Household Leverage Crisis. *American Economic Review* 101, 2132-56

Mian, A., Rao, K., Sufi, A., 2013. Household Balance Sheets, Consumption, and the Economic Slump. *The Quarterly Journal of Economics*, 1687-1726

Mills, Edwin S. 1967. An aggregative model of resource allocation in a Metropolitan area. *American Economic Review* 57: 197-210.

Molloy, R. and Shan, H., 2013. The Effect of Gasoline Prices on Household Location. *Review of Economics and Statistics*, 95(4), pp.1212-1221.

Muth, Richiard F. 1969. Cities and housing. University of Chicago Press.

Saleh, W., 2007. Success and failure of travel demand management: is congestion charging the way forward? *Transportation Research Part A: Policy and Practice*, 41 (7), 611 – 614.

Saiz, A., 2010. The geographic determinants of housing supply. *Quarterly Journal of Economics* 125(3), 1253-1296.

Small, K.A., Verhoef, E.T., 2007. The economics of urban transportation Routledge, London and New York.

Tse, C.Y, Chan, A.W.H. 2003. Estimating the community cost and commuting time property price gradients. *Regional Science and Urban Economics*, 33(6), 745-767.

Verhoef, E.T., 2002. Second-best congestion pricing in general static transportation networks with elastic demand. *Regional Science and Urban Economics* 32, 281 – 310.

Wheaton, William C. 1974. A comparative static analysis of urban spatial structure. *Journal of Economic Theory* 9: 223-237.

