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ORIGINAL ARTICLE

A new Mass Rapid Transit (MRT) line construction and housing wealth: Evidence from the Circle Line

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ABSTRACT

This study uses the opening of the new Mass Rapid Transit (MRT) in stages between 2010 and 2012 in Singapore as the exogenous event to empirically test the impact of the new Circle Line (CL) on housing wealth. Applying a "differences-in-differences" approach to the non-landed private housing transaction data covering the period from 2009 to 2013, we find that the average housing prices increase by 1.6% in the post-opening of the CL. We find significant capitalization of the new CL into housing prices, especially households living within a 400-meter radius (the treatment zone) from the closest MRT stations on the CL. The treatment effects that are measured by the "marginal willingness to pay" for houses located within the treatment zone is 13.2% relative to houses located outside the treatment zone. The new CL opening creates an estimated S$1.23 billion housing wealth effects for households living in close proximity to the CL MRT stations. However, we do not find significant "anticipative" effects on house prices in the six-month window prior to the opening of CL. The strongest treatment effect is found after the opening of the phase 1 of CL, and the treatment intensity declines in phases 2 and 3 of the CL opening.

***Keywords**: Mass Rapid Transit (MRT) line; difference-in-differences approach; treatment effects; marginal willingness-to-pay; housing wealth*

1. Introduction

Investments in public infrastructure projects, such as new MRT lines, highways *etc*., are highly risky and have a long-gestation period. It is difficult to attract sufficient private capitals into public infrastructure projects, based solely on economic considerations. Governments invariably take on the key roles and responsibilities in developing infrastructure projects. Public infrastructure investments constitute a large portion of government's fiscal expenditures in many countries. However, for fiscal discipline and prudence purposes, central planners and policymakers exercise due restraints to avoid over-committing on public infrastructure project spending.

Public infrastructure investments boost economic growth and create new employment in productive sectors, and they also generate positive spillovers that improve social welfare and environmental quality. At the urban level, new MRT line investments generate significant economic activities, which increase prices of lands surrounding MRT stations. New MRT lines radiating out of the central business district (CBD)

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improve accessibility to the key employment centre and stimulate new housing developments in the outlaying city areas. With better connectivity via new MRT lines, households who do not wish to pay high housing prices in the core central area are more willing to live further away from the city centre. As a result, a more balanced urban growth pattern is created with new housing developments gradually disperse from the centre to the fringe of a city. New transit infrastructure investments thus lead to the flattening of the bid-rent gradient in a city (McMillen and McDonald, 2004; Zheng and Kahn, 2008).

There are other non-pecuniary (less tangible) benefits associated with investments in rail transit infrastructure networks. The US evidence shows that investments in new transit lines encourage people to switch from private cars to public transports, and thus reduce congestions on public roads (Baum-Snow and Kahn, 2000). With fewer cars on the roads, marginal social benefits accrued to car-users increase; and more significantly, positive environmental externalities are created through a reduction in greenhouse gas emission. However, noise, pollution (Gatzlaff and Smith, 1993; Forrest, Glen and Ward, 1996; Heneberry 1998; McMillen and McDonald, 2004) and increased crime rates in neighbourhoods (Bowes and Ihlanfeldt, 2001) associated with the rail transit operations are sources of negative externalities that reduce surrounding house prices in some cities.

New transit lines investments bring the convenience of public transportation networks to neighbouring households. The accessibility benefits outweigh negative externalities in most instances, and are capitalized into housing prices (Capozza, 1976; Zheng and Kahn, 2008). Individual homeowners living near new transit nodes or stations enjoy significant housing wealth effects generated from new rail transit projects. This study uses the opening of the new Circle Line (abbreviated as “CL” hereinafter) MRT stations in stages between 2010 and 2012 as the treatment events to empirically test the capitalization effects of the CL project on housing prices. Like many previous studies, we use the hedonic model to empirically quantify the accessibility premiums associated with the new CL. One methodological challenge facing this type of empirical works is to resolve possible endogeneity problems in the housing price discovery process. New MRT projects bring more commercial developments and employment opportunities to areas surrounding new MRT stations (Bollinger and Ihlanfeldt, 1997; Bowes and Ihlanfeldt, 2001; Brueckner, 2003). Housing price increases caused by spillovers of the commercial activities are not correlated with households’ “marginal willingness to pay” (MWTP) for accessibility to new MRT stations.

Based on the pre-CL opening housing transactions near six existing stations on the current MRT networks, which are integrated into the planned CL line, we establish a clean boundary discontinuity in housing prices at a 400-meter radius from the MRT stations. We exploit the exogenous price variations (boundary discontinuity) between houses located within the accessibility range (the treatment group) (≤ 400 m) and those that are outside the walking distance to the MRT stations (the control group) (> 400 m) to test for accessibility benefits associated with the new CL MRT stations. We use the four stages of the opening of the CL as the exogenous shocks on price changes between the treatment group and the control group.

Based on the transactions from February 2009 to May 2013, we estimate the difference-in-differences (diff-in-diff) regression models with time (year of sales) and spatial (planning sector) fixed effects. Our results show that housing prices within a 400-m boundary from the nearest CL MRT stations, on average, increase by 1.6% in the post-CL opening period. We also find that houses located within 400-m from the closest MRT station sell at 4.2% higher in price than comparable houses located outside the 400-m radius from the MRT station. Most importantly, the opening of the CL creates positive treatment effects on houses located within a 400-m radius from the closest MRT stations, which sell at an average price premium of 13.2% relative to other houses located outside the 400-m boundary. The results verify the positive causality of accessibility effects of the CL MRT stations on housing prices. Based on the aggregate values of S$9.30 billion for the 6,564 housing transactions with an average price of S$1,416,896, we estimate the housing wealth effects of S$1.23 billion accrued to households living within 400-m radius from the closest MRT stations following the opening of the CL. In our heterogeneity tests, we find that the accessibility premiums are larger in developers' (new sale) market and for public housing buyers (HDB upgraders).

When we test for temporal variations in the treatment effects, we find no significant "anticipative" effects in the six-month window prior to the opening of the new CL. Prices for houses located in the treatment zone increase significantly by more than 14.3% compared to other houses located outside the treatment zone after the opening of CL. We find significant positive treatment effects in the first three phases of the CL opening, but the treatment intensity diminishes after phase 1. The results are consistent with the information diffusion hypothesis, but the results show no sentiment-driven momentum effects as shown in the finance literature.

There is abundance of empirical evidence in international studies showing positive effects of the proximity to transit and subway lines on neighbouring housing prices. These include some studies in major US cities (non-exhaustive), such as Washington DC (Damm, Lerman, Lerner-Lam, *et al.*, 1980), Atlanta (Nelson, 1992; Bowes and Ihlanfeldt, 2001), Miami (Gatzlaff and Smith, 1993), Chicago (McDonald and Osuji, 1995; McMillen and McDonald, 2004), San Francisco (Landis *et al.*, 1995), and other cities such as Toronto (Bajic, 1983; Dewees, 1976), Taipei (Lin and Hwang, 2003), Seoul, (Bae, Jun and Park, 2003), London (Gibbons and Machin, 2005) and the Netherlands (Amsterdam, Rotterdam and Enschede) (Debrezion, Pels and Rietveld, 2011). The study contributes to two strands of literature. First, this paper explicitly addresses the endogeneity issues in estimating capitalization effects of the proximity to MRT lines. We use the two "differences" in our treatment design to establish causality of the MRT proximity effects on housing price. The first "difference" is defined by the spatial variations in housing prices that are within and outside the proximity zones of the CL MRT stations. The second "difference" is defined by temporal variations in housing prices before and after the CL opening. The second contribution is related to the information diffusion literature[1], which finds significant empirical evidence of sentiment-driven mispricing effects in imperfect real estate markets (Ling, Naranjo and Scheick, 2014; Clayton, Ling and Naranjo, 2009; Hendershott, Hendershott, and MacGregor, 2006). Our results show significant price inefficiency associated with the news of the CL opening, but we do not see such sentiment-induced momentum in housing price changes over time.

