The Butterfly Effect of Transport Network Connectivity

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Presented by

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Motivation

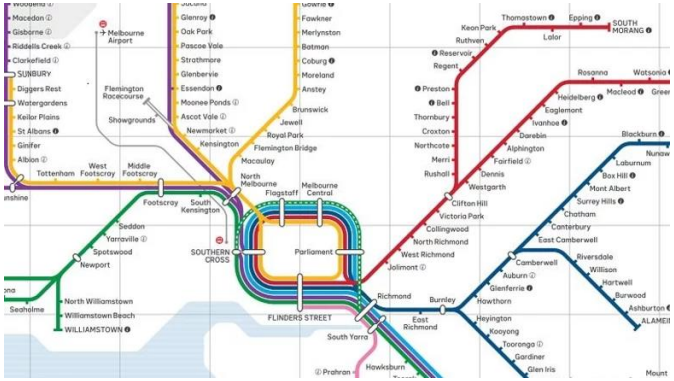
Importance of transportation is well appreciated in many fields.

- **Real estate:**
  - Dewees (1976); McMillen & McDonald (2004); Gibbons & Machin (2005); Billings (2011)
    - Hedonic pricing for real estate and benefits of public-transport (e.g., a new subway line)
    - Relationship between bid-rent and commuting cost (e.g., the monocentric city)
  - A new research possibility in RE economics and finance is the ripple effect.
- Trade, development, urban economics and regional science

However…

- Theoretical works… a parameter (e.g., NEG)
- Empirical works… a line; the proximity

In fact, transportation is a network.



Transportation is a network: Connectivity matters.

Disassociation from the network context shrouds insight in mystery.

Transportation is more about connectivity.

- Donaldson and Hornbeck (2016)
- Freeman (1979); Scott (2006); Mishra(2012)

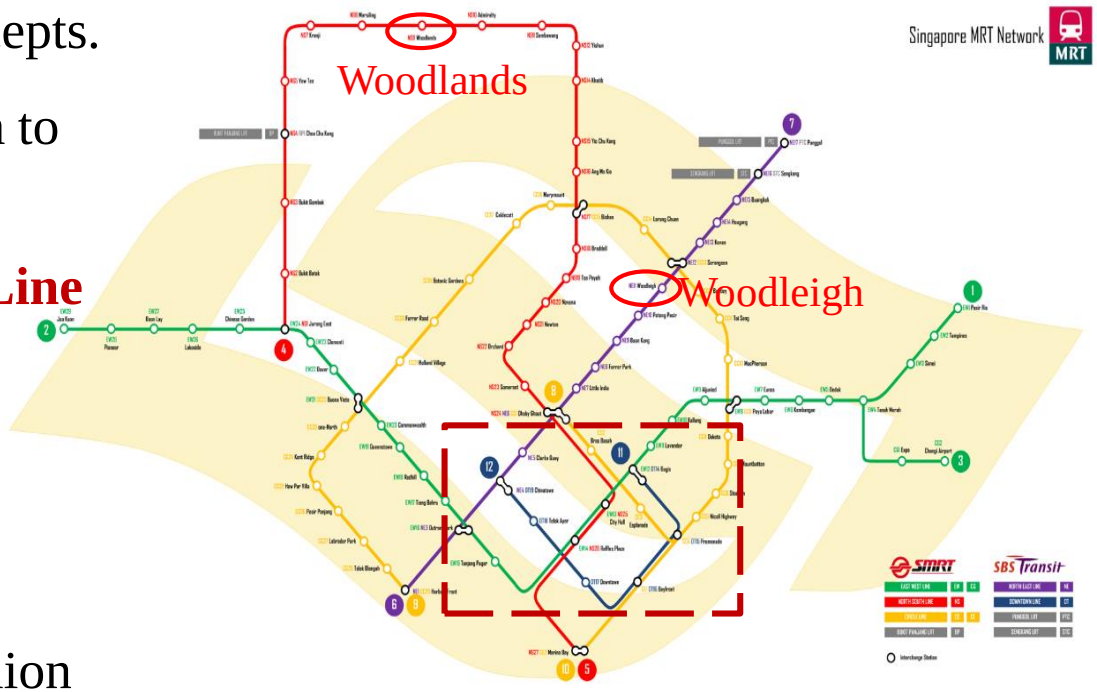
We explicitly address transportation as a network.

- Introduce **transport connectivity** into real estate study: a holistic sense.
  - A micro-level measurement of connectivity index
- **Butterfly effect**: Change or addition in a small part of a network can affect economics of all vertices.
- A novel **identification strategy** that exploits the butterfly effect to identify causal impact of transport connectivity improvement.
- Widely applicable in general economics

Singapore Mass Rapid Transit (MRT) network

Transport connectivity of an MRT station:
The ease of travel and access to destinations within a transport network

- Connectivity and accessibility (proximity) are different concepts.
- 100m to Woodlands vs. 100m to Woodleigh
- **Opening of the Downtown Line (DT) on 22 December 2013**
  - New downtown area reclaimed from the sea
  - 4.3 km (< 3 miles) long; 6 stations
  - Construction costs: 1.4 billion SGD (≈ 1.12 billion USD, 0.4% of GDP in 2013)



(Some pictures)

Research objectives

DT Line as a quasi-natural experiment

- A micro-level Connectivity Index (CI) for every station (vertex)
- Demonstrate the butterfly effect—the base of identification.
- Identify the causal impact with difference-in-differences (DD) regression:

improved transport connectivity → households' willingness to pay for the connectivity

- Many techniques and tests to strengthen robustness.
- Welfare implication: Cost-Benefit Analysis

Compare and contrast against the literature

- Urban economics: Long-established theories depict relationships between bid-rent and commuting costs
  - Alonso (1964), Lucas and Rossi-Hansberg (2002), Zheng et al. (2006) and Baum-Snow (2007).
- Hedonic pricing for empirical economic research on benefit of public transport infrastructure.
  - Dewees (1976), McMillen and McDonald (2004), Gibbons and Machin (2005), Debrezion et al. (2007), Gu and Zheng (2010) and Billings (2011)
  - Merely consider proximity (accessibility)
  - Three Issues:
    1. Confines the benefit to the vicinity of the new transit line.
    2. Implicitly assumes equal importance of all stations.
    3. The results are more vulnerable to endogeneity.
- We propose better identification and account for benefit more holistically.

Compare and contrast against the literature

- Transportation literature on network connectivity
  - Much research on line, cluster and region specific measures
  - Few incorporate transport quality.
  - Mishra et al. (2012) explicitly incorporate transport quality into various measures.
- We use Mishra et al. (2012)'s approach to address line quality, but our index follows economic notion and minimizes parameter assumptions

Compare with Donaldson and Hornbeck (2016)

Surging economic research in transport connectivity. Few explicitly incorporates a network context. They pioneered the area.

