The Dependence of Housing Prices on Public Transportation when Households Quit Driving

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Motivation

Urban sustainability urges the shift from private to public transport mode

- Automobile sales tax, gasoline tax, and road pricing policies …
  - However, only change driving costs marginally → minimal substitution
- Certificate of Entitlement (COE) in Singapore
  - COE is the quota license for driving
  - Restrict car ownership in the first place
  - Force households to quit driving: too expensive to drive

Figure 2. Dependence of public transport demand on COE price

	1997	2004	2008	2012
Public Transport Mode Share	67%	63% ↓	59%	↑ 63%
Average COE price one year before	N/A	S$28,755	S$14,143	S$48,206

Source: Household Interview Travel Survey (HITS), Land Transport Authority, Singapore.

Motivation

A new 2017 Toyota Corolla, 1.8L (50^{th} Anniversary Special Edition)

US price: $22,591

Medium HH income: $55,755

PI ratio: 0.4

Singapore price: $77,381 (COE price in Oct 2017: $30,494)

Medium HH income: $73,834

PI ratio: 1.04

Maserati Ghibli US Pricing: $71,251

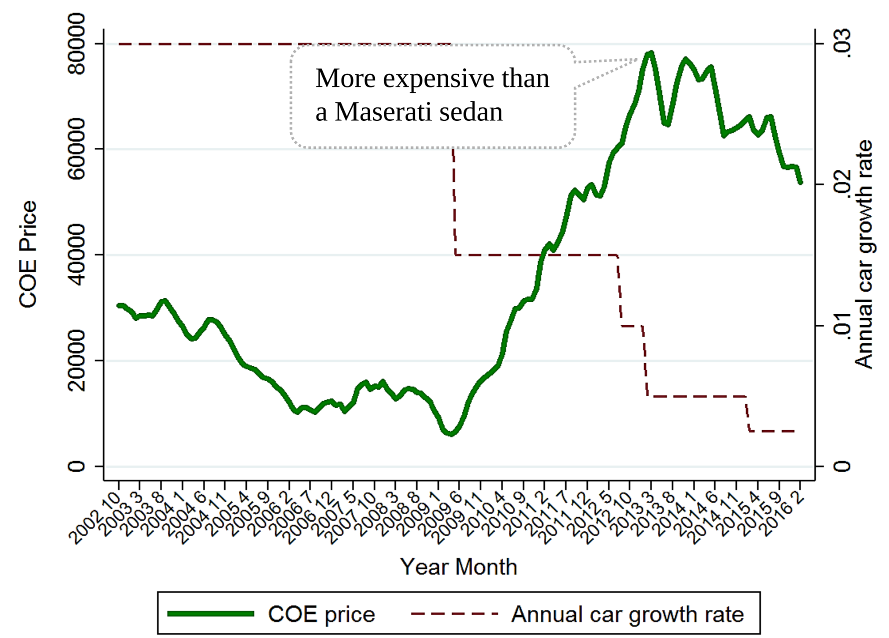
Certificate of Entitlement (COE) in Singapore

NUS National University of Singapore

COE is the quota license Singapore potential drivers must obtain

- Entitlement for 10 years
- Received via a **successful bidding** in the Vehicle Quota System (VQS) twice a month
- COE price:
  - COE **demand**: Market demand
  - COE **supply** (COE quota) is adjusted by:
    - number of deregistered cars
    - allowable annual car growth rate
    - other adjustment
- **Dramatic COE price variation** during 2002-2016, due to policy changes

Figure 1. Three-month moving average of COE price and allowable COE growth rate



Research Rationale

Research Gap

The impact of dramatic change in car acquisition costs (e.g. COE price) on travel mode choice cannot be examined in other countries

How do we test it ?

Utilizing the housing market: housing demand is the derived demand from transport advantage (e.g. Dewees, 1976; Gibbons and Machin, 2005; Billings, 2011).

- housing price comprises the implicit price for accessing to public transport (i.e., Mass Rapid Transit (MRT) in Singapore）

COE price ↑ → Demand for MRT access ↑ → Willingness-to-pay for house near MRT stations↑