The paper is organized as follows: Section 1 provides the objectives and motivations of the study of the capitalization effects of MRT line construction on housing values. Section 2 gives some background information of the development of the MRT system in Singapore. Section 3 discusses data sources and descriptive statistics. Section 4 presents the empirical design and methodology.

1. This sentiment-driven information diffusion hypothesis has been widely examined in the finance literature, where Barberis, Shleifer, and Vishny (1998); Daniel, Hirshleifer, and Subrahmanyam (1998); Hong and Stein (1999); and Baker and Wurgler (2006) are among others some of the representative studies in the field.

Section 5 covers the empirical results. Section 6 concludes the paper with a summary of key findings.

2. Singapore's Mass Rapid Transit (MRT) Network

The idea of having a mass rapid transit (MRT) system to ease anticipated heavy traffic demand had been evaluated as early as 1967 by a team of experts from the United Nations Development Programme (UNDP) in the Singapore's State and City Planning (SCP) project. The huge capital investment estimated at about S$5 billion (in 1982 dollars), which was equivalent to one-fifth of Singapore's GDP at the time, attracted diverging views among the top cabinet ministers in the Singapore's government.[2] The then-Prime Minister, Mr. Lee Kuan Yew, was in favour of the MRT project, but Dr. Goh Keng Swee, who was then the Finance Minister, was not convinced with the MRT proposal and he preferred an all-bus system instead. Dr. Goh commented: *"If you got to spend all this money and subsidise the system, why not spend the money and have an equally effective all-bus system? If an all-bus system is just as good as MRT, why have MRT if you have got to subsidise it?"*[3]

After conducting several rounds of feasibility studies by both the external experts and the in-house teams from the Ministries of National Development and Communications, the government finally decided to proceed with the massive MRT project in 1982, which was estimated to cost S$5.3 billion (in 1982 dollars). The then-Minister for Communications, Mr. Ong Teng Cheong, explained that the reclamation of the new downtown at Marina South was the catalyst for breaking through stalemate in the government's decisions on the MRT project. In Mr. Ong's words: *"Without the MRT, Marina South would have no hope for development."*[4]

Mr. Ngiam Tom Dow, the permanent secretary at the Ministry of Communications, the ministry spearheading the project, gave his reflection on how they convinced Dr. Goh on the economic impact of the MRT project: *"I disagreed with Dr. Goh. I told him that this MRT is a way of providing access to the whole of Singapore, and our land prices were bound to appreciate .... So I looked at it as an economic development project. But Dr. Goh looked at it as just a pure traffic project."*[5]

In October 1983, building works for the proposed MRT system started. A new statutory board, Mass Rapid Transit Corporation (MRTC), the predecessor of Land Transport Authority (LTA), was also established to oversee the project. The initial phase of the MRT system includes 42 stations built along the two North-South and East-West MRT lines. These lines, comprising 67-kilometer of rail networks of which 19 kilometers were built underground, form the backbone of Singapore's MRT system today. MRT trains started running on the 6-kilometer stretch of the North-South line

2. "Financing a city: developing foundations for sustainable growth," *Urban Systems Studies*, published by the Centre for Liveable Cities Singapore, First Edition, 2014.

3. This statement is extracted from page 44, the Urban Systems Studies (USS) report "Financing a city: developing foundations for sustainable growth," published by the Centre for Liveable Cities (CLC) Singapore, First Edition, 2014.

4. Urban Systems Studies (USS) report "Financing a city: developing foundations for sustainable growth," published by the Centre for Liveable Cities (CLC) Singapore, First Edition, 2014.

5. Ngiam, Tong Dow. "Success and Failure of Public Policies: The Singapore Experience, 1960-2000". In: *A Mandarin and the Making of Public Policy: Reflections by Ngiam Tong Dow*. Singapore: NUS Press, 2006, p. 150.

from Yio Chu Kang to Toa Payoh in 1987, and the two lines in the MRT system were completed and in full operation in July 1990.

The MRT system has since been expanded over the years; three more new MRT lines (North-East line, Circle Line and Downtown Line) and other extensions have been added. By the end of 2014, the total rail network coverage consists of 154.2 km MRT rail line and 28.8 km light rail transit (LRT) line. There are 106 MRT stations and 38 LRT stations at the end of 2014. The annual daily ridership for the MRT system is estimated at 2,879,000 as in 2015.[6] In the Land Transport Master Plan (LTMP) 2008, the LTA projects that Singapore's MRT rail network will be doubled to 360 km by 2030, which will exceed Tokyo's and Hong Kong's current rail length. More households will enjoy MRT convenience; and eight in ten homes island-wide will be within a 10-minute walk of a train station by 2030.

Financing new MRT projects is expensive and highly risky. Keeping MRT fares affordable without over-stretching government's fiscal burden is equally challenging. Singapore's government adopts an infrastructure investment model that separates capital investments from operational expenses. The government provides capital for the construction of MRT tracks and infrastructure and the acquisitions of new MRT trains, and then transfers the MRT operations to private companies on long-term leases. Private operators are required to charge fares that are affordable to commuters, and not based on the full cost recovery basis. Commercial MRT operators are expected to extract dividends through improving cost efficiency in running the MRT projects. The public-private partnership (PPP) arrangement is proven to be an economic viable and sustainable way of investing in public infrastructure projects.

The Circle Line (2009-2012)

In this study, we use the opening of the CL spanning over 35.7 kilometers in length and with 28 stations (excluding Bukit Brown) in the design of our natural experiment. The fully automated CL represented by the orange-coloured line in the MRT system map (Figure 1) is Singapore's fourth MRT line run by the operator, SMRT. The CL is projected to serve half a million ridership, on average, each day. The CL symbolises a circular course skirting around the Central Area, and connecting all major MRT routes leading to the CBD. The CL splits into two branches at the Promenade station: one terminating at Dhoby Ghaut interchange, and another terminating at Marina Bay on the North-South extension (which was completed in 2014).

The CL is connected to the existing MRT lines via six MRT stations ("MRTold"), which include Buona Vista, Paya Lebar (East-West line), Bishan, Dhoby Ghaut interchange (North-South line), Serangoon, and Harbour Front (North-East line). Marina Bay and Botanic Garden stations on the CL are subsequently connected to the North-East line extension (2014) and the new Downtown line (2017). The CL connections to the major existing MRT lines are strategically planned to reduce the commuting time from the northern part of the island to the eastern and the western regions without having to go through the interchanges at City Hall and Raffles Place in the CBD. In our empirical tests, we use the 6 existing stations, as indicated by the dummy "MRTold = 1", to establish a linear

