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

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**Abstract**

This paper examines the extent to which a change in the cost of car ownership may tilt the house price gradient with respect to distance from the central business district (CBD). Theory suggests that as transportation costs increase, the price of housing near the city center will increase. However, relative changes in house prices at various distances may simultaneously affect demand for, and hence the price of, private transportation, suggesting a reverse causality issue may be present. 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 COE prices increase, the price of housing closer to the city center increases, suggesting that increases in transportation costs cause individuals to increase their willingness to pay to locate closer to the CBD, consistent with the predictions of the monocentric city model.

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 get to work.[1] However, estimating the effect of transportation costs on the urban price gradient is problematic, as the price of housing at various distances may simultaneously affect the demand for private transportation (i.e. private transportation may be complementary to housing further away from the city center), and subsequently its price. To address this reverse causality concern, 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,

[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] Twice each month, there is an on-line auction where individuals can bid for a COE, where the price of the COE is determined by the lowest bid among those bids that are within the quota allocated for that auction. We discuss the auction process in detail later in the paper.

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).

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] However, there may be concerns about reverse causality if, for example, a price increase in housing further away from the city center subdues the demand for, and hence the price of, private transportation. Such a problem is likely to be present if housing units located further away from the city center and private transportation are complementary goods. To obtain causal estimates of the effect of transportation costs on the price of housing throughout the city, we use the number of COEs released by the Land Transport Authority as an exogenous, supply-driven instrument for the price of a COE. The number of COEs released in advance of each auction is based on the government's desire to reduce congestion from previously observed statistics and is unlikely to be affected by the future relative change in the price of housing at various locations throughout the city. Therefore, we use the number of COEs released each quarter as an instrument for the price of a COE.[5] 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 car ownership, 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. To the extent that all units within each residential project are homogenous, which is likely true given that all units have the same interior design, the same furnishing,

[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 a valid proxy for transportation costs.
[5] Data on the number of COEs released each period and their relative price was obtained from www.lta.gov.sg/.

the same major electrics, and the same outdoor facilities, we have high-frequency transaction records for almost identical units in the property sales market (Baltagi and Li, 2015).[6] 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 those 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 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 standard urban model. Our findings are consistent across various specifications, including 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 since Alonso (1964).[7] 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) 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

[6] Baltagi and Li (2015) focus on condos only. Apartments do not have outdoor entertainment facilities, but units within these complexes are homogenous as well, and therefore are included in our analysis.
[7] Arnott and MacKinnon (1978) also examined these price gradients, allowing for congestion.

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 the 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.

We contribute to this literature by focusing on 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 of car ownership and hence have been the focus of most previous studies (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, for example) and the cost of acquiring a car is substantially larger than the usage costs (Chu, 2014; 2015). Therefore, we expand upon this literature by examining how changes in the acquisition costs of a car affect the price of housing at various locations throughout the city. 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.[8]

[8] 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 as supply-side instruments 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.

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

## 2. Vehicle Ownership and Residential Property Market in Singapore

### 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[9] 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. COEs are distributed via five categories of vehicles, and

[9] 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 on congestion pricing in Singapore, please 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.

households primarily obtain COEs for their personal cars from categories A and B, but sometimes through category E as this is an open category.[10]

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 as determined by the government, and adjustments to account for changes in the vehicle population. 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 three day 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]

Lim 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 specific example). Of this total cost of car ownership, the acquisition cost is 122,144 SGD, the operating costs are 61,530 SGD, and the resale value is 33,673 SGD.[12] In the case that Lim et al. (2014) discuss, the COE premium was 63,630 SGD, which is based on 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.[13] 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 also highlights the importance of considering the

[10] 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 & buses, Category D refers to motorcycles, and Category E can be used for any type of vehicle.
[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 how this bid process works, 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.
[13] See Appendix Table A2 for a full breakdown of all the costs of owning a car in Singapore.

impact of acquisition cost of a personal vehicle in the 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 known as Housing and Development Board (HDB) flats. Private landed properties are those residential 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 properties that are 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[14]), we exclude these units due to the high subsidy received when purchasing a HDB unit from the government as well as other policies that restrict the demand and supply of HDB units.[15]

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

[14] The Household Expenditure Survey (HES) collects detailed information on the latest consumption expenditures of resident 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.

[15] For more information on the policies and 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

(Liang, Phillips, and Yu, 2015).[16] As such, it is important to match hedonic characteristics to track price changes of these *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).[17] This feature allows us to closely track the price change of almost identical units in the same project to explore how house prices respond to changes in the cost of car ownership.