- General equilibrium model => a railroad market access measure.
- Change of railroad market access affect population and agricultural-land value of US counties in the 19th century
- Endogenous railroad placement: constraint of natural geography
- Waterway market access as the IV
  - Violation of exclusionary restriction: Early trading cities emerged along waterways for transportation.
  - Vulnerable to unobservables: Waterways relate to natural geography and correlate with geographic amenities inevitably

Similarity: the connectivity index.

Differences: We introduce the butterfly effect and exploit it for better identification.

Background

The Mass Rapid Transit (MRT)

Public transit is the dominant transport mode of Singapore residents.

- Driving is expensive
- MRT is the backbone of public transit
  - Daily ridership: from 1.34 million(2005) to 2.62 million (2013)

TABLE 1. SINGAPORE MRT LINES IN 2014

MRT Line	Operator	Initial Opening Date	Full Opening Date[b]	Terminals[c]		Length (km)	Stations
North South Line (NS)	SMRT[a]	7 Nov 1987	23 Nov 2014	Jurong East	Marina South Pier	44.7	27
East West Line (EW)	SMRT	7 Nov 1987	8 Feb 2002	Joo Koon	Pasir Ris Changi Airport	49.7	31
North East Line (NE)	SBS	20 Jun 2003	20 Jun 2011	HarbourFront	Punggol	20	16
Circle Line (CC)	SMRT	28 May 2009	14 Jan 2012	Dhoby Ghaut Marina Bay	Harbourfront	35.5	30
Downtown Line (DT)	SBS	22 Dec 2013	22 Dec 2013	Bugis	Chinatown	4.3	6

- Will expand from 149km in 2012 to 360km by 2030.
- The 4.3-km DT Line, the 5th MRT line, opened in 22 December 2013

Singapore Housing Market

The public housing

- The Housing Development Board builds HDB flats (public housing)
- New-sale flats are heavily subsidized and regulated.
- Resale flats are transacted in a free market (suitable for hedonic pricing)

Public vs. private housing

- More than 80% of Singaporean families live in HDB flats
  - HDB residents have lower income than private housing residents
  - HDB residents need and value convenient public transportation

We focus on HDB resale flats.

Methodology and Data

1. Connectivity Index
   - MRT system map – Land Transport Authority (LTA).
   - Route distances – Google Map's measurement tool.
   - Service schedules; operation hours; train speeds – MRT operators & LTA
   - Commercial space stock – Urban Redevelopment Authority (URA)
2. Difference-in-Differences
   - Public-housing resale data (primary) – Housing Development Board (HDB)
   - Private-housing transaction data (supplementary) – URA
3. Cost-Benefit Analysis
   - Land area and housing stock of HDB Towns – HDB Annual Report 2013-2014

Methodology 1: Connectivity Index (CI)

$\boldsymbol{N}$: the entire set of stations; $\boldsymbol{n}$: a station in N. Then, $\forall \{\boldsymbol{n}, \boldsymbol{n'}\} \subset \boldsymbol{N}$

- **Shortest route's distance: $\boldsymbol{d_{n \to n'}}$**
  - A 92×92 matrix, for Singapore MRT of 2013
- **Weighted average quality: $\boldsymbol{\tilde{q}_{n \to n'}} = \sum_{l \in L} \frac{d_{l \cap n \to n'}}{d_{n \to n'}} q_l$**
  - q_l: line-specific quality. $q_l = \alpha(F_l \times H_l) \times \beta V_l$ (Mishra,2012)
- **Node accessibility: $\boldsymbol{A_{n \to n'}} = \tilde{q}_{n \to n'} \times e^{-\boldsymbol{\lambda} d_{n \to n'}}$**
  - λ is calibrated according to literature. λ=*0.1* in the benchmark case.
- **Transport-infrastructure CI**

$$CI_n = \sum_{n' \neq n} \mathrm{A}_{n \to n'}$$

- **Market-access CI**

$$CI_n^M = \sum_{n' \neq n} \mathrm{A}_{n \to n'} \times \frac{E_{n'}}{\bar{E}}$$

Methodology 2: Difference-in-Differences (DD)

The treatment event: DT-Line opening on 22 December 2013.

The treatment group: HDB resale units in proximity (<=800m) to any MRT station. These units benefit from CI change

- The proximity is estimated.
- The $\Delta \ln CI_n$ is the continuous treatment variable, where n is the nearest MRT station. The bigger the $\Delta \ln CI_n$, the stronger the treatment intensity.

The control group: those resale units without the proximity.

Two event windows: 3+6 months and 12+12 months.

The Baseline DD Regression

$$\ln P_{irnt} = \beta_0 + \boldsymbol{\beta_1 MRT_n} + \boldsymbol{\beta_2 ln\,\overline{CI}_n} + \boldsymbol{\beta_3 \Delta ln\, CI_n} + \boldsymbol{\beta_{DD} \Delta ln\, CI_n \times T_{after}} + X_{irnt}\gamma + \boldsymbol{\theta_t} + \boldsymbol{\delta_r} + \epsilon_{irnt}$$

- i – unit; r – HDB town; n – nearest station; t – time

1. The DD estimator
   - β_{DD} : Implicit price of (improved) transport connectivity
2. Unobserved time-variant heterogeneity commonly affecting both groups
   - θ_t
3. Unobserved time-invariant heterogeneity varying across the two groups
   - β_1, β_2, β_3 and δ_r together serve the purpose.
   - A shifter (link)

- Identification: The butterfly effect as an exogenous shock.
  - Implement handles which enhance or confirm quality.

A Few Widgets

Treated vs. Control: How to define proximity?

- Local Polynomial Smooth and Locally Weighted Scatterplot Smoothing estimate a cutoff-distance to define proximity.

Cluster standard errors are applied throughout. How to cluster?

- Observations are sorted into groups by contexts of treatment status/intensity and time.
  - Potential correlation of the errors within the groups.
- Cluster level: The Cartesian product of two sets: MRT stations and proximity.
  - Greater than the rule of thumb of at least 50 groups (Angrist and Pischeke, 2009)
- Time dimension: unnecessary as year-month fixed effects are much finer than the pre-/post-treatment indicator.

A Few Widgets

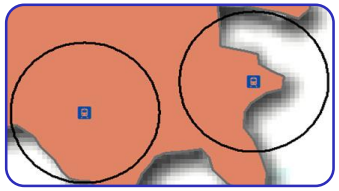
Treated and Control imbalance: Propensity Score Matching (PSM)

- Mitigate selection on observables and remove confounding.
- A good matched sample mimic a randomized control trial.
- Matching based on: house age, area, floor, distance to CBD, etc.
- Matching by location (26 HDB towns) (Caliendo & Kopeining, 2008; Heckman et al., 1998)
- 1-to-1 nearest-neighbor matching in the common support and without replacement.