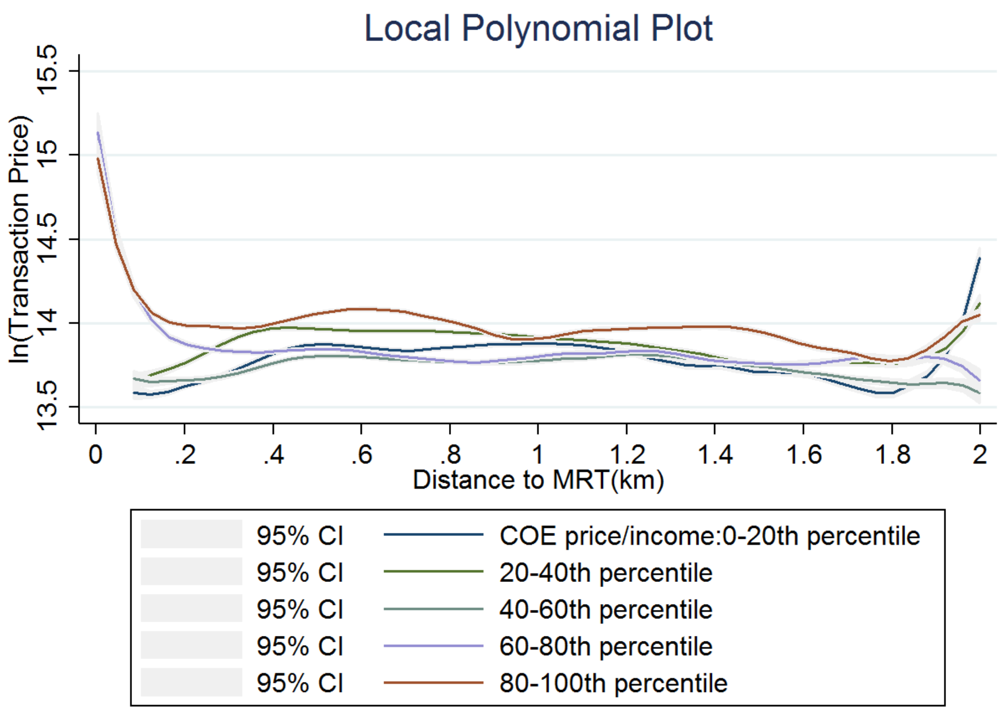
- Interesting finding: WTP responds to COE price non-constantly: convex-concave pattern ➔ Implication: COE only affects in a certain range

Data

- Singapore Private Housing Transaction (REALIS): 2002.10-2015.05
- COE Bidding Results from the Land Transport Authority of Singapore

Research Rationale

How the housing price w.r.t. distance to MRT station change with COE price?



Theoretical Framework

A monocentric-city model with two transportation modes

A Simple Monocentric City Model

A monocentric city, productions take place in CBD.

- Homogeneous households endowed with one unit of labor.
- Wage premium for one unit of labor: w

Two modes of transport: **Car** (private) and **MRT** (public)

- Car commuting cost: $\tau_a zw + \pi w$

  driving cost | car price, include COE price

- Two MRT stations: at CBD ($z = 0$) and z_m
  - Households can walk from either side of the station (τ_f) and take MRT (τ_m)
  - $\tau_f > \tau_m > \tau_a$, all the commuting costs are in terms of labor
  - MRT commuting cost: $\tau_f\,|z - z_m|w + \tau_m z_m w$