Figure 1: Bid Rent Function with One Mode of Transportation

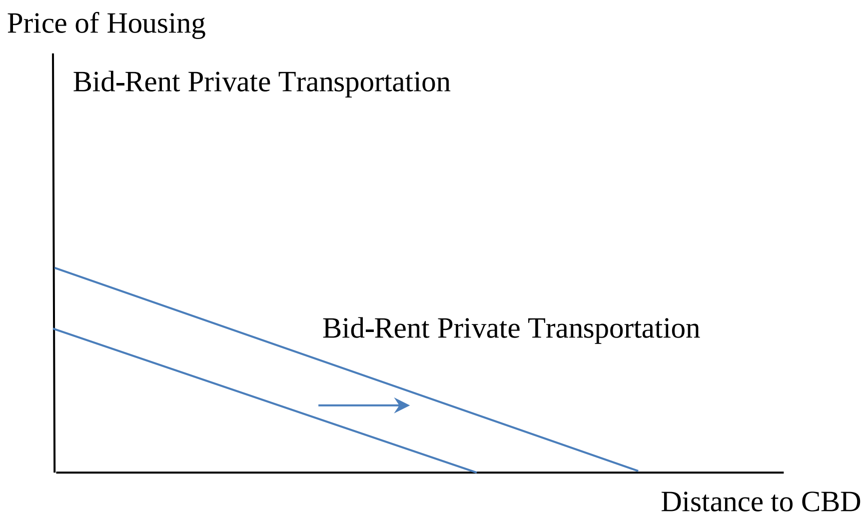


Figure 2: Bid Rent Function with Two Modes of Transportation

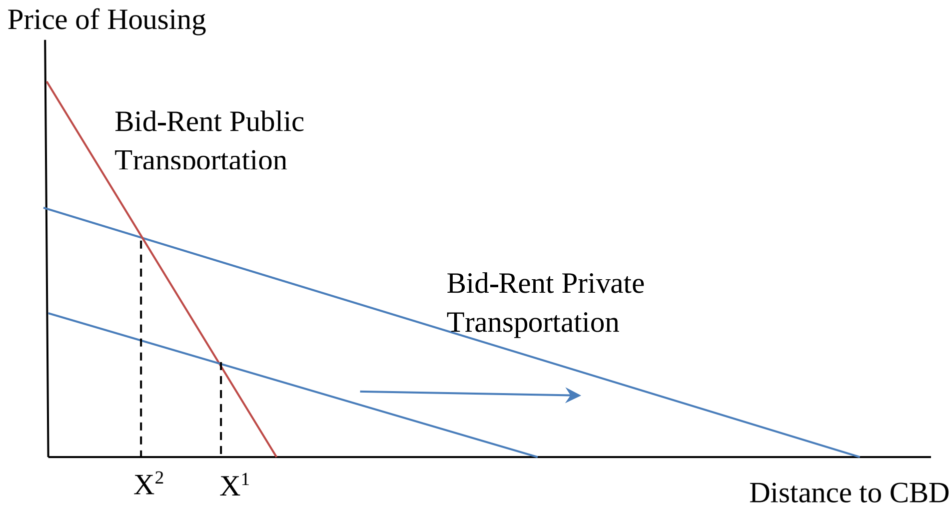
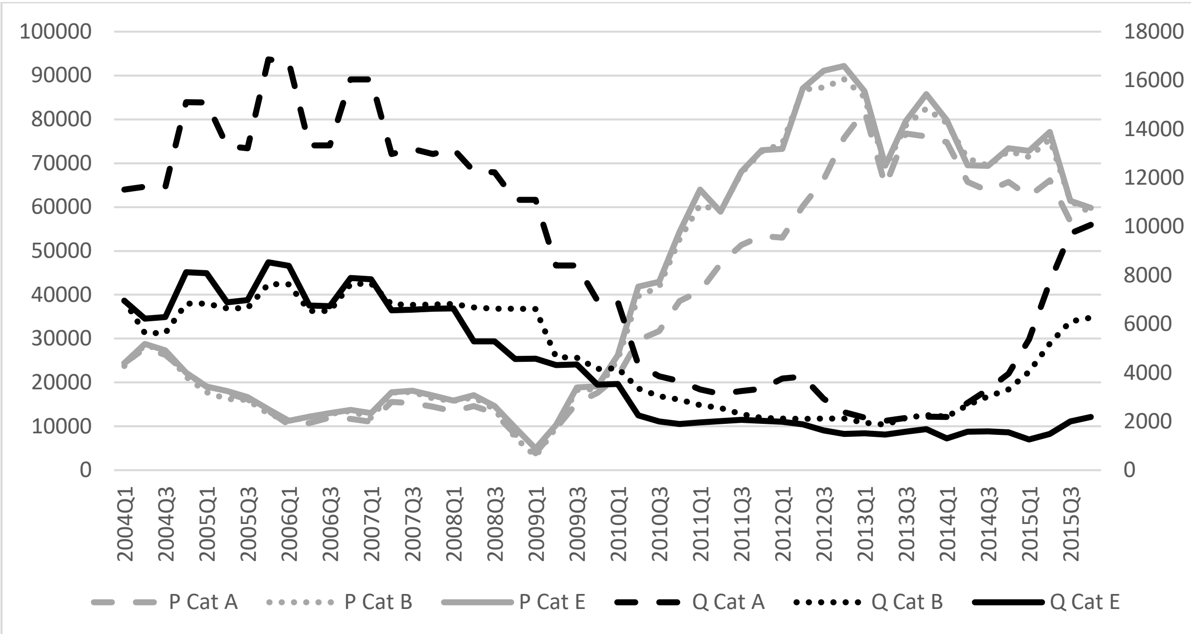


Figure 3: COE Premiums and COE Quotas



Notes: This figure presents COE premiums trends and COE quotas from 2004 quarter 1 in Singapore. The data is from http://coe.sgcharts.com/ based on Results of Bidding Exercises for Certificates of Entitlement from Land Transport Authority.

Table 1: Summary Statistics

	Observations	Mean	Std. Dev.	Min	Max
Area-adjusted Median Transaction Price[1]	43,073	10,677.39	5,742.30	1,150	73,629
COE Premium	43,073	38,826.45	24,786.63	3,589.50	83,425.49
COE Quota	43,073	12,524.66	66,77.38	3,894.00	24,503.00
Distance to Downtown Raffles Place MRT[2]	43,073	7.00	3.93	0.38	18.58
Distance to Downtown City Hall MRT[2]	43,073	6.47	3.88	0.10	17.64
Housing Price Index	43,073	118.77	24.71	79.60	148.90

[1] Area adjustment is achieved by dividing the unit transaction price by the corresponding floor area.
[2] Distance is measured in kilometers.