Methodology 3: Cost-Benefit Analysis

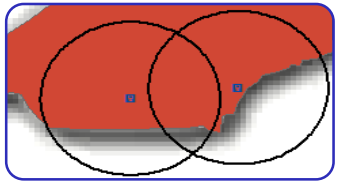
- Cost of building this 6-station DT line: S$1.4 billion
- Welfare benefit: aggregate housing-price increases in HDB estates.
  - (1) $\widehat{\boldsymbol{\beta}}_{\boldsymbol{DD}}$: estimated marginal willingness to pay for improved transport connectivity; (2) $\boldsymbol{\Delta lnCI_n}$: the CI change of station *n*; (3) $\overline{\boldsymbol{P}}_{\boldsymbol{r}}$: average resale price of in HDB town *r*; (4) H_r: total number of housing units in town *r*; (5) $\boldsymbol{A_n}$: total land area within 800m of station *n*; $\boldsymbol{A_r}$: the build-up area of town *r*.

$$\Delta\tilde{P} = \sum_{r\in R}\sum_{n\in N}\Delta\tilde{P}_{rn}$$



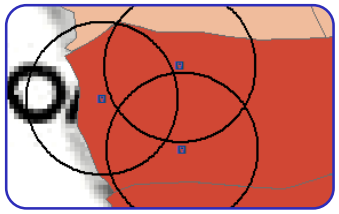
Case 1: $A_{n\cap r} \cap A_{n'\cap r} = \emptyset, \forall n'.$

$$\Delta\tilde{P}_{rn} = \hat{\beta}_{DD} \times \Delta \ln CI_n \times \bar{P}_r \times H_r \times \frac{A_{n\cap r}}{A_r}$$



Case 2: $A_{n\cap r} \cap A_{n'\cap r} \neq \emptyset, \forall n'.$

$$\Delta\tilde{P}_{rn} = \hat{\beta}_{DD} \times \Delta \ln CI_n \times \bar{P}_r \times H_r \times \frac{A_{n\cap r} - \frac{1}{2}(A_{n\cap r} \cap A_{n'\cap r})}{A_r}$$



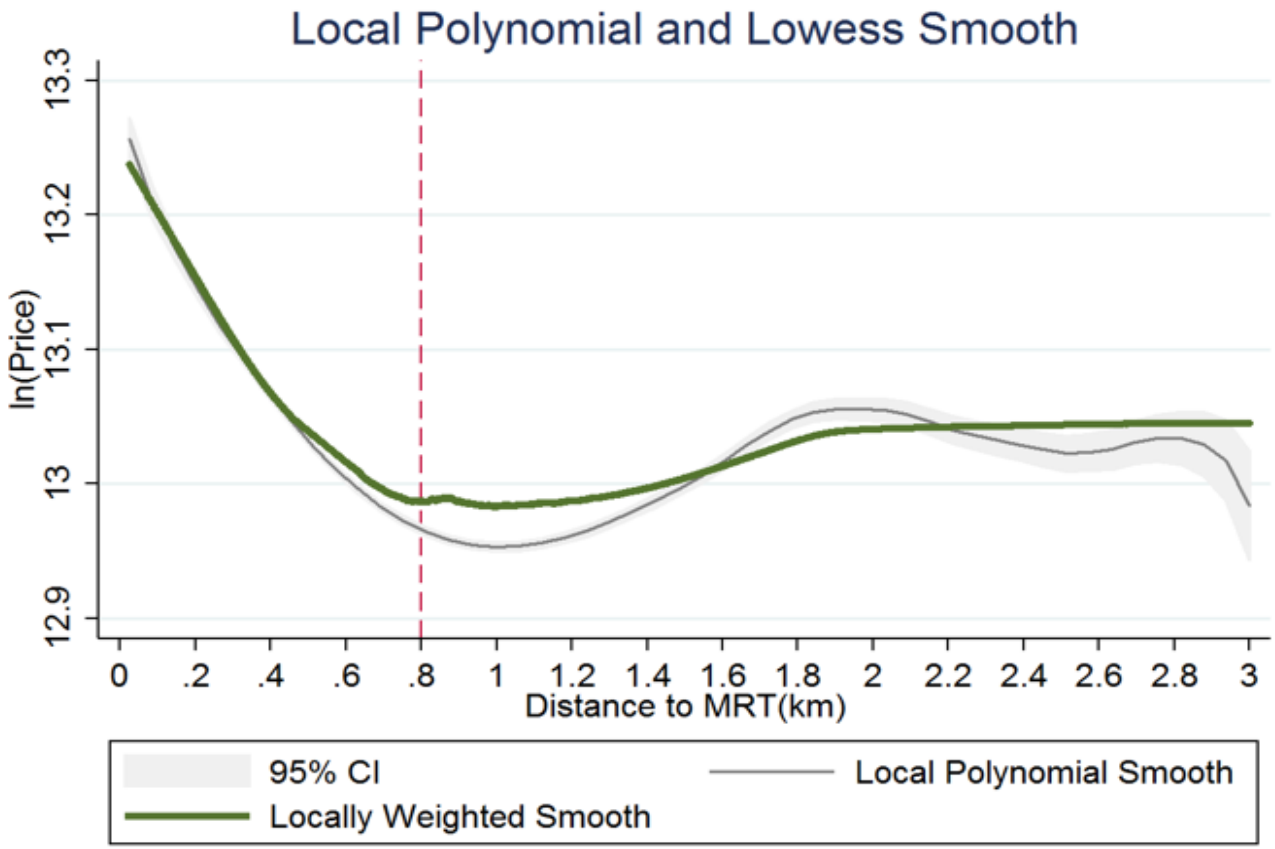
Case 3: three stations' accessible areas overlap.

$$\Delta\tilde{P}_{rn} = \hat{\beta}_{DD} \times \Delta \ln CI_n \times \bar{P}_r \times H_r \times \frac{A_{n\cap r} - \frac{1}{2}(A_{n\cap r} \cap A_{n'\cap r}) - \frac{1}{2}(A_{n\cap r} \cap A_{n''\cap r}) + \frac{1}{3}(A_{n\cap r} \cap A_{n'\cap r} \cap A_{n''\cap r})}{A_r}$$

Results

1. Connectivity Index
2. The treated and controls
3. Baseline DD regression – transport infrastructure CI
4. Baseline DD regression – market access CI
5. Event study
6. Falsification and placebo tests
7. Supplementary analyses
8. Cost and Benefit Analysis

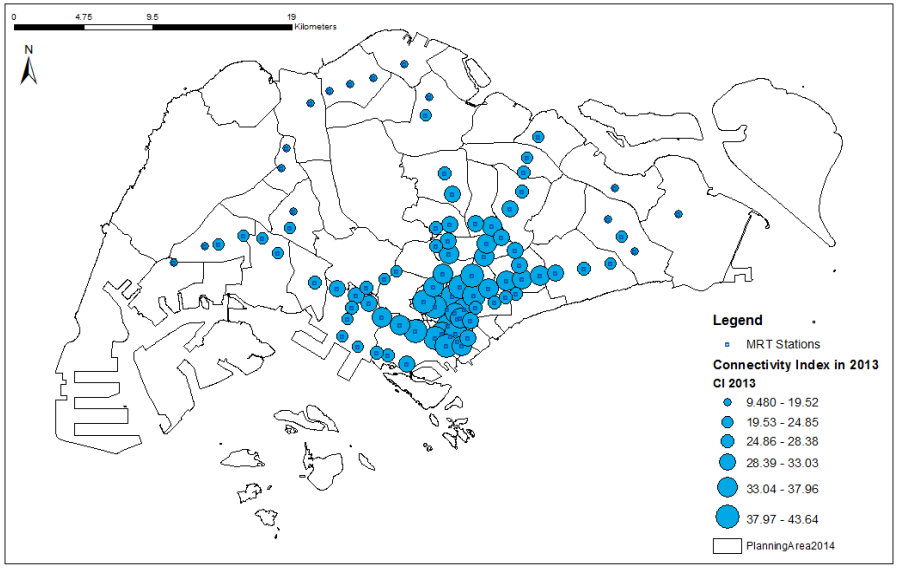
Proximity is within 800 meters to the station.