6. Singapore Land Transport: Statistics in Brief 2015. Source: Land Transport Authority.

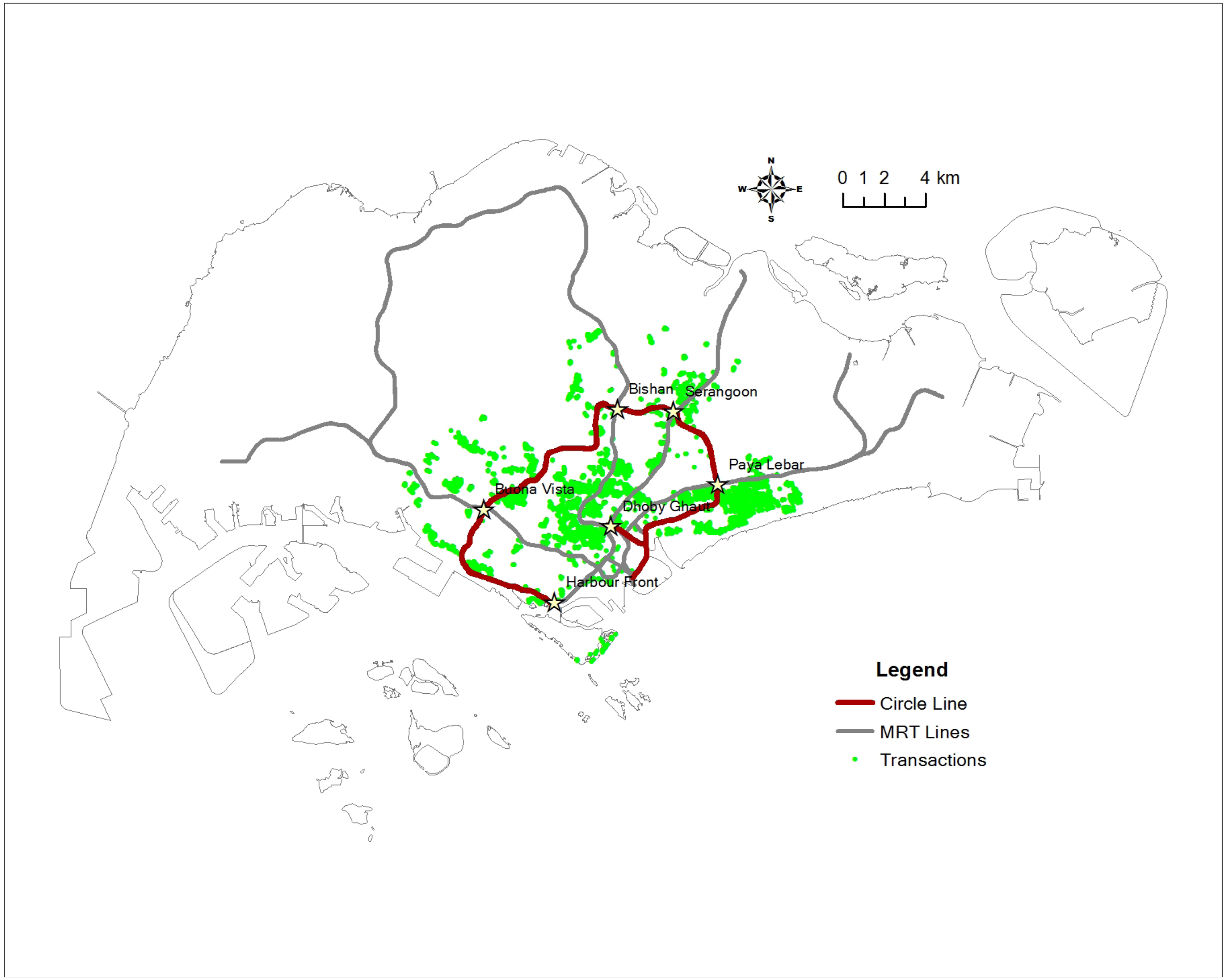

Figure 1. Distributions of Housing Sales and Circle Line MRT Networks
Note: The figure shows the map of Singapore with the grey darkened lines showing the existing MRT networks. The red darkened line shows the Circle Line (CL) and six of the interchanges and terminal on the CL are indicated on the map. The green dots represent on the map represent the sample of housing sales within a 4000 meter boundary from the MRT stations on the CL.

cut-off distance (in meter) within which private non-landed houses command proximity premiums to the closest MRT station.

The tunnelling works for the entire CL line were then completed on August 17, 2009, but the CL stations were opened in phases over four different time periods:

- Phase 1: 28 May 2009: (Bartley - Marymount)
- Phase 2: 17 April 2010: (Dhoby Ghaut - Bartley) (eastern stretch)
- Phase 3: 8 October 2011: (Marymount – Harbour Front) (western stretch)
- Phase 4: 14 January 2012: CL Extension (CLe) (Promenade - Marina Bay)

The ridership on the opening of the first section of CL on 28th May, 2009, (a 5-kilometer 5-station segment stretching from Bartley to Marymount) was estimated at 32,000 passengers per day (ppd), which was lower than the projected 55,000 ppd. The demand, however, picked up upon the opening of the last 12 CL stations after 2011.[7] We use the opening of CL stations as temporal shocks in our experiment to test for changes in housing values "before and after" the CL opening events. We use a dummy, "Ph_k", where k = (1, 2, 3, 4), to represent different phases of the CL opening events.

3. Data sources and Descriptive Statistics

The non-landed housing transactions is the main data source obtained from the "Realis" system of the Urban Redevelopment Authority (URA). We collect a large sample of 138,360 non-landed strata housing sales from the database, which consist of 63.31% condominiums, 28.83% apartments and 7.85% executive condominiums (ECs). The samples cover the period from 2 February, 2009, to 3 May, 2013.[8] EC is a new housing scheme introduced by the Housing and Development Board (HDB) in 1995 to cater for the demand from the "sandwiched" (middle-income) households, who were crowded out from the overheating private housing markets in the mid-1990s. HDB sells development sites to private developers, who build EC projects and sell them to eligible Singaporean households whose monthly income is below S$14,000 (with effects from August 2015).

Unlike condominiums and apartments, ECs are not truly considered laissez-faire deals, where sale restrictions are imposed on buyers in the initial 5 years and 10 years after the purchases. We exclude ECs from our empirical analyses. The sale data include information on sale prices, physical attributes (such as unit size, floor, age, and housing type), land tenure, sale date, buyer type, and also sale type (pre-completion sales and resale). The pre-completion sales include both developers' sales of new units, and also sub-sales by individuals. In our tests, we use a dummy, "dumresale", to separate the new sales (pre-completion sales) from the re-sales (sales of completed units).

7. "Unexpected demand creates human jams at Circle Line", by Tony Ng, Asiaone, 13th Oct 2011. http://www.asiaone.com/Motoring/News/Story/A1Story20111013-304810.html

8. The sample period is deliberately chosen to reduce possible estimation biases caused by the Subprime Crisis in 2007 and 2008, if sales in these two years are used as the control group samples. The short window period of approximately 4.25 years could also reduce serial correlations that could distort the difference-in-differences (Diff-in-Diff) models that will be used in our study (Betrand, Duflo and Mullainathan 2004).

Next, we measure the linear distance of each sample housing unit to the nearest CL MRT station using the ArcGIS tool, and use the distance variable ("distmrt") to capture proximity premiums of housing units to MRT stations. To control for boundary and spatial discontinuity, we drop sample houses that are located more than 4 km from the MRT stations on the CL. We retain the final sample of 81,316 houses for empirical analyses.

3.1. Descriptive Statistics

Table 1 reports the descriptive statistics for the dependent variable, which is the log sale prices of non-landed private housing, "lnprice", and other control variables. Column 1 reports the means and standard deviations (in parentheses) of the variables for the filtered sample (81,316), and Columns 2 and 3 report the statistics for the sub-samples, which are sorted by the sale date into either a treatment group (47,577 observations), where the dummy "after" has a value of 1 if a sale is done after the opening of the nearest CL MRT station (indicated by the "Ph_k" dummy), or a control group ("after = 0") (33,739 observations).