Table 2: OLS Regressions
Dependent Variable: Area-adjusted Median Transaction Price
(t statistics are reported in parentheses using clustered standard errors at the project level)

	(1)	(2)	(3)	(4)	(5)
COE Premium	0.0947***	0.0309***	0.0298***	-	-
	(53.77)	(17.57)	(17.40)	-	-
COE Premium × Distance to Downtown	-0.0018***	-0.0021***	-0.0022***	-0.0022***	-0.0029***
	(-10.82)	(-13.60)	(-13.64)	(-13.91)	(-10.25)
Housing Price Index	-	92.6842***	85.5108***	-	-
	-	(52.38)	(40.56)	-	-
Year Trend	NO	NO	YES	NO	NO
Year × Quarter Fixed Effects	NO	NO	NO	YES	YES
Year Trend × Planning Area	NO	NO	NO	NO	YES
Project Fixed Effects	YES	YES	YES	YES	YES
Observations	43,073	43,073	43,073	43,073	43,073
R-squared	0.450	0.699	0.700	0.712	0.789

Table 3a: IV Regressions – First Stage
(t statistics are reported in parentheses using clustered standard errors at the project level)

	(1)		(2)		(3)		(4)	(5)
	COE Premium	COE Premium × Distance to DT	COE Premium	COE Premium × Distance to DT	COE Premium	COE Premium × Distance to DT	COE Premium × Distance to DT	COE Premium × Distance to DT
COE Quota	-2.8581***	0.5720***	-2.0146***	6.6435***	-2.1075***	5.9628***	-	-
	(-163.36)	(4.84)	(-114.17)	(36.64)	(-134.24)	(36.88)	-	-
COE Quota × Distance to DT	-0.0095***	-3.0277***	-0.0051**	-2.9956***	-0.0039**	-2.9873***	-2.9591***	-2.3285***
	(-4.93)	(-148.27)	(-2.56)	(-148.68)	(-2.22)	(-161.57)	(-248.18)	(-82.77)
Housing Price Index	-	-	350.1318***	2,520.4106***	-56.2757***	-457.9634***	-	-
	-	-	(79.44)	(48.11)	(-9.93)	(-10.08)	-	-
Year Trend	NO	NO	NO	NO	YES	YES	NO	NO
Year × Quarter Fixed Effects	NO	NO	NO	NO	NO	NO	YES	YES
Year Trend × Planning Area	NO	NO	NO	NO	NO	NO	NO	YES
Project Fixed Effects	YES	YES	YES	YES	YES	YES	YES	YES
Observations	43,073	43,073	43,073	43,073	43,073	43,073	43,073	43,073
R-squared	0.640	0.648	0.698	0.693	0.732	0.720	0.916	0.986

Table 3b: IV Regressions – Second Stage
Dependent Variable: Area-adjusted Median Transaction Price
(t statistics are reported in parentheses using clustered standard errors at the project level)

	(1)	(2)	(3)	(4)	(5)
COE Premium	0.1196***	0.0447***	0.0454***	-	-
	(54.17)	(21.37)	(21.55)	-	-
COE Premium × Distance to Downtown	-0.0032***	-0.0034***	-0.0034***	-0.0034***	-0.0037***
	(-15.20)	(-17.68)	(-17.73)	(-17.98)	(-10.07)
Housing Price Index	-	88.9396***	82.3325***	-	-
	-	(47.47)	(38.26)	-	-
Year Trend	NO	NO	YES	NO	NO
Year × Quarter Fixed Effects	NO	NO	NO	YES	YES
Year Trend × Planning Area	NO	NO	NO	NO	YES
Project Fixed Effects	YES	YES	YES	YES	YES
Observations	43,073	43,073	43,073	43,073	43,073

Table 4: IV Regressions - Sample Restricted to Projects Beyond 1,000 Meters of the Closest MRT Station – Second Stage
Dependent Variable: Area-adjusted Median Transaction Price
(t statistics are reported in parentheses using clustered standard errors at the project level)

	(1)	(2)	(3)	(4)	(5)
COE Premium	0.1283***	0.0604***	0.0612***	-	-
	(26.75)	(15.52)	(15.44)	-	-
COE Premium × Distance to Downtown	-0.0041***	-0.0040***	-0.0041***	-0.0040***	-0.0035***
	(-9.90)	(-11.54)	(-11.56)	(-11.65)	(-6.03)
Housing Price Index	-	78.0234***	71.3582***	-	-
	-	(25.51)	(19.64)	-	-
Year Trend	NO	NO	YES	NO	NO
Year × Quarter Fixed Effects	NO	NO	NO	YES	YES
Year Trend × Planning Area	NO	NO	NO	NO	YES
Project Fixed Effects	YES	YES	YES	YES	YES
Observations	12,099	12,099	12,099	12,099	12,099

Table 5: IV Regressions – Using City Hall MRT Station as the City Center– Second Stage
Dependent Variable: Area-adjusted Median Transaction Price
(t statistics are reported in parentheses using clustered standard errors at the project level)