Note: This figure plots the housing price gradient based on the full (unmatched) HDB resale data. The price gradient of Distance to MRT station are calculated using both locally weighted scatterplot smooth (the thick green line) and local polynomial regression (the thin gray line). Time period is from Jan 2013 to Jan 2015.

"Transport-infrastructure" Connectivity Index

Panel A. CI_n in 2013



Panel B. Percent Change of CI_n

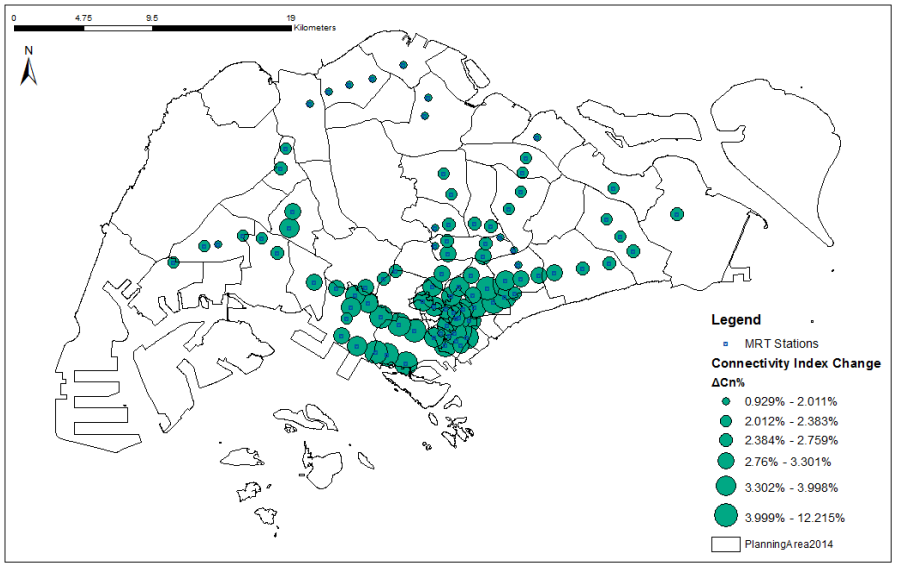
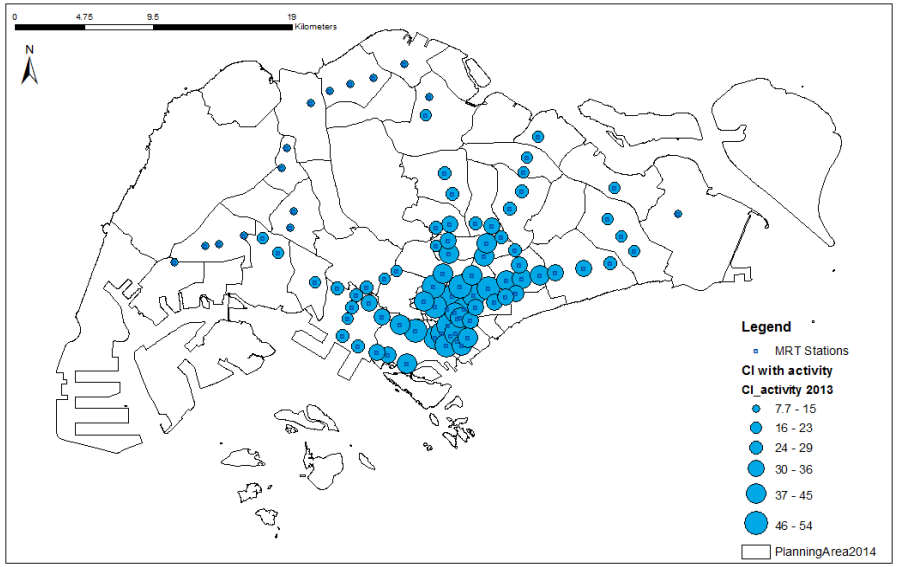


Figure 3. "Transport-infrastructure" Based Connectivity Index

Summary Statistics of "Transport-infrastructure" CI					
$\overline{CI}_n$	90	28.891	8.600	9.480	43.642
$\Delta \ln CI_n$	90	0.030	0.016	0.009	0.115

"Market-access" Connectivity Index

Panel A. CI_n^M in 2013



Panel B. Percent Change of CI_n^M

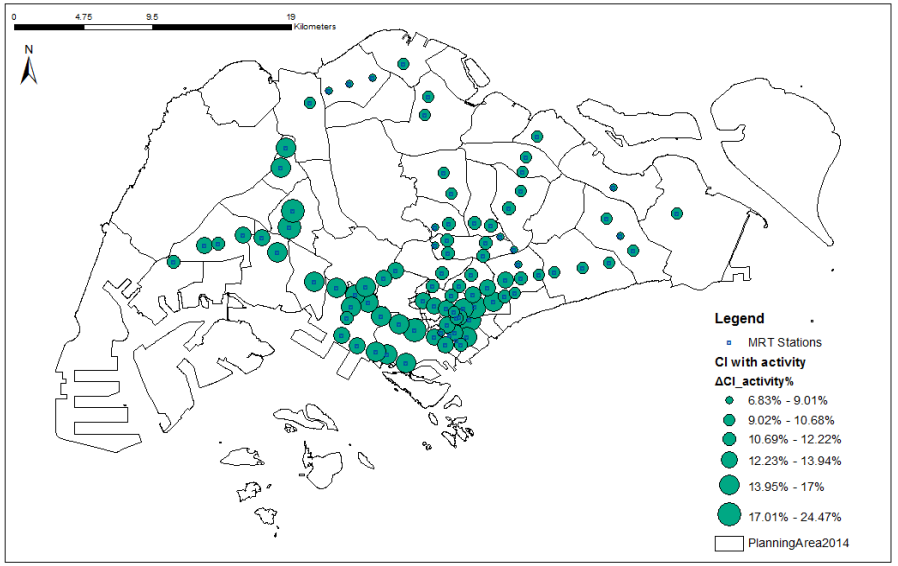


Figure 4. "Market-access" Connectivity Index

Summary Statistics of "Market-access" CI					
$\overline{CI}_n^M$	90	30.156	13.597	7.652	53.804
$\Delta \ln CI_n^M$	90	0.116	0.027	0.066	0.219