    walking cost | MRT cost

A Simple Monocentric City Model

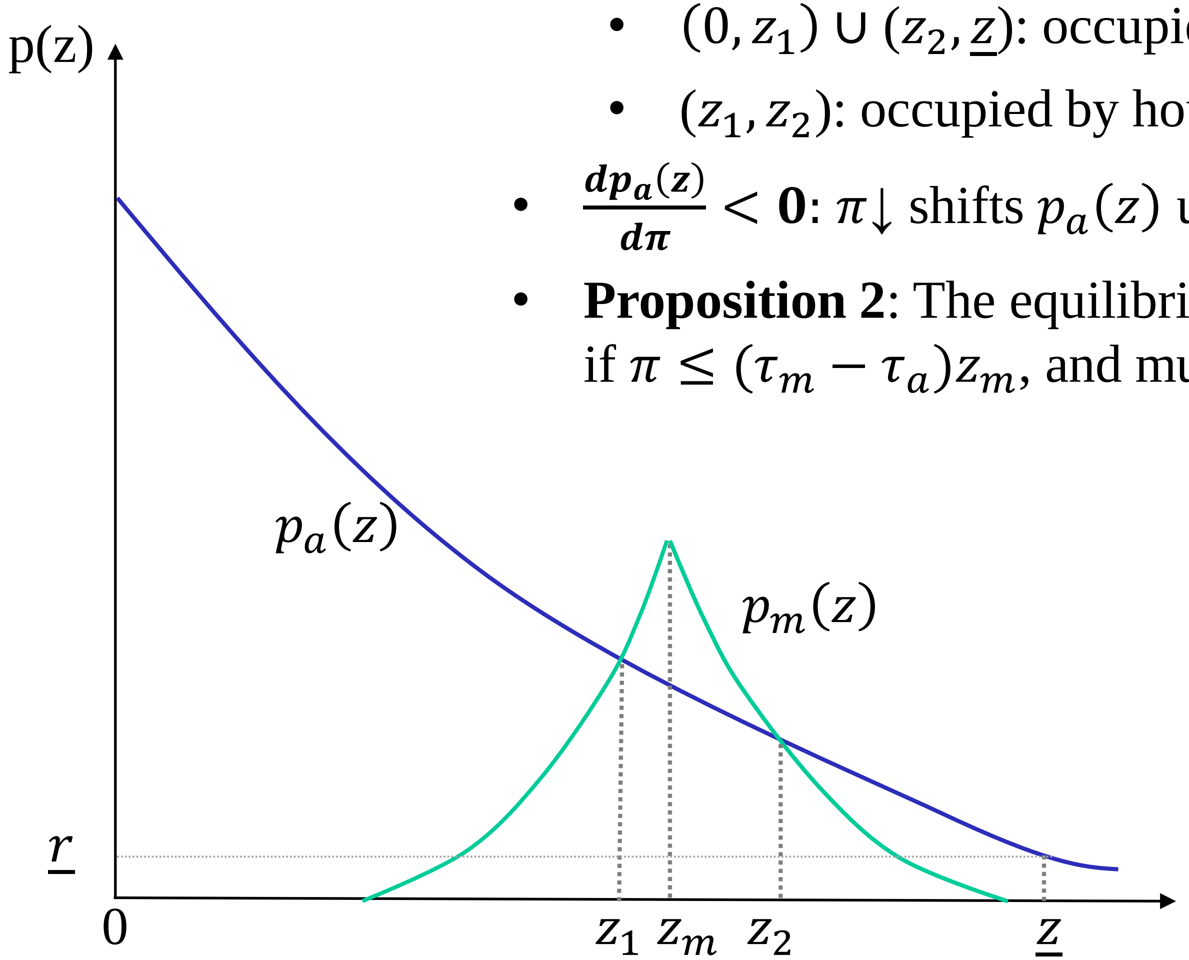
- Households:
  - Assume the preference is Cobb-Douglas, i.e.,
    $$u(c,q) = c^{1-\alpha}q^{\alpha}$$
  - For car drivers, the budget constraint:
    $$c + p_a(z)q(z) = w - \tau_a zw - \pi w$$
  - For MRT commuters, the budget constraint:
    $$c + p_m(z)q(z) = w - \tau_f\,|z - z_m|w - \tau_m z_m w$$
- No housing production without lose of generality
- City population N is exogenously given
- The agricultural land rent is $\underline{r}$

Fit this model in the theoretical literature that assumes limited accessibility to public transport

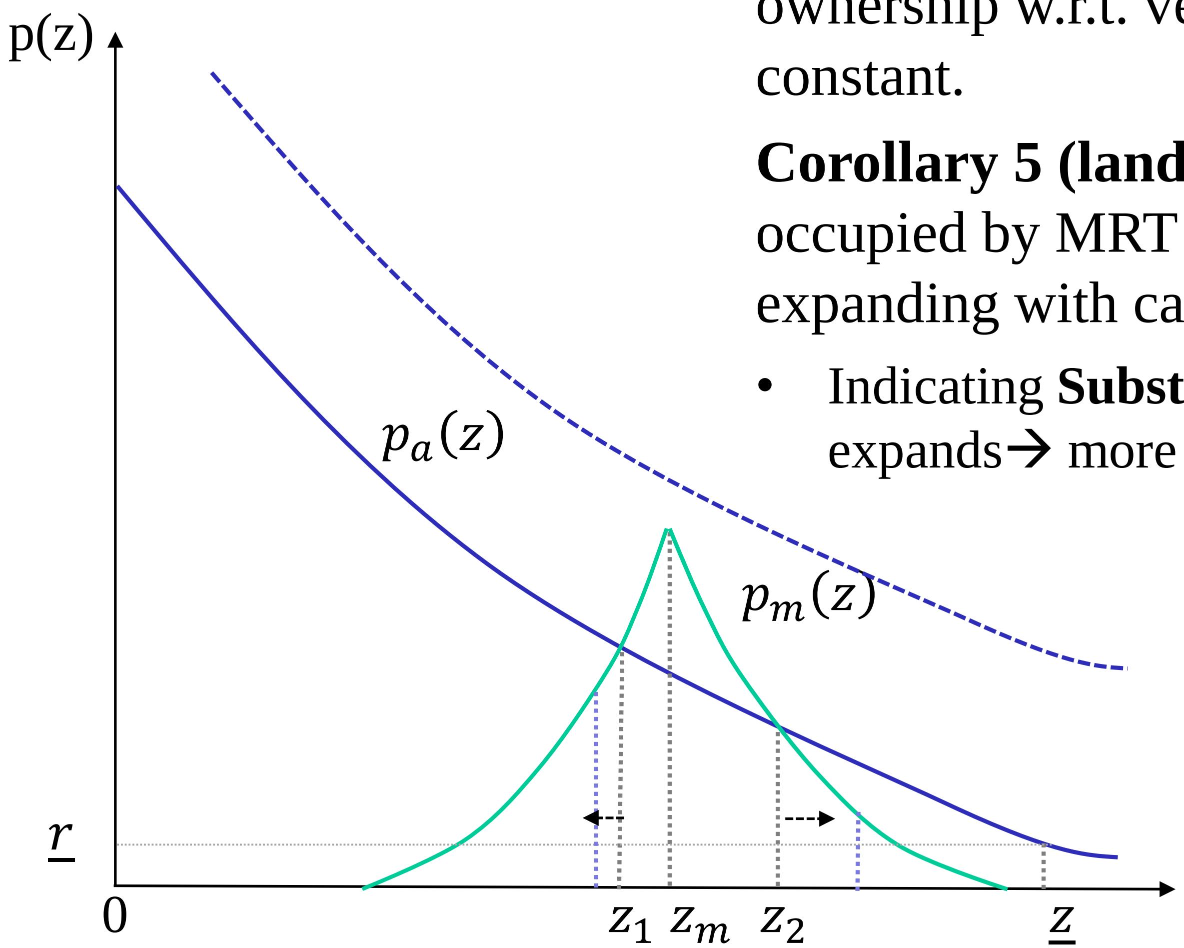
➔ a monocentric-city model with non-monotonic price gradient where the bid-rent curve peaks at the station (e.g., Anas and Moses, 1979; Baum-Snow, 2007; Duranton and Puga, 2015).