	(1)	(2)	(3)	(4)	(5)
COE Premium	0.1177***	0.0427***	0.0434***	-	-
	(55.46)	(20.96)	(21.16)	-	-
COE Premium × Distance to Downtown	-0.0032***	-0.0033***	-0.0033***	-0.0034***	-0.0036***
	(-14.83)	(-17.18)	(-17.23)	(-17.48)	(-9.75)
Housing Price Index	-	88.9397***	82.3076***	-	-
	-	(47.44)	(38.28)	-	-
Year Trend	NO	NO	YES	NO	NO
Year × Quarter Fixed Effects	NO	NO	NO	YES	YES
Year Trend × Planning Area	NO	NO	NO	NO	YES
Project Fixed Effects	YES	YES	YES	YES	YES
Observations	43,073	43,073	43,073	43,073	43,073

Table 6: IV Regressions – Using Vehicle Categories A, B, and E – Second Stage
Dependent Variable: Area-adjusted Median Transaction Price
(t statistics are reported in parentheses using clustered standard errors at the project level)

	(1)	(2)	(3)	(4)	(5)
COE Premium	0.1199***	0.0448***	0.0449***	-	-
	(53.82)	(21.79)	(21.74)	-	-
COE Premium × Distance to Downtown	-0.0032***	-0.0035***	-0.0035***	-0.0035***	-0.0036***
	(-15.25)	(-18.16)	(-18.21)	(-18.47)	(-9.92)
Housing Price Index	-	88.7099***	81.7859***	-	-
	-	(46.98)	(37.18)	-	-
Year Trend	NO	NO	YES	NO	NO
Year × Quarter Fixed Effects	NO	NO	NO	YES	YES
Year Trend × Planning Area	NO	NO	NO	NO	YES
Project Fixed Effects	YES	YES	YES	YES	YES
Observations	43,073	43,073	43,073	43,073	43,073

Appendix

Table A1: Calculation of COE Quota Premium[1]

Reserve Price	Bid Status	Remarks
S$100	Successful	Only the first 2 bids will be successful. The COE Price (or Quota Premium) will be S$71. The 3rd and 4th bids (both with reserve price of S$70) are not accepted as then the number of successful bids would exceed the COE Quota of 3. The remaining 1 unallocated COE Quota will be carried forward to the next corresponding COE bidding exercise in the following month (i.e. 2nd COE Open Bidding Exercise in month (N+1).
$88	Successful	
$70	Unsuccessful	
$70	Unsuccessful	
$41	Unsuccessful	

[1] An example: COE Quota for Category A = 3. Number of bidders = 5 with reserve prices of S$100, S$88, S$70, S$70 and S$41. Source of the example: Land Transport Authority of Si

Table A2: Cost of a New Mid-range Car with 7-year Usage in Singapore

Main Components		Singapore Dollars
	OMV (open market value)	16,000
	Customs duty	3,200
	Goods and services tax	1,344
	ARF (additional registration fee）	16,000
	Registration fee	170
	CEVS (carbon emission-based vehicle scheme)	5,000
	COE[1]	63,630
	Retailer margin	16,800
Acquisition costs	Total	122,144
Total operating costs		61,530
Resale value incl. tax refund		-33,673
Total cost		150,001
Total cost/km		1.13

Source: Kochhan, R., Lim, J., Knackfuß, S., Gleyzes, D. and Lienkamp, M., 2014. Total Cost of Ownership and Willingness-to-Pay for Private Mobility in Singapore. In Sustainable Automotive Technologies 2013 (pp. 251-261). Springer International Publishing.
[1]This is based on the average 2012 COE bidding results.

Table A3: IV Regressions – Sample Restricted to Projects Beyond 1,000 Meters of MRT Station – First Stage
(t statistics are reported in parentheses using clustered standard errors at the project level)