Treated and Controls: PSM Quality

Table 2. Panel A. Mean Difference between Full (unmatched) and Matched Sample

Panel A.1		Treatment		Control		
Full (unmatched) Sample	**Variables**	**Obs.**	**Mean**	**Obs.**	**Mean**	**Mean Diff.**
	Area (sqm)	8032	93.372	6707	95.983	2.611***
	House Age (year)	8032	24.298	6707	25.053	0.755***
	Floor	8032	7.970	6707	7.619	-0.352***
	Distance to CBD (km)	8032	11.679	6707	12.655	0.976***
	< 200m to Parks	8032	0.020	6707	0.026	0.006***
Panel A.2		Treatment		Control		
Matched Sample	**Variables**	**Obs.**	**Mean**	**Obs.**	**Mean**	**Mean Diff.**
	Area (sqm)	4732	93.241	4732	93.575	0.334
	House Age (year)	4732	25.213	4732	25.632	0.419**
	Floor	4732	7.479	4732	7.553	0.074
	Distance to CBD (km)	4732	12.909	4732	12.853	-0.056
	< 200m to Parks	4732	0.012	4732	0.016	0.004

Treated and Controls: PSM Quality

Panel A. Full (unmatched) Sample

Panel B. Matched Sample

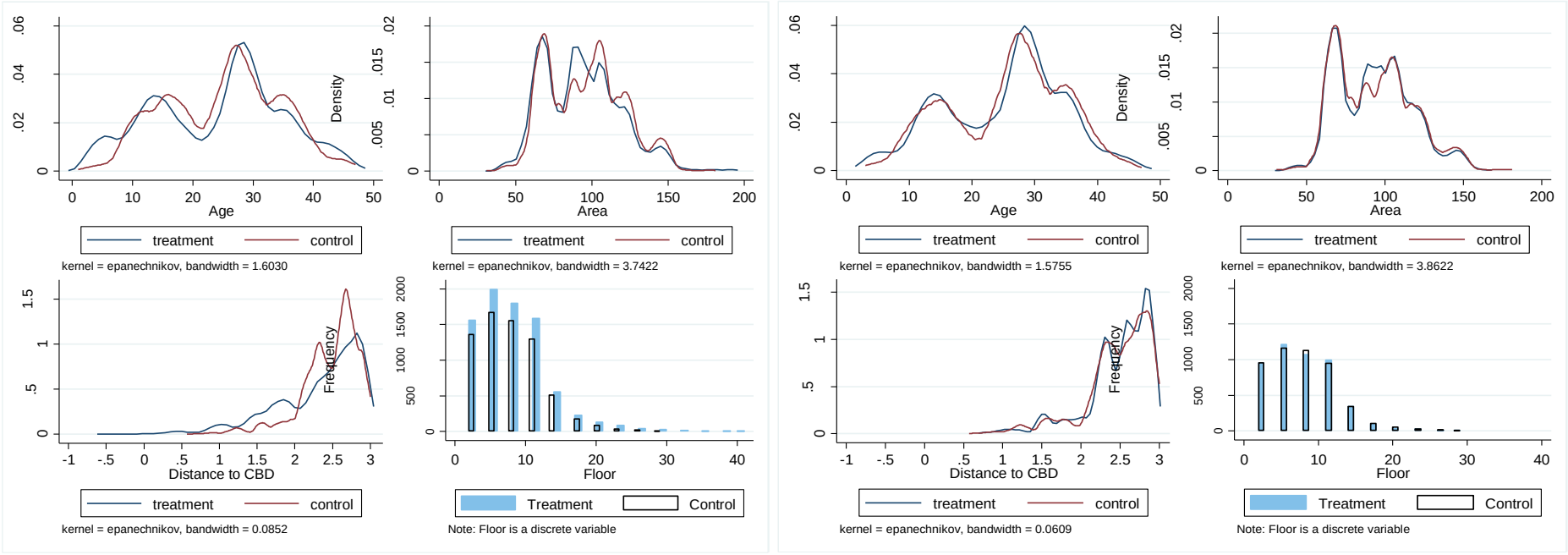


Figure 6. Distribution of Key Variables

We focus on the matched sample for the regressions.

Summary statistics of Matched Sample

Variables	Obs.	Mean	Std. Dev.	Min	Max
Dependent Variable					
Resale Price	9,464	437,693	112,319	210,000	1,050,000
Independent Variables					
Area (sqm)	9,464	93.408	23.864	31.000	181.000
House Age (year)	9,464	25.423	9.398	3.000	47.000
Floor	9,464	7.516	4.346	2.000	29.000
< 200m to Parks	9,464	0.014	0.119	0.000	1.000
Distance to CBD (km)	9,464	12.881	4.174	1.771	20.097
Distance to MRT (km)	9,464	0.817	0.374	0.047	2.544
"Transport-infrastructure" Connectivity Index					
$\overline{CI}_n$	90	28.891	8.600	9.480	43.642
$\Delta \ln CI_n$	90	0.030	0.016	0.009	0.115
"Market-access" Connectivity Index					
$\overline{CI}_n^M$	90	30.156	13.597	7.652	53.804
$\Delta \ln CI_n^M$	90	0.116	0.027	0.066	0.219

Baseline DD: "transport-infrastructure" CI

Table 3. Impact of Transport Connectivity on HDB Resale Price: 2013.10-2014.06

	(1)	(2)	(3)	(4)	(5)
Sample	Matched Sample	Matched Sample	Exclude MRT within 2 stations from DT line	Exclude MRT within 2 stations from DT line	Matched Sample
Dependent Variable	ln(Resale Price)	ln(Resale Price)	ln(Resale Price)	ln(Resale Price)	ln(Resale Price)
MRT_n	0.0377*		0.0192		0.0786**
	(0.0209)		(0.0218)		
$\ln \overline{CI}_n$	0.0394		0.0344		0.0460**
	(0.0259)		(0.0253)		
$\Delta \ln CI_n$	0.1951		1.1522		0.0102
	(0.9343)		(0.9351)		
$\Delta lnCI_n \times T_{after}$	0.3675**	0.3672**	0.4025**	0.3934**	0.0160**
	(0.1629)	(0.1536)	(0.1730)	(0.1668)	
Results on the rest covariates are suppressed					
Constant	13.1020***	12.4760***	13.1304***	12.5013***	
	(0.4683)	(0.1183)	(0.4658)	(0.1339)	
Flat Types[a]	Y	Y	Y	Y	Y
Treatment×MRT FE	N	Y	N	Y	N
HDB Town FE	Y	Y	Y	Y	Y
Year-Month FE	Y	Y	Y	Y	Y
Observations	9,464	9,464	9,313	9,313	9,464
R-squared	0.9134	0.9212	0.9136	0.9207	0.9134

Note: *** p<0.01, ** p<0.05, * p<0.1.