Model Solution

- Bid-rent curve $p_a(z)$ and $p_m(z)$ are both strictly convex
  - $(0, z_1) \cup (z_2, \underline{z})$: occupied by households who drive
  - (z_1, z_2): occupied by households who take MRT
- $\frac{dp_a(z)}{d\pi} < 0$: $\pi\downarrow$ shifts $p_a(z)$ upward
- **Proposition 2**: The equilibrium features total car reliance if $\pi \leq (\tau_m - \tau_a)z_m$, and multi-mode transport otherwise



Model Solution (continued.)



Proposition 4: The elasticity of car ownership w.r.t. vehicle price ($\varepsilon_{\pi}^{N_a}$) is non-constant.

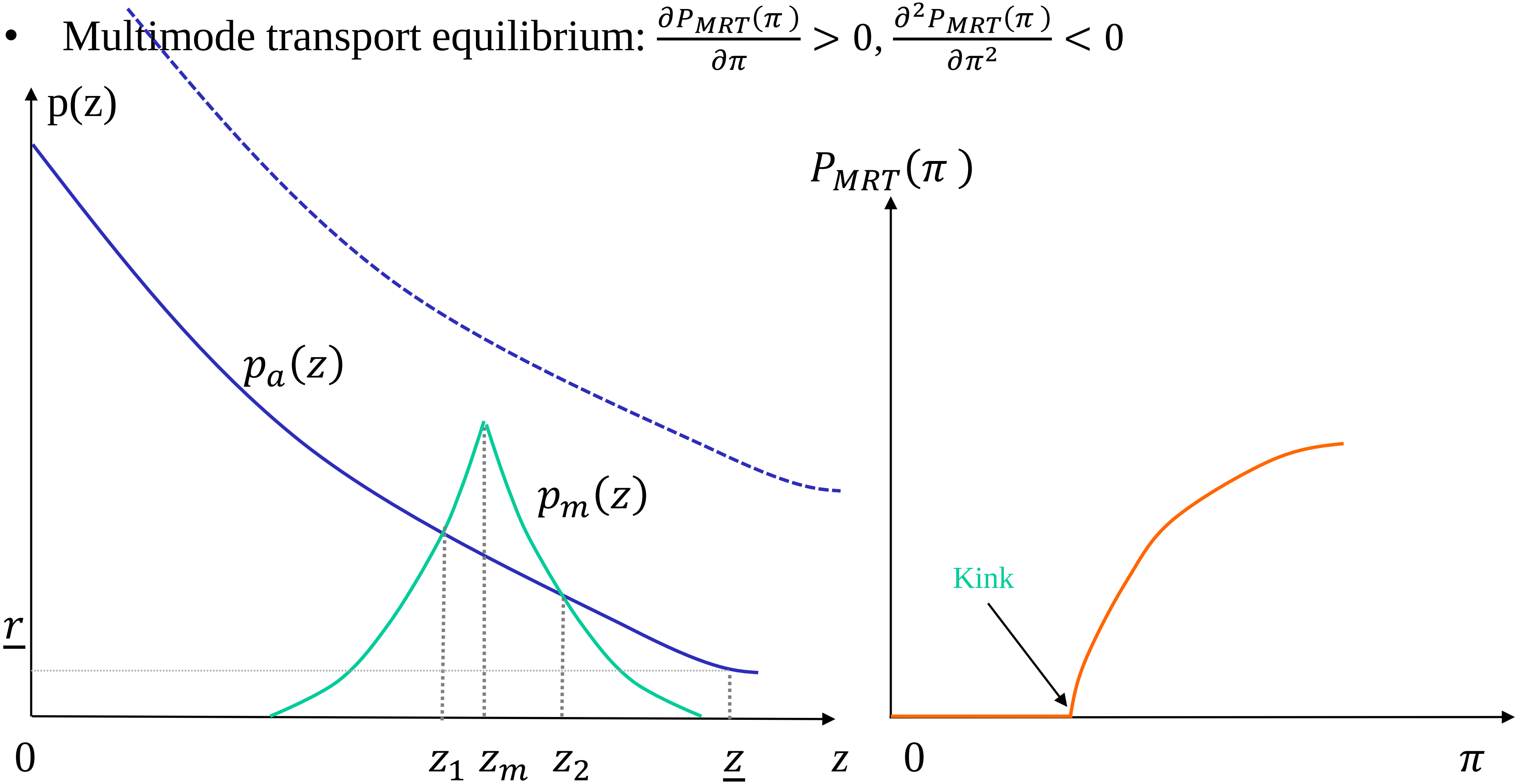
Corollary 5 (land use): The location occupied by MRT commuters $\tilde{z} = z_2 - z_1$ is expanding with car price π.