The mean sale price of the housing sample is estimated at S$1,546,549 (or 14.069 in the natural log-term). Housing units sold "before" the opening are more expensive with an average sale price estimated at S$1,629,331 (or 14.120 in the natural log-term) relative to S$1,487,845 (or 14.034 in the natural log-term) for housing units (unadjusted for heterogeneity of housing and spatial attributes) sold after the opening of the closest MRT stations. The standard deviation for the sales before the MRT line opening is estimated at S$1,278,837, which is higher than $1,241,668 estimated for housing units sold after the MRT line opening.

In terms of physical attributes, the average floor level for the housing samples is 9.514 ("floor"), which reflects the high-rise high-density living environment in Singapore. The housing units have an average size ("area") of 110.715 square meters (sqm), and the units are relatively new with an average age of 4.218 years. For the "before" and "after" subsamples, the housing samples in the pre-MRT line opening periods have a higher average floor (10.689 level), larger average unit area (117.371 sqm) and newer (4.260 years) compared to housing units sold in the post-MRT opening periods (floor level of 8.680; unit size of 105.995 sqm, and age of 4.359 years, on average). We find that 61.6% of the sample houses sold have a freehold tenure ("dumfh"), and more freehold units are sold in the "before" subsample (66.1%) than in the "after" subsample (58.6%).

By housing type, the non-landed housing samples include only condominiums ("dumcond") and apartments ("dumapt"). The ECs samples were dropped from the empirical tests. Both condominiums and apartments are developed and sold by private developers; the differences between the two development types are in terms of open space, land area, recreational facilities and sale restrictions. For a condominium development, it must be built on a land with a minimum size of 0.4 hectare. The site coverage (building floor plate) is capped at a maximum of 40% of the land area, so that sufficient communal space is set aside in the development. Condominium projects are usually equipped with full recreational facilities such as swimming pools, barbeque pits, tennis courts, gymnasium room, minimarts, *etc.*, and services such as landscaping, 24-hour securities, cleaning and rubbish disposals, *etc.* Whereas, recreational facilities and services are less comprehensive in apartments due a smaller land area. Condominiums are freely transferrable in housing markets with no restrictions of sales to foreigners; whereas the Residential Property Act restricts the sales of

Table 1. Descriptive statistics

Variable	Symbol	distmrt<=4000	after==0	after ==1	dumMRT ==0	dumMRT==1
Observation		81,316.00	33,739.00	47,577.00	74,752.00	6,564.00
Sale price (in SGD)	price	$1,546,549.00	$1,629,331.00	$1,487,845.00	$1,557,934.00	$1,416,896.00
		($1,259,147.00)	($1,278,837.00)	($1,241,668.00)	($1,289,634.00)	($826,063.00)
ln-sale price	lnprice	14.069	14.120	14.034	14.071	14.052
		(0.557)	(0.568)	(0.547)	(0.566)	(0.446)
Floor level	floor	9.514	10.689	8.680	9.543	9.182
		(8.445)	(9.461)	(7.533)	(8.543)	(7.229)
Unit size (sqm)	area	110.715	117.371	105.995	111.298	104.078
		(57.682)	(59.804)	(55.649)	(58.569)	(45.881)
Building age	age	4.318	4.260	4.359	4.339	4.079
		(7.552)	(7.556)	(7.549)	(7.589)	(7.114)
Freehold tenure	dumfh	0.616	0.661	0.584	0.640	0.349
		(0.486)	(0.473)	(0.493)	(0.480)	(0.477)
Condominium dummy	dumcond	0.588	0.625	0.561	0.587	0.599
		(0.492)	(0.484)	(0.496)	(0.492)	(0.490)
Apartment dummy	dumapt	0.412	0.375	0.439	0.413	0.401
		(0.492)	(0.484)	(0.496)	(0.492)	(0.490)
Resale dummy (secondary market)	dumresale	0.410	0.400	0.417	0.416	0.338
		(0.492)	(0.490)	(0.493)	(0.493)	(0.473)
Newsale dummy (sales by developers)	dumnews	0.472	0.446	0.491	0.467	0.531
		(0.499)	(0.497)	(0.500)	(0.499)	(0.499)
Sub-sale dummy (sale by individuals)	dumsubs	0.118	0.154	0.092	0.116	0.131
		(0.322)	(0.361)	(0.289)	(0.321)	(0.337)
HDB buyer dummy	hdbbuyer	0.343	0.300	0.374	0.344	0.335
		(0.475)	(0.458)	(0.484)	(0.475)	(0.472)
Distance to the nearest MRT station (in meter)	distmrt	1536.357	1509.933	1555.096	1646.854	278.000
		(903.328)	(836.038)	(947.718)	(857.723)	(89.980)

Note: The table shows the means (first row for each variable) and standard deviations (in parentheses) for the dependent variable, which is the natural logarithm of housing prices (lnprice), and other control variables (the descriptions and symbols are given in the first and the second columns). The full sample includes 81,360 non-landed private housing sales in a 4000 meter boundary from the MRT stations on the CL. Based on the time of the transactions, the sample is further sorted into a sub-sample of sales before the opening of CL (after =0) (Column 4) and a sub-sample of sales after the opening of the CL (after=1) (Column5). Based on the cutoff distance of 400 meters from the closest MRT station, the sample is also sorted into the treatment group (400 meters) (the treatment group) (Column 6) and the control group (>400 meters) (Column 7).

apartment units in buildings that are below six-storey in height to foreigners. The housing sample is made up of 58.8% of condominiums and 41.2% of apartments. More condominiums (62.5%) were sold in the pre-MRT opening period compared to 56.1% of condominiums sold in the post-MRT opening period.

By sale type, we divide the sale samples into the primary market (new and uncompleted units) ("dumresale" =0) and the secondary market ("dumresale" =1), which consist mainly of completed units sold by individual owners. The primary market consists mainly of housing units sold by developers in new developments ("dumnews" 47.2%); some of the new units in projects under construction are sold by individual buyers to other buyers before temporary occupation permits (TOPs)[9] are granted, and these sales are classified as "subsales" ("dumsubs" 11.8%). The resales make up about 41.0% of the sample. The resale units take up 40.0% and 41.7% of the full samples in the "before" and "after" periods, respectively.

By the linear distance (in meter) to the closest CL MRT stations, the average distance is estimated at 1,536.357 meters. For the "before" and "after" the CL opening subsamples, the average distances to the closest CL MRT stations are estimated at 1,509.933 meters and 1,555.096 meters, respectively. Figure 2 shows a scatter plot of log-sale price ("lnprice") against distance to the closest MRT station ("distmrt"). The sale distributions appear random within the 4-km bounded area, though we observe a marginal downward trend in housing price over the MRT distance range. We conduct further tests in the next section to see if the price gradient is monotonically decreasing.

3.2. Cut-off boundary (discontinuity) to the closest MRT stations

In our empirical tests for MRT proximity effects on housing prices, the cut-off distance—that shows discontinuity in housing price changes with respects to distance (accessibility) to the nearest MRT station—is important. As an identification strategy, we need to households' "marginal willingness to pay" (MWTP) for being close to a MRT station; or in other words, we need to identify how far (maximum distance) a typical buyer is willing to "walk" to the nearest MRT station so as to take a MRT ride to his/her destination. Instead of having an arbitrarily selected distance,[10] we use the pre-CL opening sales of non-landed housing that are located within 2-km boundary of the six MRT stations on the existing lines (operational stations) ("MRTold" =1) to test the MWTP for MRT accessibility effects. We create discrete distance dummies starting with the first dummy: "dist2 200 meters", and an increment of 100-meter in length for subsequent dummies (*i.e.*, "dist3 = 201 to 300 meters", "dist4 = 301 to 400 meters" ... to "dist15 = 1,401 to 1,500 meters").