DD Regression: "Market-Access" CI

Table 4. "Market-Access" Based Connectivity Index

Sample	(1) Matched Sample	(2) Matched Sample	(3) Exclude MRT within 2 stations from DT line	(4) Exclude MRT within 2 stations from DT line	(6) Matched Sample
Dependent Variable	ln(Resale Price)	ln(Resale Price)	ln(Resale Price)	ln(Resale Price)	Standardized Coefficients ln(Resale Price)
MRT_n	0.0213		0.0046		0.0443**
	(0.0306)		(0.0318)		
ln $\overline{CI}_n^M$	0.0256*		0.0300**		0.0565**
	(0.0140)		(0.0145)		
$\Delta \ln CI_n^M$	0.1508		0.2819		0.0353*
	(0.2418)		(0.2416)		
$\Delta lnCI_n^M \times T_{after}$	0.0746**	0.0722**	0.0779**	0.0740**	0.0148**
	(0.0367)	(0.0361)	(0.0371)	(0.0370)	
	Results on the rest covariates are suppressed				
Constant	12.8561***	12.4761***	13.0505***	12.5011***	
	(0.2673)	(0.1183)	(0.2757)	(0.1339)	
Flat Types	Y	Y	Y	Y	Y
Treatment×MRT FE	N	Y	N	Y	N
HDB Town FE	Y	Y	Y	Y	Y
Year-Month FE	Y	Y	Y	Y	Y
Observations	9,464	9,464	9,313	9,313	9,464
R-squared	0.9134	0.9212	0.9135	0.9207	0.9134

Note: ***The studied time period for this table is 2013.10-2014.06.

Parameter Sensitivity Test

- **Node Accessibility** of each station pair: $A_{n \to n'} = \tilde{q}_{n \to n'} \times e^{-\lambda d_{n \to n'}}$
  - Exponential decay parameter: λ=0.1
  - Calibrate the value of λ according to literature on intra-city transportation
  - Typically in [0.05, 0.18] (e.g., Handy, 1993; Song, 1996; Kwan, 1999; Signorino, ect., 2011)

Table 5. Distance-decay parameter sensitivity test

Parameter λ	0.05	0.075	0.1	0.125	0.15	0.175	0.2
$\hat{\beta}_{DD}$	0. 3721**	0. 3707**	0. 3675**	0. 3554**	0. 3297**	0. 2919*	0. 2480*

Event Study: 9 months and 2 years

$$\ln P_{irnt} = \beta_0 + \beta_1 MRT_n + \beta_2 \ln\overline{CI}_n + \beta_3 \Delta \ln CI_n + \sum_{\tau=-q}^{m} \varphi_\tau \Delta \ln CI_n \times T_\tau + X_{irnt}\gamma + \theta_t + \delta_r + \epsilon_{irnt}$$

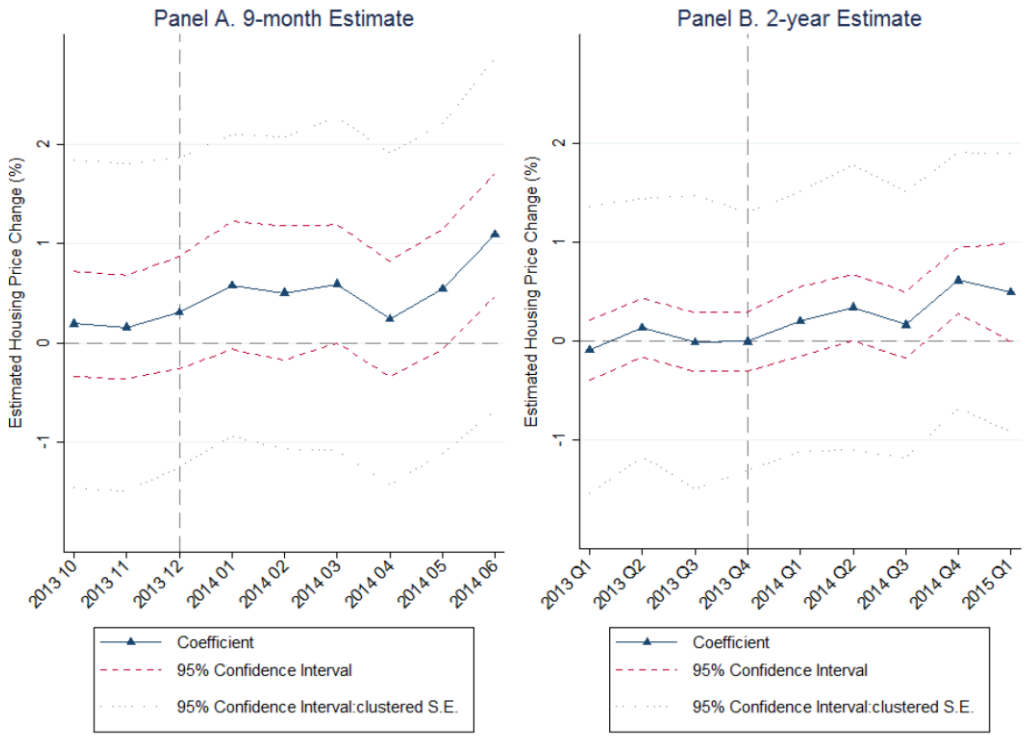
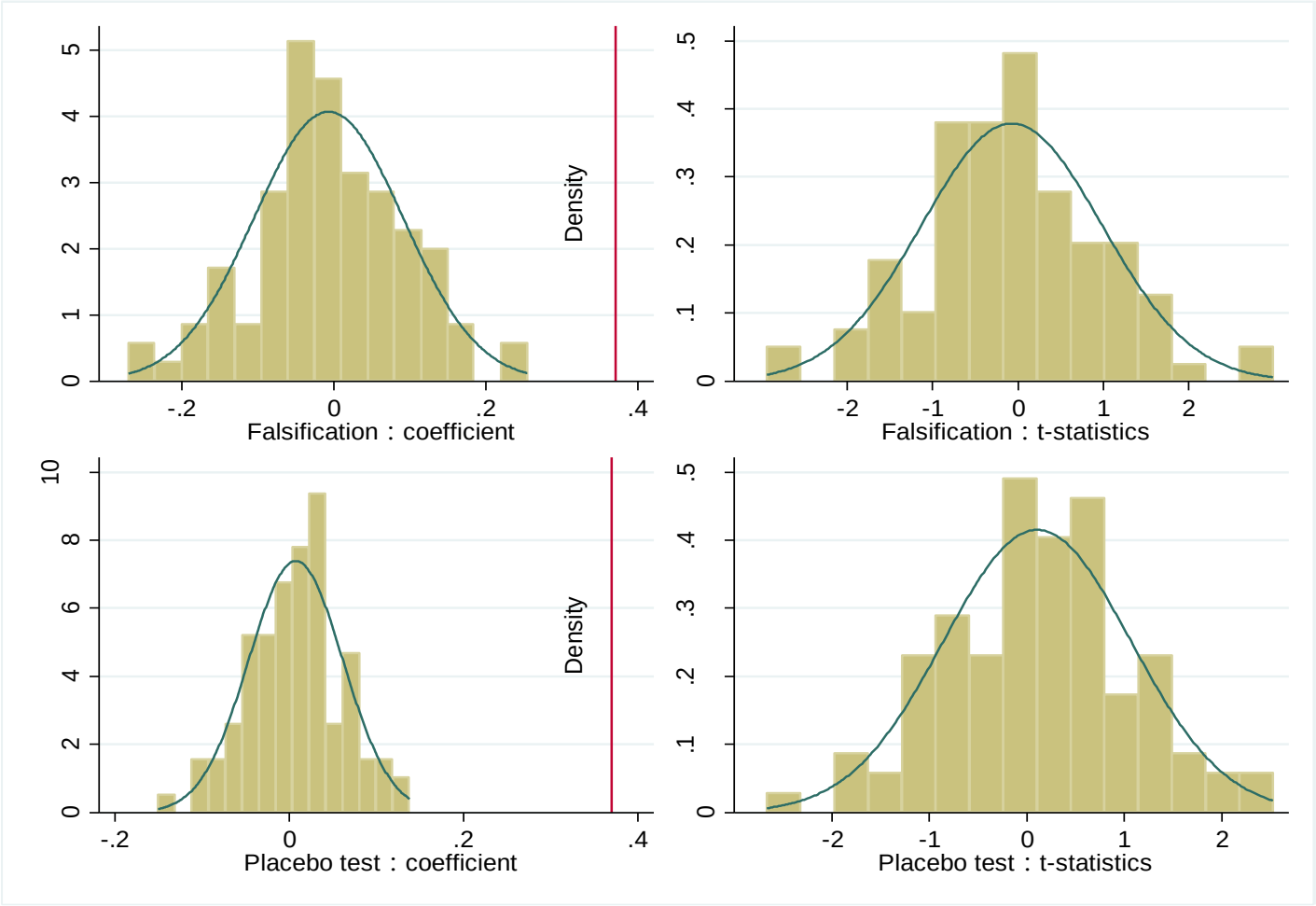