- Indicating **Substitution**: π increase, $\tilde{z}$ expands→ more people take MRT

Model Solution (continued.)

Proposition 6: The average housing premium of MRT accessibility ($P_{MRT}(\pi) = \frac{\int_{z_1}^{z_m}[p_{m,1}(z)-p_a(z)]dz}{z_m-z_1} + \frac{\int_{z_m}^{z_2}[p_{m,2}(z)-p_a(z)]dz}{z_2-z_m}$) w.r.t. π exhibits a "**convex-concave**" pattern.

- Total car reliance equilibrium: the average premium of MRT $P_{MRT}(\pi) = 0$
- Multimode transport equilibrium: $\frac{\partial P_{MRT}(\pi)}{\partial \pi} > 0$, $\frac{\partial^2 P_{MRT}(\pi)}{\partial \pi^2} < 0$



Empirical Evidences

- Corollary 5 and Proposition 6
- Method: Varying-Coefficient Model (non-parametric) and OLS

Empirical Evidence

Corollary 5: $\pi \uparrow$, locations with positive MRT proximity premium $\tilde{z}$ expands.

Proposition 6: $\pi \uparrow$, the average housing premium of MRT accessibility ($P_{MRT}(\pi) = \frac{\int_{z_1}^{z_m}[p_{m,1}(z)-p_a(z)]dz}{z_m-z_1} + \frac{\int_{z_m}^{z_2}[p_{m,2}(z)-p_a(z)]dz}{z_2-z_m}$) exhibits a "**convex-concave**" pattern.

⬇

Estimation method

- Varying-Coefficient Model (non-parametric estimation)
- OLS estimation

Non-parametric estimation

A Varying Coefficient Model (VCM)

$$ln(p_{irnt}) = U(PREINC_t)MRT_{800} + X'_{irnt}\alpha + \theta_r + \delta_t + \varepsilon_{irnt}$$

- $\ln(p_{irnt})$: logarithmic housing price for housing unit i at location r with its nearest MRT station n and transacted at time t
- X'_{irnt}: a vector of housing characteristics. θ_r: planning area fixed effect. δ_t: year-quarter fixed effect
- $U(PREINC_t)$: non-constant WTP for public transport, function of COE PI ratio. $PREINC_t$: COE price to income ratio (car affordability)

Economics behind: COE↑ → demand for public transport↑→ WTP for MRT accessibility↑→ WTP depends on COE