We run OLS regressions with two sets of distance "treatment" dummies: the first set includes houses located within the first 1-km boundary from the closest MRT stations, and the second set extends the boundary area to 1.5 km. The models control for heterogeneity in housing and spatial attributes, and sale type. The results are summarized in Table 2. Models 1 and 2 do not have the year of sale fixed effects ("saleyear"); whereas Models 3 and 4 include the year of sale fixed effects. The estimated coefficients on the control variables are consistent across the models, and have the

9. When a building is completed, a developer can apply to the Commissioner of Building Control for a Temporary Occupation Permit (TOP) before giving keys to flats in a project and allowing buyers / owners to move into the building.

10. Diao, Leonard and Sing (2016) propose a local-polynomial-regression-based approach to identify the housing price discontinuity boundary to the MRT stations in Singapore.

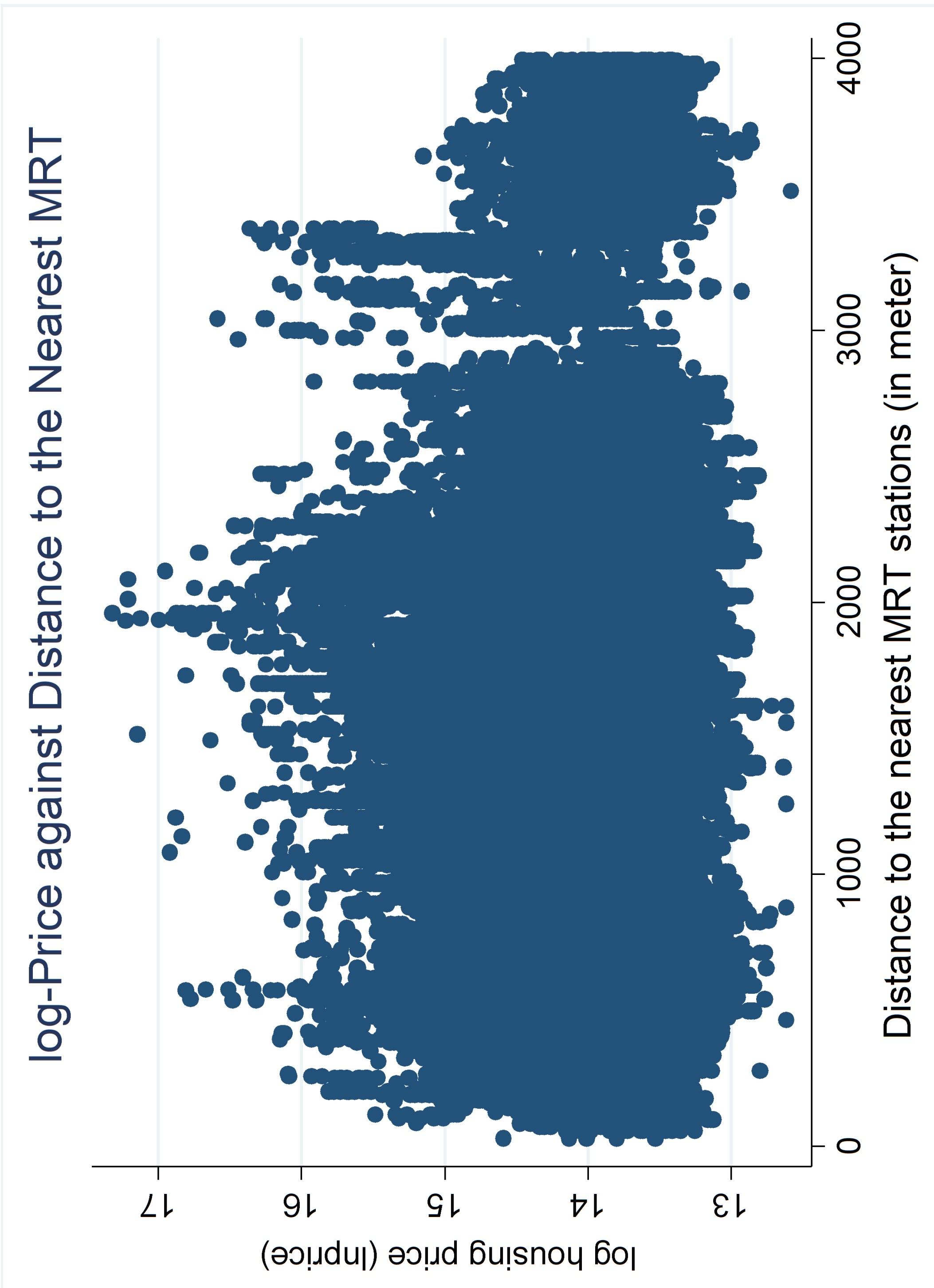

Figure 2. Scatter plot of log-price against distance to the nearest MRT stations
Note: The figure shows the scattered plot of the natural log of housing prices ("lnprice") (y-axis) against the distance to the closest MRT station ("distMRT") (x-axis). The figure includes only the housing samples that are located within a 4,000-meter radius from the nearest MRT stations on the CL are included in the plots.

Table 2. Boundary discontinuities in housing prices

		(1)	(2)	(3)	(4)
Distance<200m	dist2	0.090*	0.090*	0.172***	0.173***
		(0.052)	(0.049)	(0.051)	(0.048)
201 to 300m	dist3	0.118***	0.125***	0.191***	0.193***
		(0.024)	(0.023)	(0.023)	(0.022)
301 to 400m	dist4	-0.029	0.009	0.054**	0.085***
		(0.022)	(0.021)	(0.022)	(0.021)
401 to 500m	dist5	-0.063**	-0.040*	0.014	0.034
		(0.025)	(0.023)	(0.024)	(0.023)
501 to 600m	dist6	0.069***	0.088***	0.140***	0.158***
		(0.026)	(0.025)	(0.026)	(0.025)
601 to 700m	dist7	-0.035*	-0.053***	0.030	0.008
		(0.019)	(0.018)	(0.019)	(0.018)
701 to 800m	dist8	-0.156***	-0.161***	-0.087***	-0.096***
		(0.019)	(0.018)	(0.019)	(0.018)
801 to 900m	dist9	-0.026	-0.052***	0.062***	0.033**
		(0.017)	(0.016)	(0.017)	(0.016)
901 to 1000m	dist10	0.030*	0.087***	0.113***	0.162***
		(0.017)	(0.016)	(0.017)	(0.016)
1001 to 1100m	dist11			0.197***	0.166***
				(0.013)	(0.012)
1101 to 1200m	dist12			0.279***	0.229***
				(0.018)	(0.018)
1201 to 1300m	dist13			0.208***	0.236***
				(0.022)	(0.021)
1301 to 1400m	dist14			0.150***	0.181***
				(0.018)	(0.017)
1401 to 1500m	dist15			0.055**	0.097***
				(0.023)	(0.022)
Floor level	floor	0.013***	0.013***	0.013***	0.013***
		(0.001)	(0.001)	(0.001)	(0.001)
Unit size	area	0.006***	0.006***	0.006***	0.006***
		(0.000)	(0.000)	(0.000)	(0.000)
Condominium dummy	dumcond	0.226***	0.219***	0.231***	0.235***
		(0.009)	(0.008)	(0.009)	(0.008)
Freehold dummy	dumfh	0.251***	0.259***	0.223***	0.235***
		(0.011)	(0.011)	(0.011)	(0.011)
Age	age	-0.011***	-0.012***	-0.010***	-0.011***
		(0.001)	(0.001)	(0.001)	(0.001)
Resale dummy	dumresale	-0.069***	-0.091***	-0.072***	-0.093***
		(0.011)	(0.011)	(0.011)	(0.011)
Constant	Constant	13.038***	12.969***	12.968***	12.905***
		(0.016)	(0.015)	(0.016)	(0.015)
R-squared		0.674	0.706	0.692	0.722