Finally, private non-landed housing in Singapore is generally considered the high-quality sector of housing. As almost all Singaporeans enjoy a large government subsidy in their early years of homeownership to purchase an HDB flat, the demand for private non-landed housing is likely to be driven by a desire of individuals to upgrade from HDB units to higher-quality housing. Those who can afford the upgrade are relatively wealthy households. Figure 1 shows the average monthly household income per household member by dwelling type from the HES survey. Households living in private condos and apartments generally earn more than twice as much as HDB dwellers.[18] In this case, private housing dwellers are more likely to be able to afford a car and hence are more likely to take into consideration the cost of car ownership when purchasing housing. In this sense, the willingness to pay for a private housing is more likely to be subject to the cost of car ownership relative to the willingness to pay for an HDB flat.

## 3. Identification Strategy

We estimate how differences 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 may vary based on the distance of the

[16] This is especially true for the 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.

[17] 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.

[18] The average monthly income per household member living in the private housing market is 4,089 SGD, while the average monthly income per household member living in HDB flats is only 1,497 SGD.

housing project from the CBD to estimate the housing 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 initially focus on COEs in categories A and B and calculate $COEP_t$ based on the quarterly COE premium weighted by the quarterly COE quota in each category.[19] $DD_i$ represents the distance (in kilometers) between project $i$ and the city center, which we define as the Raffles Place MRT station.[20] 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.[21] Individual project fixed effects, $\gamma_i$, are included to control for project-specific characteristics that could affect the price of housing, including the amenities in the unit as well as distance to the city center. We also include 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.[22]

If we estimate equation (1) using OLS, $\beta_1$ captures the overall price response of residential properties with respect to changes in the price of the COE. Our primary variable of interest is $\beta_2$, which 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.

[19] Categories A and B are the primary categories for personal vehicles. As a robustness check, we include Category E COEs as well, which can be used for any type of vehicle.

[20] The Raffles Place MRT stop is commonly considered the CBD in Singapore because it is directly beneath the center of the financial district of Raffles Place, located in the Downtown Core area. As a robustness check, we use the City Hall MRT stop as the city center as this stop is considered the closest to the political center of Singapore.

[21] For more information on the creation of house price indices, see Bailey, Muth, and Nourse (1963) and Case and Shiller (1987, 1988).

[22] There are 55 urban planning areas in Singapore, spanning five different 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

However, there may be reverse causality present which would cause an OLS model to produce biased coefficients. For example, it is possible that housing further away from the city and cars are complementary goods, as individuals with further commutes are more likely to rely on personal vehicles for transportation. Therefore, if the price of housing further from the CBD increases, then this would decrease the demand for personal vehicles and hence 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]

To address this concern and obtain causal effects, we instrument for the COE premium using the COE quota, announced by the Land Transport Authority on a quarterly basis. The COE quota measures the supply of COEs available 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 at various distances from the CBD. 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 2 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

[23] Specifically, we argue that housing prices for units further 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.

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).

## 4. 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).[24] The REALIS database provides proprietary information on the universe of all residential property sales since January 1, 1995.[25] The data contains information on the transaction date, transaction price, unit attributes (project identity, building block, floor level, and living area), and project attributes (project size, location by postal district, completion date, and land title).[26]

We aggregate the house price data to the project-quarter level. To do so, we compute the median of the 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 floor-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. Transactions that took place under an en bloc sales (collective sales) agreement are not included in our sample as they are not conducted in a standard market and thus may bias our results.[28]

[24] https://spring.ura.gov.sg/lad/ore/login/index.cfm

[25] Sales are logged with the Singapore Land Authority (SLA) by the purchasers' lawyers within a short period of time in order to protect buyers' interest.

[26] Property ownership takes the form of a 99 year lease from the government, a 999 year lease, or freehold which means an individual owns the land. We focus only on those properties that are on land that is leased from the government.

[27] To calculate the floor-area-adjusted price, we first divide the transaction price by its corresponding floor area. We then take the median of the floor-area-adjusted price among all the transactions within a quarter for a particular project. The median floor-area-adjusted prices are, in this sense, specific to each project and quarter. We only keep records of projects that have at least three transactions during a 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.