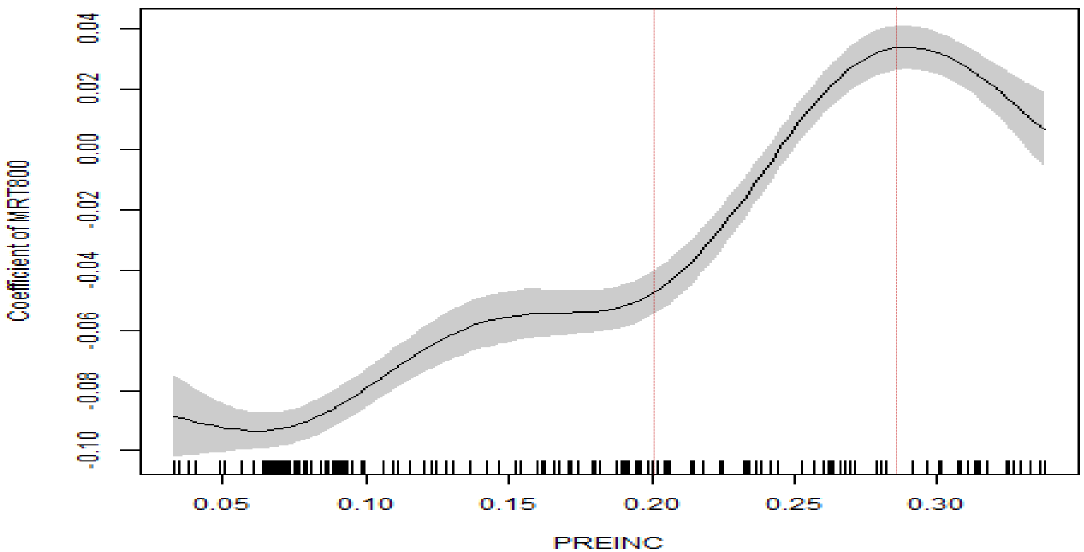


Figure 5. VCM Coefficient Plot: MRT800

→ Verification of Proposition 6

OLS estimation

An interaction approach:

$$\ln(p_{irnt}) = \beta D_{MRT} \times PREINC_t + \gamma D_{MRT} + X'_{irnt}\alpha + \theta_r + \delta_t + \varepsilon_{irnt}$$

IV: D_{MRT} × COE quota, $D_{MRT} \times Rate_t$

- D_{MRT}: MRT proximity indicator, e.g., proximity dummies or distance to MRT station.
- $Rate_t$: the allowable annual car growth rate at time *t*.
- β: captures the relationship between MRT proximity premium and COE price.

OLS estimation: Corollary 5

Table 2. MRT Ring Effect When COE Price Changes

Variables	(1) ln (Price)	(2) ln (Price)	(3) ln (Price)	(4) ln (Price)
Distance to MRT	0.0570**			
	(0.0026)			
Distance to MRT×*PREINC*	**-0.3117*** **			
	(0.0119)			
MRT500		-0.0105		-0.0967**
		(0.0038)		(0.0043)
MRT500×*PREINC*		**0.1471**		**0.4176*** **
		(0.0175)		**(0.0197)**
MRT800			-0.1129***	
			(0.0035)	
MRT800×*PREINC*			**0.5063*** **	
			(0.0161)	
MRT500_800				-0.1779***
				(0.0046)
MRT500_800×*PREINC*				**0.6899*** **
				(0.0215)
MRT800_1000				-0.0997*
				(0.0059)
MRT800_1000×*PREINC*				**0.1656**
				(0.0294)
Constant	13.5854***	13.5706***	13.5939***	13.6110***
	(0.1336)	(0.1341)	(0.1332)	(0.1299)
Housing and Subzone Characteristics	YES	YES	YES	YES
Year Quarter FE	YES	YES	YES	YES
Planning Area FE	YES	YES	YES	YES
R-squared	0.5451	0.5441	0.5458	0.5475
Observations	269,982	269,982	269,982	269,982

Table 5. IV Regression: Second Stage

Variables	(1) ln (Price)	(2) ln (Price)	(3) ln (Price)	(4) ln (Price)
Distance to MRT	0.0750***			
	(0.0282)			
Distance to MRT×*PREINC*	**-0.4179*** **			
	(0.1364)			
MRT500		-0.0783*		-0.1656***
		(0.0412)		(0.0508)
MRT500×*PREINC*		**0.5320*** **		**0.8073*** **
		(0.1838)		**(0.2214)**
MRT800			-0.1618***	
			(0.0418)	
MRT800×*PREINC*			**0.7896*** **	
			(0.1775)	
MRT500_800				-0.1919***
				(0.0504)
MRT500_800×*PREINC*				**0.7705*** **
				(0.2257)
MRT800_1000				-0.0709
				(0.0664)
MRT800_1000×*PREINC*				**-0.0224**
				(0.2935)
Constant	13.4739***	13.4651***	13.4798***	13.4956***
	(0.1581)	(0.1594)	(0.1570)	(0.1548)
Housing and Subzone Characteristics	YES	YES	YES	YES
Year-Quarter FE	YES	YES	YES	YES
Planning Area FE	YES	YES	YES	YES
R-squared	0.5449	0.5433	0.5453	0.5467
Observations	269,982	269,982	269,982	269,982
Underidentification Test (*Kleibergen-Paap Statistic*)	189.415***	275.008***	548.848***	121.416***
Weak Identification Test (*Cragg-Donald F Statistic*)	1.6e+05***	1.9e+05***	1.8e+05***	5.6e+04***
Overidentification Test (*Hansen J Statistic*)	2.463	0.093	0.972	3.816