*Note: This table summarizes the OLS regression results with the ln-housing price (lnprice) as the dependent variables. The models are estimated using only 7,679 housing transactions located within 2,000 meters from the 6 existing MRT stations (Buona Vista, Paya Lebar (East-West line), Bishan, Dhoby Ghaut inter-change (North-South line), Serangoon and Harbour Front (North-East line) before the opening of the CL. The "dist2" and "dist_k", where k=(3…15) are distance dummies with a 100-meter interval. Column (4) includes the planning sector fixed effects (FE), which is defined by the first 2 digits of the postal code. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1*

correct signs. The models show that housing attributes, such as floor level, unit size, freehold tenure, and condominium dummy all have positive effects on housing prices; whereas, the age variable has a negative effect on housing prices. Housing prices in the resale market are lower than prices for comparable houses in the developers' sale market.

In Models 1 and 2, where housing sales in the 1-km to 2-km boundary are used as the control sample, we find that houses located in the first 200 meters and between 201 and 300 meters have positive price premiums relative to the control sample of houses located outside the 1-km boundary from the nearest CL MRT stations. The proximity premiums ranging between 9.0% and 12.5% are statistically and economically significant. However, the premiums disappear for houses in the 301-m to 400-m region, and then become negative for houses located in the 401-m to 500-m region. The premium is positive again in the 501-m to 600-m region, and then becomes negative beyond the 601-m radius range. The results are consistent in the two models, and we observe a reasonable clear discontinuity in housing price at the 301-m radius, though we believe the 601-m radius could be caused by the trade-off against other negative externalities associated with being close to MRT stations, such as noise, traffic congestion, *etc.* (Bollinger and Ihlanfeldt, 1997; and Bowes and Ihlanfeldt 2001)

In Models 3 and 4, where we include 5 more discrete distance dummies ranging from 1,001 to 1,500 meters into the treatment group, and use housing sales between 1,600 meters and 2,000 meters as the control sample. The two models are consistent and the coefficients do not vary significantly in Model 4, where the year of sale fixed effects are added. We observe a similar pattern of price increases for houses located near the MRT stations, and the positive premiums are economically and statistically significant and positive in the first 400 m range. The coefficient on "dist5" (401- to 500-meter range) is positive but insignificant, and the coefficient on "dist6" (501- to 600-meter range) is again positive and significant. Figure 3 plots the coefficients on the "dist_i", where [i= (2, 3, ….., 15]; and we could see the clear discontinuity in the price premiums for houses located up to 400 meters from the closest MRT stations on the CL. The positive premiums for houses located in the range from 1,000-m to 1,500-m range relative to the control sample (1,501-m to 2,000-m range) could be due to factors other than being in close proximity to the CL MRT stations.

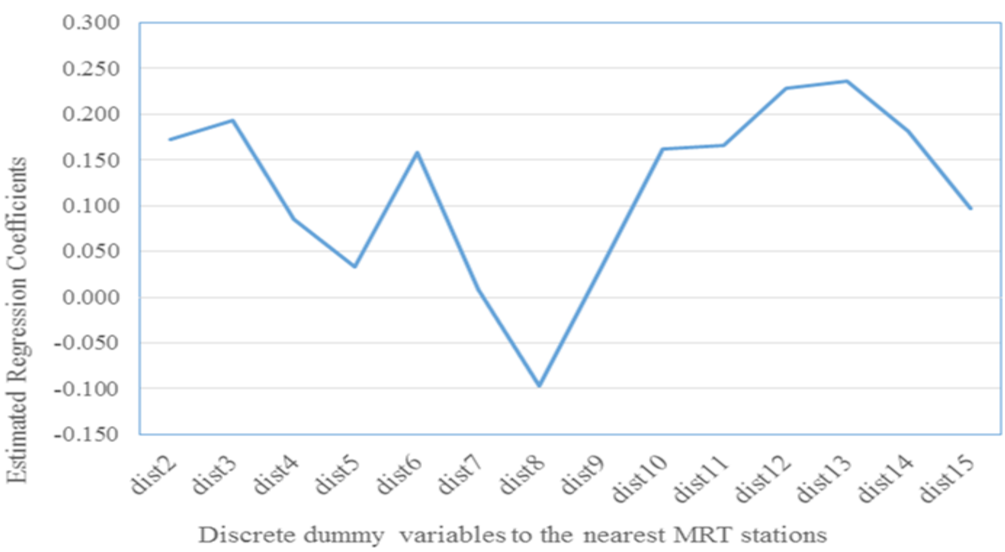

Figure 3. Estimated coefficients of the distance to the closest CL MRT stations
Note: The graph shows the estimated ln-housing price regression against different dummies on the distance to the closest MRT stations ("dist2" and "dist_k", where k=(3, 4, …15), where the sample includes houses that are located within 2,000 meters from the nearest CL MRT stations. We control for other variables in the models as shown in Table 2 (Column 4).

Therefore, based on the above results, we set the treatment boundary at 400 meters to capture the proximity (accessibility) effects; we use a dummy variable, "dumMRT", to sort houses into the treatment group if they are located within 400 meters from the nearest CL MRT station, and otherwise into the control group (*i.e.*, distmrt > 400 meters). We estimate the descriptive statistics for the housing samples in the treatment and the control groups, and the results are summarized in the last two columns of Table 1. There are 6,564 housing samples in the treatment group compared to 74,752 housing samples in the control group (those located outside the 400-m radius from the closest MRT station). The average (unconditional) sale price for houses in the treatment group is estimated at $1,416,896 (or 14.052 in the natural log-term), which is lower than the average housing price in the control group (S$1,557,934) (or 14.071 in the natural log-term). The average floor level of houses located in the accessibility range to the MRT station is 9.182, compared to 9.543 for those located outside the range. The average size for houses located in the treatment range is smaller at 104.078 sqm, but they are newer with an average age of 4.079 years, compared to bigger (111.298 sqm) but older (4.339 years) houses located outside the CL MRT accessibility range. 64.0% of the houses sold in the control group have a freehold tenure, compared to 34.9% of freehold-tenured houses sold in the treatment region. Condominiums make up 58.7% of the housing sample in the control group relative to 59.9% in the treatment group. Developers' sales constitute the majority share of 53.1% of the total sales, compared to the second-hand (resale) sales of 33.8% of the sample houses located within the MRT accessibility region. For the housing market outside the MRT accessibility region, resale housing units and developers' new sale units make up about 41.6% and 46.7%, respectively. The sub-sales make up the balance of 11.6% and 13.1% in the control and the treatment regions, respectively.