FIGURE 7. EVENT STUDY

- Validates **common-trend** assumption: coefficients for pre-treatment responses are close to 0.
- Establishes the **causal inference** by ruling out reverse causality.

Falsification and Placebo Tests

Figure 8. Falsification and Placebo Test



Is There Announcement or Construction Effect?

Is the true β_{DD} under- or over-estimated?

- Significant announcement effect $\Longrightarrow$ Underestimation
  - Less worrisome from a policy view point
- Significant construction effect $\Longrightarrow$ Overestimation

We hypothesize that the announcement and construction effects are minimal and negligible in the inland-wide context, because the effects would be confined to the DT Line's vicinity even if it exists.

Practically, designing an empirical test is not straightforward.

An Alternative "Ring Approach"

$$\ln P_{irnt}^{k} = \alpha^{k} + \beta_{1}^{k} MRT_{\mathrm{n}}^{k} + \beta_{DD}^{k} MRT_{n}^{k} \times T_{after}$$
$$+ X_{irnt}^{k} \gamma^{k} + \theta_{t}^{k} + \delta_{r}^{k} + \epsilon_{irnt}^{k}, \ \forall k$$

- 4 distance strata: whether the housing unit's nearest station is less than 2 stations away, between 2 stations to 5 km, between 5 and 10 km, or beyond 10 km from the planned DT line.

Announcement Effect

Table 6. Announcement Effect

Sample	(1) Unmatched < 2 stations to DT line	(2) Unmatched 2 stations - 5km to DT line	(3) Unmatched 5-10km to DT line	(4) Unmatched >10km to DT line	(5) Matched < 2 stations to DT line	(6) Matched 2 stations - 5km to DT line	(7) Matched 5-10km to DT line	(8) Matched >10km to DT line
Dependent Variable	ln(Resale Price)	ln(Resale Price)	ln(Resale Price)	ln(Resale Price)	ln(Resale Price)	ln(Resale Price)	ln(Resale Price)	ln(Resale Price)
MRT_n	0.0901***	0.0367*	0.0557***	0.0546***	0.0838***	0.0370**	0.0467***	0.0482***
	(0.0197)	(0.0186)	(0.0119)	(0.0070)	(0.0117)	(0.0154)	(0.0083)	(0.0068)
$MRT_n \times T_{after}$	0.0335*	0.0148	0.0074	0.0019	0.0264**	0.0157	0.0049	0.0061
	(0.0175)	(0.0090)	(0.0081)	(0.0054)	(0.0093)	(0.0136)	(0.0083)	(0.0071)
Results on the rest covariates are suppressed								
Constant	9.6100***	11.1010***	11.0945***	11.8256***	10.4480***	10.9049***	11.1477***	11.9261***
	(0.1452)	(0.1811)	(0.2577)	(0.1482)	(0.1396)	(0.2276)	(0.1851)	(0.1755)
Flat Types	Y	Y	Y	Y	Y	Y	Y	Y
HDB Town FE	Y	Y	Y	Y	Y	Y	Y	Y
Year-Month FE	Y	Y	Y	Y	Y	Y	Y	Y
Observations	585	2,496	6,750	8,356	321	1,854	4,407	5,038
R-squared	0.9385	0.9190	0.9033	0.9061	0.9338	0.9156	0.9030	0.9111

Note: The DT line announcement time was on June 14, 2005. A "ring approach" by using proximity to MRT stations is adopted. If our hypothesis of no butterfly effect holds, the announcement would only increase prices in the stratum close to the DT line. The chosen time period if 2005.03-2006.11.*** p<0.01, ** p<0.05, * p<0.1. Standard errors are clustered at the HDB Block level.

Construction Effect

Table 7. Construction Effect

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Sample	Unmatched	Unmatched	Unmatched	Unmatched	Matched	Matched	Matched	Matched
	< 2 stations to DT line	2 stations - 5km to DT line	5-10km to DT line	>10km to DT line	< 2 stations to DT line	2 stations - 5km to DT line	5-10km to DT line	>10km to DT line
Dependent Variable	ln(Resale Price)	ln(Resale Price)	ln(Resale Price)	ln(Resale Price)	ln(Resale Price)	ln(Resale Price)	ln(Resale Price)	ln(Resale Price)
MRT_n	0.1785***	0.0749***	0.1060***	0.0977***	0.1697***	0.0640**	0.0892***	0.0977***
	(0.0107)	(0.0254)	(0.0153)	(0.0094)	(0.0029)	(0.0273)	(0.0143)	(0.0075)
$MRT_n \times T_{after}$	-0.0368***	-0.0002	0.0017	0.0045	-0.0357**	0.0061	-0.0025	-0.0035
	(0.0033)	(0.0093)	(0.0057)	(0.0041)	(0.0091)	(0.0120)	(0.0067)	(0.0049)
	Results on the rest covariates are suppressed							
Constant	11.1251***	11.3314***	11.1125***	12.5996***	11.2413***	11.1304***	11.6358***	12.0985***
	(0.0980)	(0.1197)	(0.3166)	(0.2072)	(0.0867)	(0.1730)	(0.2075)	(0.2729)
Flat Types	Y	Y	Y	Y	Y	Y	Y	Y
HDB Town FE	Y	Y	Y	Y	Y	Y	Y	Y
Year-Month FE	Y	Y	Y	Y	Y	Y	Y	Y
Observations	580	2,225	5,418	7,711	293	1,576	3,588	5,981
R-squared	0.9513	0.9310	0.9038	0.9068	0.9541	0.9214	0.9031	0.9071

Note: The commencement of DT line's construction was in 2008.02. The time period for this construction effect test is from 2007.12-2008.08. Robust standard errors in parentheses. Standard errors are clustered at the Cartesian product of MRT station and treatment level.