The second dataset we use 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 number of COE permits allocated each auction (known as the COE quota), the number of successful bids, the number of bids received, and the COE premium (COE price) for categories A, B, C, D, and E in each auction. To calculate the quarterly COE premium, we first 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.[30] The quarterly COE quota is calculated in the same manner. We initially focus on categories A and B as these are the primary categories through which households obtain a COE registration for their car. As a robustness check we use categories A, B, and E, since category E is open to all types of vehicles.

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 141 MRT stations in Singapore.[31] We calculate the distance from each project to the Raffles Place MRT station to determine the distance from each building to the city center.[32] 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.[33] 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. Since new MRT lines and stations are being

[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

[30] We directly use data from http://coe.sgcharts.com/, which provides a cleaned version of results of bidding exercises for Certificates of Entitlement from Land Transport Authority.

[31] Since Singapore is a small city-country, each building has a unique postal code.

[32] As a robustness check, we use the City Hall MRT station as the city center, using the same type of distance calculation.

[33] The buildings within a project are relatively close to one another, so distance does not vary much from building to building.

built, and where these stations will be built is known, we use the 2015 proposed and existing MRT stations as the anticipatory effects of future MRT stations may affect housing 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 non-landed private housing prices, 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 during 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, ranging from 3,590 SGD to 83,425 SGD. The quarterly COE quota also 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 city center, while the farthest ones units are 18,580 meters away.

## 5. 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. These results are presented in Table 2. Column (1) 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[34] specific linear time trend. T-statistics are reported in parentheses below each coefficient, which are calculated using standard errors clustered at the project level.

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

Looking at our OLS estimates in Table 2, we see that a higher COE premium is associated with a higher median price in a given private residential project. However, 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 existing 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).

However, as discussed above, there may be a reverse causality issue that would cause OLS estimates to be biased. To address this endogeneity concern and obtain unbiased coefficient estimates, we instrument for the COE premium with the COE quota released each quarter. The COE quota is a supply side measure, controlled by the government to reduce congestion and traffic. Therefore, we expect that the price of a COE will be correlated with the COE quota, but we do not expect the quota to be affected housing prices at various distances, as the quota was created to address traffic concerns. We expect that if there are more COEs available in a given quarter, then the price of a COE premium will decrease, as suggested in Figure 2. 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), 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%.[35] However, 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%

[35] This is calculated using the mean of floor-area-adjusted median housing price at the project level as the base. Statistics are shown in Table 1. Therefore, the effect represents the marginal effect at the average price.

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 we cannot identify the relationship between COE premium and average housing price levels independent of distance.

## 6. Robustness Checks

To show that the results presented above are robust, we perform three additional tests.[36] First, in Table 4 we restrict our sample to projects that are more than 1,000 meters from the closest MRT station.[37] Singapore has an extensive subway system, which may simultaneously affect both the housing price gradient and the demand for a car. When we restrict our sample to projects that are more than 1,000 meters from an MRT station, we are removing those projects that are generally considered to be within walking distance of an MRT stop. Therefore, we are restricting our sample to those housing units where individuals are more likely to consider car usage given that they do not have close access to a public transportation hub.[38] 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 what is considered to be the financial center of Singapore. To show that our results are not driven by our definition of the CBD, in

[36] Our sample changes slightly with each robustness check. We show in Appendix Tables A 3, A4, and A5 the first stage results for each model. In all three models, our instrument continues to be strong.
[37] This includes all MRT stations that have ever been developed or are now under development in Singapore.
[38] 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.

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 at 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 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 may be relevant.[39] 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.

## 7. 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 transportation on house prices may suffer from a reverse causality issue, specifically if car ownership and housing further 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 also one of the main 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 each

[39] While it is possible to use a category E COE for personal vehicles, because category E can be used for any vehicle type it is typically the most expensive. Therefore, not many people obtain a COE from category E for their personal cars.

period 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 further from the CBD decreases. This is consistent with the standard urban model, which suggests that 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. Specifically, 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. Our results are robust when we restrict the sample to those projects that are sufficiently far from an MRT stop that it is likely individuals will rely on a car for transportation, alternative definitions of the CBD, and to including different categories of COEs to calculate the COE premium. Therefore, our findings suggest that the urban price gradient responses to changes in transportation costs 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.