We draw the kernel density plots of the in-housing price sorted by the timing of the sales ("before" and "after" the opening of CL line); and we also plot the two graphs, where one is for the full sample and another is for the sample located in the 400-m treatment range, as shown in Figure 4. We find that the kernel density plots for the "before" and "after" sub-samples do not show significant variations, but the kernel density plots show clear differences in log-prices for houses in the 400-m radius from the MRT station. For housing transactions in the treatment region (≤ 400 meters from the MRT station) (Figure 5), we find significant increases in sales of houses in the price range of approximately between S$806,130 ("lnprice" = 13.6) and S$1,623,346 ("lnprice" = 14.3) after the new CL opening. Sales of more expensive houses (more than S$1,600,000 price range) significantly decrease in the accessibility range to the MRT station after the CL opening.

4. Empirical Design and Methodology

We design an empirical strategy to test for housing wealth effects surrounding the CL opening as the treatment event. We hypothesize that households are willing to pay a premium to live close to MRT stations for the convenience of public transportation. House buyers capitalize the accessibility to MRT stations into housing prices; houses located in close proximity to MRT stations (within walking distance, which in our context, is set at not more than 400 meters) command price premiums relative to other houses located outside the MRT accessibility zone.

Empirical studies attempting to test the capitalization effects of MRT proximity face the challenges of having to ensure that the causality goes in the direction from being close to MRT stations to housing price increases. There are two possible sources of endogeneity. First, if central planners choose to locate MRT stations in high growth neighbourhoods, housing price increases in these neighbourhoods may be uncorrelated with being close to MRT stations. Second, the

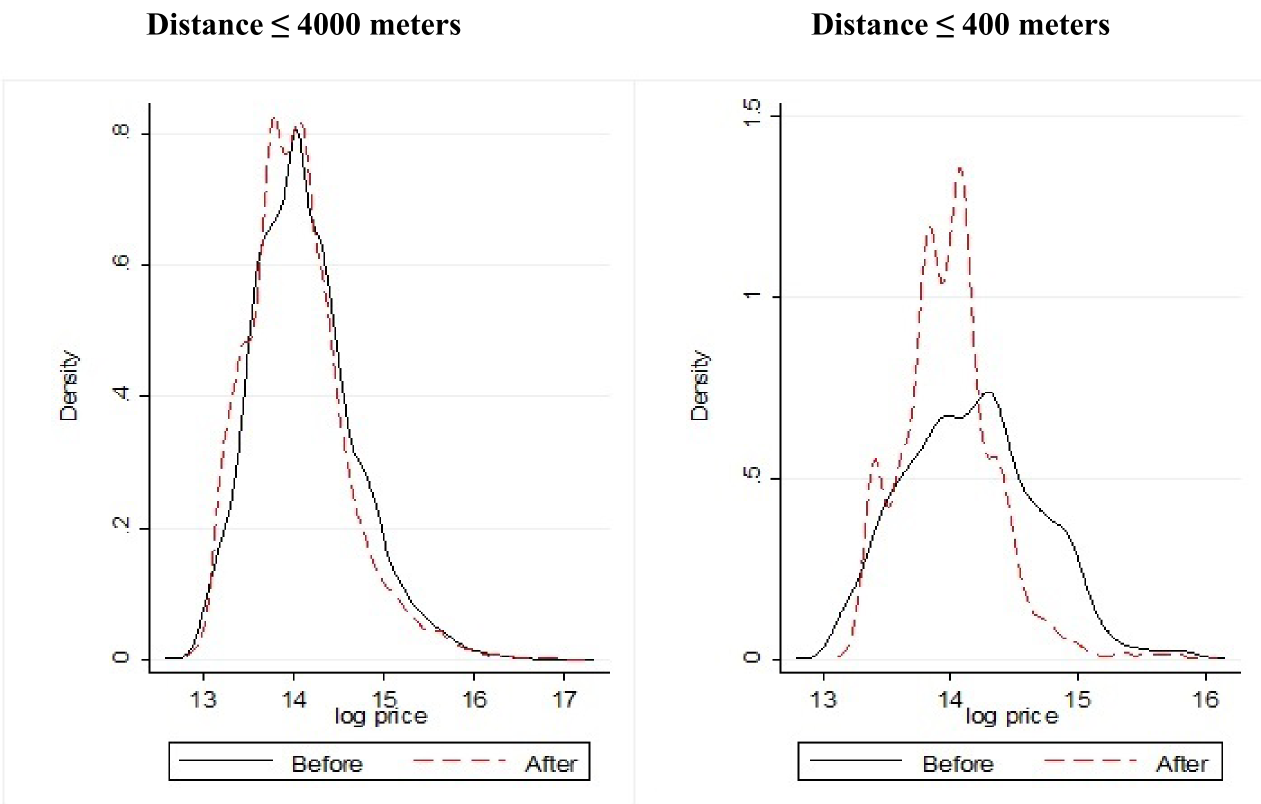

Figure 4. Kernel density plots of housing prices "Before" and "After" the opening of CL
Note: The graphs show the kernel density of the ln-housing prices (lnprice) using two sub-samples of housing transaction data. The left panel shows the kernel density with the full sample of houses located within 4,000 meters from the closest MRT stations; and the right panel shows the kernel density with a smaller subsample of houses located within 400 meters from the closest MRT stations. In each graph, the kernel density of ln-housing prices "before" (darkened line) and "after" (dashed line) the opening of CL are plotted.

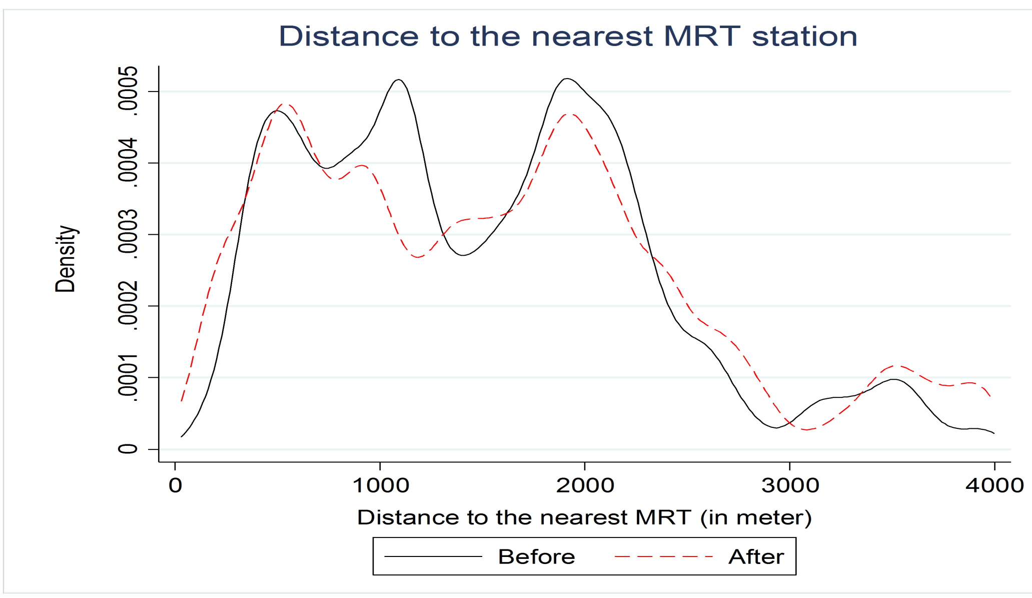

Figure 5. Kernel density plot housing sales by the distance to the nearest MRT station
Note: The graph plots the kernel density on the housing sales identified by the distance to the closer CL MRT stations. The darkened line represents the kernel density plots for the housing sales "before" the CL opening, and the dashed line represents the kernel density plot for housing sales "after" the CL opening.

simultaneity effects correlated with the completion of MRT line; for example, if more commercial amenities were attracted to neighbourhoods close to MRT stations, buyers may pay high price premiums for accessibility to such amenities, rather than MRT stations (Brueckner 2003). Our empirical strategies to minimize endogeneity are as follows: First, we use the CL opening dates, which are assumed to be exogenous to house buyers, to test temporal variations in housing price changes before and after the opening of the CL MRT line. Some may argue that price increases during the opening of MRT line could be correlated with other cofounding events occurring around the same time, such as completion of new amenities in the area. Our second strategy is to identify houses that are more likely to be affected by the treatment of the new MRT line opening. We use the 400-m boundary to separate houses that are more likely to enjoy accessibility benefits from those that are not directly affected by the new MRT line opening. The distance identifier could be exogenous to the MRT stations, and housing price changes in the treatment area are unlikely to be influenced by factors other than the MRT line opening. Third, we use the year of sale fixed effects to control for other macro-housing price trends that are orthogonal to the MRT line opening. We also use the planning sector (based on the first 2 digits of the 6-digit postal code) fixed effects to remove spatial non-MRT amenities, such as schools and shopping malls, that could affect housing values in neighbourhoods with and those without MRT accessibility convenience.