Cost-Benefits Analysis

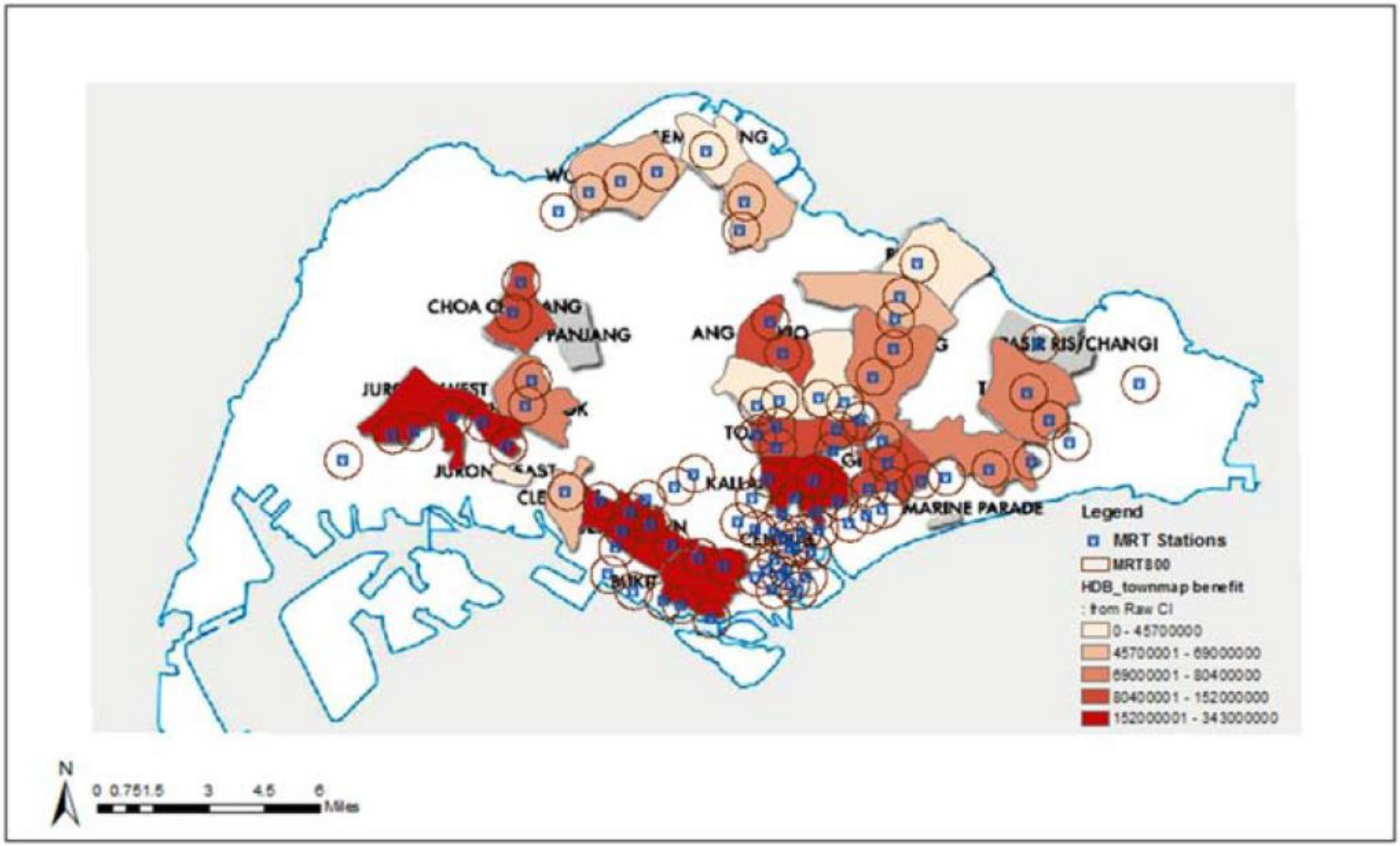
Focus on public housing, as private housing has no significant premium for the CI change. (a supplementary test)

- Benefits to HDB Towns

Town	Benefit: "transport-infrastructure" CI	Benefit: "market-access" CI	Town	Benefit: "transport-infrastructure" CI	Benefit: "market-access" CI
Ang Mo Kio	92,700,000	86,400,000	Jurong West	174,000,000	191,000,000
Bedok	79,600,000	58,200,000	Kallang/Whampoa	182,000,000	129,000,000
Bishan	40,800,000	35,600,000	Marine Parade	#N/A	#N/A
Bukit Batok	71,400,000	73,900,000	Pasir Ris	35,000,000	26,900,000
Bukit Merah	343,000,000	224,000,000	Punggol	23,900,000	23,900,000
Bukit Panjang	#N/A	#N/A	Queenstown	230,000,000	192,000,000
Bukit Timah	#N/A	#N/A	Sembawang	14,000,000	17,800,000
Central Area	#N/A	#N/A	Sengkang	57,500,000	57,100,000
Choa Chu Kang	95,600,000	122,000,000	Serangoon	45,700,000	41,400,000
Clementi	69,000,000	66,300,000	Tampines	80,400,000	64,800,000
Geylang	96,000,000	69,900,000	Toa Payoh	153,000,000	125,000,000
Hougang	74,200,000	69,900,000	Woodlands	54,600,000	83,100,000
Jurong East	-	-	Yishun	58,300,000	65,200,000
Aggregate Benefit				**2.07 billion**	**1.82 billion**

- Cost of DT line: 1.4 billion Singapore Dollar

Distribution of HDB Town Benefits



Benefit based on the transport-infrastructure CI

Key Findings

- 1% transport-connectivity improvement → 4% increase in public housing resale prices.
- DT Line improved all stations' connectivity level by 3% on average → 1.2% increase in the average price (≈$4340 USD per unit)
- S$2.07-billion welfare benefit > S$1.4-billion construction cost.

Highlight of Contribution

- Explicitly addresses the long-neglected nature of transportation: It's a network!
- There exists a "*butterfly effect*"! A small addition of transport infrastructure can improve the connectivity levels of all locations in the transport network.
- The butterfly effect can identify causal impact of improved transport connectivity.
- Useful framework for policy analysis.

- A final remark: Butterfly effect vs. IV

Questions are welcome!

Thank you