	(1)		(2)		(3)		(4)	(5)
	COE Premium	COE Premium × Distance to DT	COE Premium	COE Premium × Distance to DT	COE Premium	COE Premium × Distance to DT	COE Premium × Distance to DT	COE Premium × Distance to DT
COE Quota	-2.8279***	0.8060***	-1.9946***	8.3297***	-2.1041***	7.3331***	-	-
	(-70.22)	(2.73)	(-49.17)	(21.54)	(-58.91)	(21.48)	-	-
COE Quota × Distance to DT	-0.0117***	-3.0412***	-0.0086**	-3.0131***	-0.0059*	-2.9884***	-2.9375***	-2.4691***
	(-3.06)	(-80.71)	(-2.21)	(-80.02)	(-1.70)	(-87.90)	(-138.20)	(-51.86)
Housing Price Index	-	-	338.5273***	3,056.3486***	-65.1444***	-616.4223***	-	-
	-	-	(46.42)	(33.31)	(-6.51)	(-6.43)	-	-
Year Trend	NO	NO	NO	NO	YES	YES	NO	NO
Year × Quarter Fixed Effects	NO	NO	NO	NO	NO	NO	YES	YES
Year Trend × Planning Area	NO	NO	NO	NO	NO	NO	NO	YES
Project Fixed Effects	YES	YES	YES	YES	YES	YES	YES	YES
Observations	12,099	12,099	12,099	12,099	12,099	12,099	12,099	12,099
R-squared	0.648	0.654	0.704	0.702	0.737	0.731	0.949	0.991

Table A4: IV Regressions – Using City Hall MRT Station as the City Center– First Stage
(t statistics are reported in parentheses using clustered standard errors at the project level)

	(1)		(2)		(3)		(4)	(5)
	COE Premium	COE Premium × Distance to DT	COE Premium	COE Premium × Distance to DT	COE Premium	COE Premium × Distance to DT	COE Premium × Distance to DT	COE Premium × Distance to DT
COE Quota	-2.8573***	0.5204***	-2.0136***	6.1534***	-2.1072***	5.5148***	-	-
	(-170.22)	(5.14)	(-118.62)	(36.78)	(-139.09)	(36.99)	-	-
COE Quota × Distance to DT	-0.0104***	-3.0295***	-0.0056***	-2.9977***	-0.0043**	-2.9885***	-2.9600***	-2.3329***
	(-5.34)	(-156.25)	(-2.81)	(-155.85)	(-2.38)	(-168.72)	(-253.64)	(-82.66)
Housing Price Index	-	-	350.1057***	2,337.4053***	-56.2764***	-433.1928***	-	-
	-	-	(79.42)	(46.20)	(-9.93)	(-10.17)	-	-
Year Trend	NO	NO	NO	NO	YES	YES	NO	NO
Year × Quarter Fixed Effects	NO	NO	NO	NO	NO	NO	YES	YES
Year Trend × Planning Area	NO	NO	NO	NO	NO	NO	NO	YES
Project Fixed Effects	YES	YES	YES	YES	YES	YES	YES	YES
Observations	43,073	43,073	43,073	43,073	43,073	43,073	43,073	43,073
R-squared	0.640	0.649	0.698	0.692	0.732	0.719	0.908	0.985

Table A5: IV Regressions – Using Vehicle Categories A, B, and E – First Stage
(t statistics are reported in parentheses using clustered standard errors at the project level)

	(1)		(2)		(3)		(4)	(5)
	COE Premium	COE Premium × Distance to DT	COE Premium	COE Premium × Distance to DT	COE Premium	COE Premium × Distance to DT	COE Premium × Distance to DT	COE Premium × Distance to DT
COE Quota	-2.2869***	0.4787***	-1.7299***	4.4214***	-1.7400***	4.3473***	-	-
	(-166.39)	(5.41)	(-122.94)	(33.76)	(-130.62)	(34.60)	-	-
COE Quota × Distance to DT	-0.0077***	-2.4267***	-0.0042***	-2.4018***	-0.0030*	-2.3931***	-2.3713***	-1.8776***
	(-5.22)	(-161.48)	(-2.60)	(-153.83)	(-1.95)	(-157.73)	(-264.00)	(-83.79)
Housing Price Index	-	-	288.0990***	2,039.1012***	-5.4179	-97.1091**	-	-
	-	-	(67.20)	(47.35)	(-0.95)	(-2.27)	-	-
Year Trend	NO	NO	NO	NO	YES	YES	NO	NO
Year × Quarter Fixed Effects	NO	NO	NO	NO	NO	NO	YES	YES
Year Trend × Planning Area	NO	NO	NO	NO	NO	NO	NO	YES
Project Fixed Effects	YES	YES	YES	YES	YES	YES	YES	YES
Observations	43,073	43,073	43,073	43,073	43,073	43,073	43,073	43,073
R-squared	0.682	0.693	0.714	0.717	0.733	0.731	0.927	0.987