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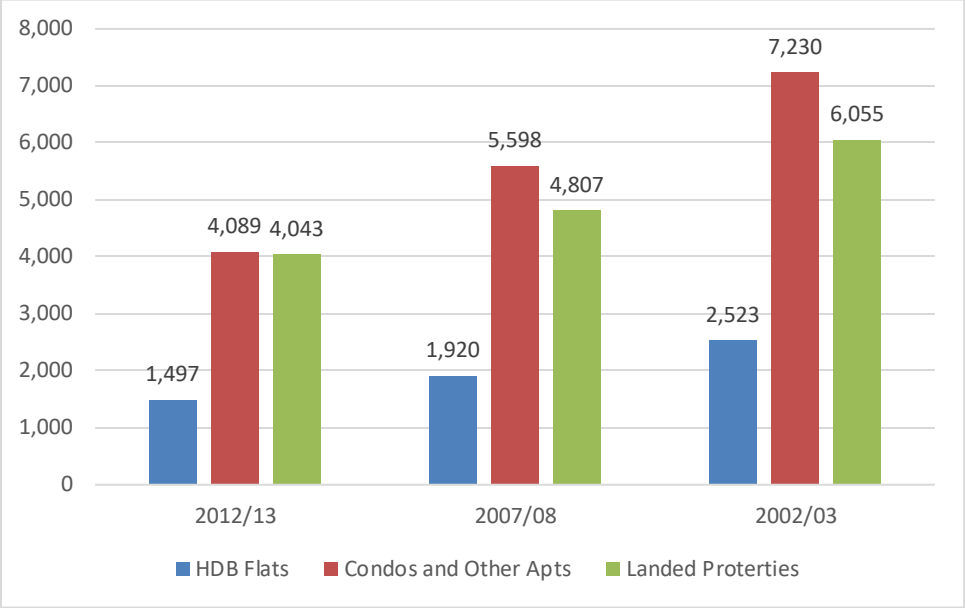
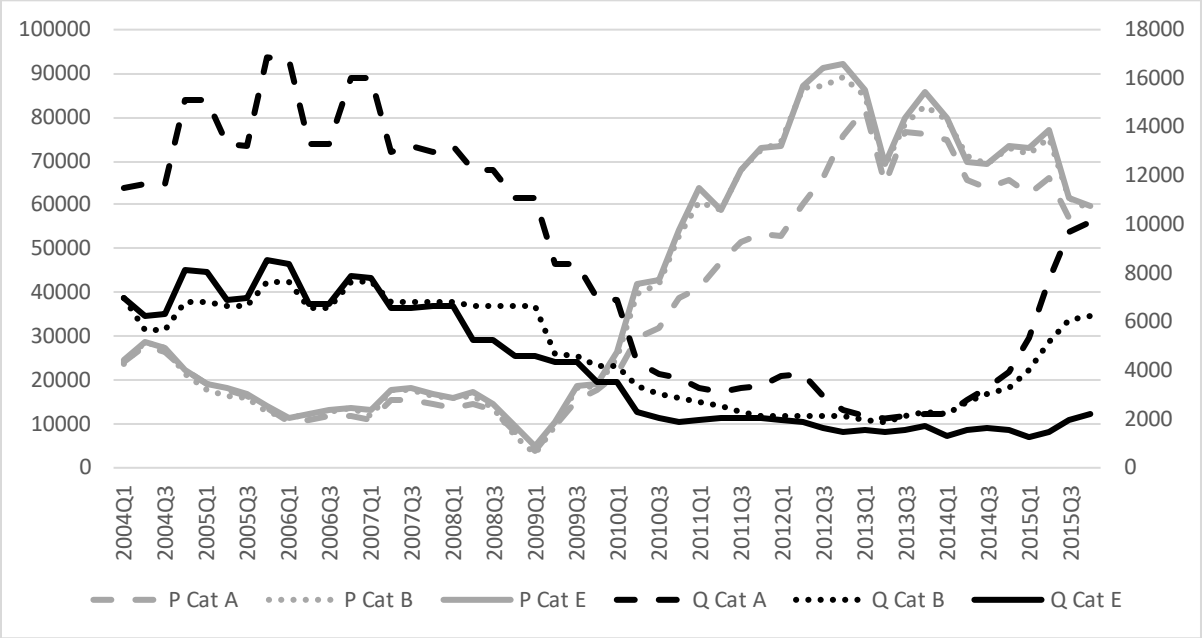
**Figure 1: Average Monthly Household Income per Household Member by Type of Dwelling**




Notes: This figure presents average monthly household income per household member by types of dwelling. The data is based on the household expenditure survey.

**Figure 2: 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 Singapore

**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 |