OLS estimation

A stratification approach:

To test these two propositions, divide the sample into 10 strata according to the 10th percentile of COE PI ratio ($PREINC_t$), for each stratum:

$$ln(p_{irnt}) = \gamma D_{MRT} + X'_{irnt}\alpha + \theta_r + \delta_t + \varepsilon_{irnt}$$

- Corollary 5 (land use):

$$ln(p_{irnt}) = \beta_1 MRT_{500} + \beta_2 MRT_{500\_800} + \beta_3 MRT_{800\_1000} + X'_{irnt}\alpha + \theta_r + \delta_t + \varepsilon_{irnt}$$

  – Base group: $MRT_{>1000}$

- Proposition 6 (convex-concave housing premium):

$$ln(p_{irnt}) = \beta MRT_{800} + X'_{irnt}\alpha + \theta_r + \delta_t + \varepsilon_{irnt}$$

OLS estimation: Corollary 5

Land use :

$$ln(p_{irnt}) = \beta_1 MRT_{500} + \beta_2 MRT_{500\_800} + \beta_3 MRT_{800\_1000} + X'_{irnt}\alpha + \theta_r + \delta_t + \varepsilon_{irnt}$$

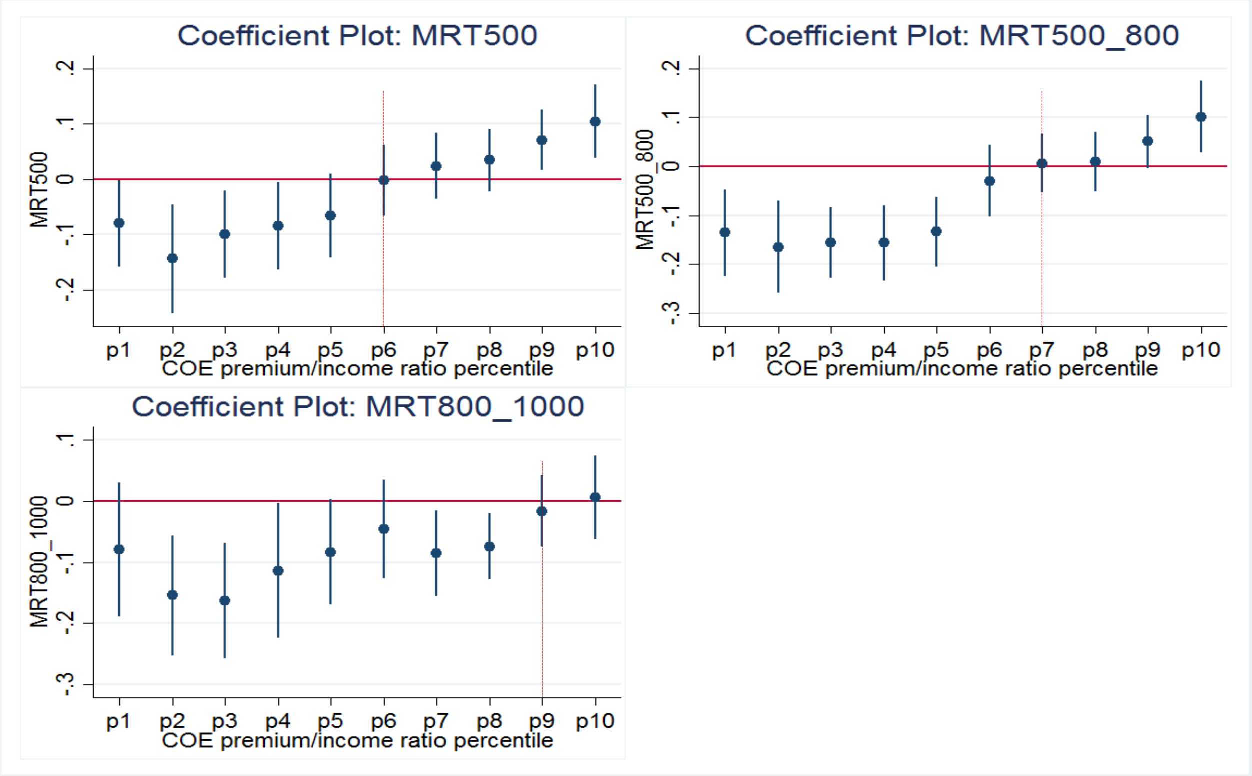


Figure 7. MRT Ring Coefficient Plot

OLS estimation: Proposition 6

Convex-concave housing premium:

$$ln(p_{irnt}) = \beta MRT_{800} + X'_{irnt}\alpha + \theta_r + \delta_t + \varepsilon_{irnt},$$ for each $PREINC_t$ stratum

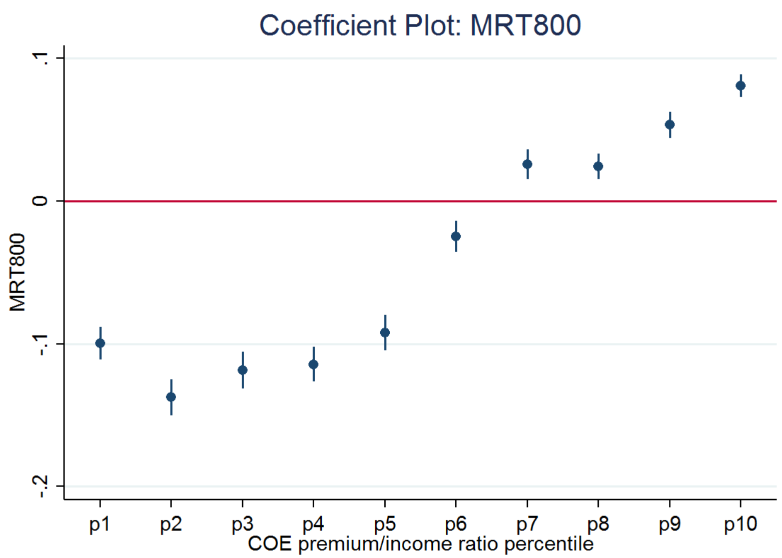


Figure 6. OLS Coefficient Plot: MRT800

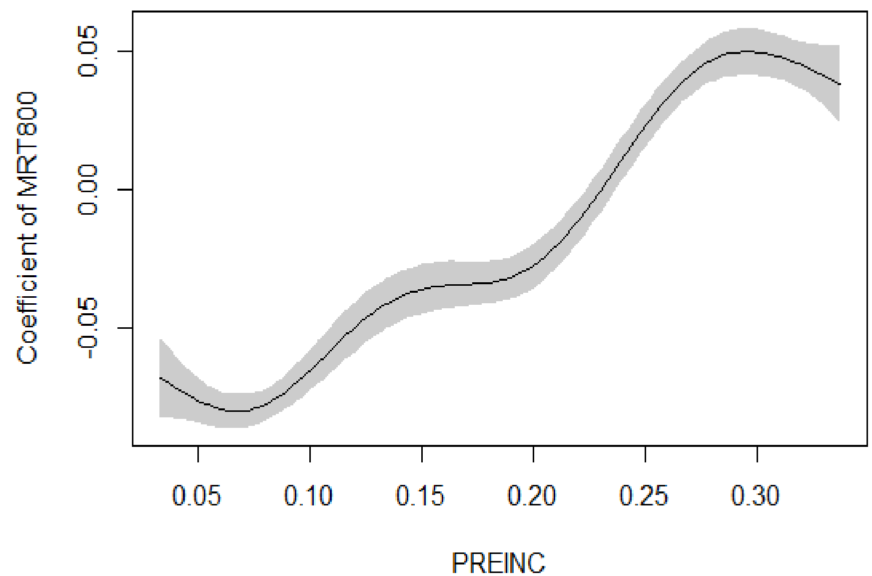


Figure 5. VCM Coefficient Plot: MRT800

Highlight of Contribution

- Convex-concave pattern: a interesting stylized fact unexplored in the literature.
  - Rationalized in a standardized monocentric city model
  - Justified by data
- Policy implication:
  - Urban sustainability urges a powerful policy to promote public transportation.
    - The effectiveness of COE policy has been justified, in contrast to low substitution in previous literature.
  - Effective substitution only happens in the middle range of COE prices
    - COE is too low: driving is affordable, ineffective substitution → explain why substitution is low in the literature with western context
    - COE is too high: drivers exists anyway, ineffective substitution

Questions are welcome!

Thank you

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