We implement the empirical strategies in the difference-in-differences (diff-in-diff) framework by estimating the natural log-prices of houses (a dependent variable) ("$\ln P_{i,t}$") against the MRT distance dummy ("dumMRT"), the opening of CL time dummy ("after"), and the interactive two terms ("aftdumMRT = after × dumMRT"), controlling for a hedonic attribute vector, $\mathbf{X}_{i,t}$, as well as the time (τ_t) and spatial (λ_i) fixed effects. The model specification is written as:

$$\ln P_{i,j,t} = \alpha_i + \beta_i X_{i,t} + \delta_i dumMRT_{i,j,t} + \theta_i after_{i,j,t} + \gamma_i aftdumMRT_{i,j,t} + \tau_t + \lambda_i + \varepsilon_i \qquad (1)$$

where the vector of control (hedonic) variables ($\mathbf{X}_{i,t}$) include housing attributes, such as floor level (height) ("floor"), unit size (in sqm) ("area"), age (in year), housing type (a condominium dummy, "dumcond"), housing tenure (a freehold tenure dummy, "dumfh"), and a sale type dummy (to separate secondary market sales of completed units versus uncompleted units) ("dumresale"). α_i, β_i, δ_i, θ_i, and γ_i are the estimated coefficients, and ε_i is the error term.

For the treatment effects, we use the two variables: a spatial dummy, "dumMRT", which uses the cut-off distance of 400 meters to capture discontinuity in housing price with respect to distance to the nearest MRT station; and another dummy, "after", that identifies time variations in housing prices by differentiating housing sales "before" and "after" the opening of a MRT station *j*. If a house near the MRT station *j* were sold after the MRT station opening, the dummy "after" has a value of 1, and otherwise a value 0. The CL was opened in stages over four different periods: "Ph_1": 28 May, 2009; "Ph_2": 17 April, 2010; "Ph_3": 8 October, 2011; and "Ph_4": 14 January, 2012. In our empirical analyses, we need to match a house i to the closest MRT station j on the CL, and then compare the sale date of the house with the opening of the MRT station to derive the value for the "after" dummy. As a robustness test, we create a dummy, "bef6mth", which has value of 1, if a house *i* were sold in less than 180 days before the opening of the MRT station *j*, and use the dummy to test the "anticipative" effects in the pre-opening of CL.

Table 3. Treatment effects of the opening of new CL MRT stations

Sample criteria: Distance to the MRT stations ("distMRT")		**(1)**	**(2)**	**(3)**
		<=4000m	**<=4000m**	**<=2000m**
Floor level	floor	0.015***	0.007***	0.007***
		(0.000)	(0.000)	(0.000)
Unit size	area	0.007***	0.007***	0.007***
		(0.000)	(0.000)	(0.000)
Condominium dummy	dumcond	0.133***	0.165***	0.154***
		(0.003)	(0.002)	(0.002)
Freehold dummy	dumfh	0.149***	0.099***	0.086***
		(0.003)	(0.002)	(0.003)
Age	age	-0.011***	-0.009***	-0.008***
		(0.000)	(0.000)	(0.000)
Resale dummy	dumresale	0.017***	-0.052***	-0.051***
		(0.003)	(0.002)	(0.003)
After the opening of MRT line	after	0.051***	0.016***	0.015***
		(0.002)	(0.002)	(0.003)
Proximity to MRT (≤ 400m)	dumMRT	0.126***	0.042***	0.049***
		(0.007)	(0.005)	(0.005)
After × Proximity to MRT	aftdumMRT	-0.078***	0.132***	0.122***
		(0.009)	(0.006)	(0.006)
Constant	Constant	12.959***	13.532***	13.539***
		(0.004)	(0.008)	(0.009)
Observations		81,316	81,316	57,417
R-squared		0.669	0.865	0.859
Planning Sector FE		No	Yes	Yes
Year of Sale FE		No	Yes	Yes

*Note: This table summarizes the OLS regression results with the ln-housing price (lnprice) as the dependent variables. Models in Columns (1) and (2) are estimated using a sample of 81,316 transactions found within a 4,000-meter boundary from the closest CL MRT stations, and Column (3) is estimated using a sub-sample that includes only 57,417 transactions within a 2000 meter boundary. The models include a vector of control variables that include floor level ("floor"), unit size ("area"), condominium dummy ("dumcond"), freehold dummy ("dumfh"), age, and resale dummy ("dumresale"). "After" is the treatment dummy that have a value of 1, if a sale occurs after the CL opening; and otherwise 0 for a sale occurs before the CL opening. "dumMRT" is the proximity dummy that has a value of 1, if a house is located within 400 meters from the closest CL MRT station; and 0 otherwise; and "aftdumMRT" is the interactive term of the two treatment variables. The planning sector fixed effects (FE) is defined by the first 2 digits of the postal code, and the year of sale fixed effect is also included in the model. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1*

5. Empirical Analysis and Results

5.1. Housing wealth effects and MRT line opening

We estimate the baseline OLS model as in Equation 1 without the year of sale and the planning sector (spatial) fixed effects, and use only the housing sales that fall within 4,000 meters from the closest MRT station so as to minimize boundary discontinuity effects. The results are summarized in Column 1 of Table 3. The adjusted R^2 of the model is estimated at 0.669. The estimated coefficients on the vector of hedonic attributes are all statistically significant and have the correct signs. Variables such as floor level, unit size, condominium dummy, freehold dummy and resale dummy are positively correlated with housing prices; whereas, housing age is negatively correlated with housing prices.

The results on the key treatment variables in the model shows that the CL opening has positive impact on housing prices, and houses located within 400-meter radius from the CL MRT stations are sold for higher prices than other houses located outside the vicinity. The results seem to be consistent with the expected treatment outcomes. However, when we look at the interactive term, it has an incorrect sign, which implies that housing prices in the treatment area decrease more than the house prices in the control area after the CL opening. The results could be influenced by unobserved spatial heterogeneity and time variations that are not controlled for in the model.

In Column 2, we include the planning sector and the year of sales fixed effects to the model, and the goodness of fit of the model increases significantly to 0.865. While most of the estimated coefficients on the hedonic variables are significant and have the correct signs, but the values of the coefficients are different. For the resale dummy, we find that the coefficient becomes negative after controlling for the spatial and temporal variations in the housing price model. We show that the treatment effects are more consistent with the expected outcomes. The results show that housing prices in the post-CL opening period increase at a more moderate rate of 1.6% compared to 5.1% estimated in the baseline model. We find that houses located within 400 meters from the closest CL MRT station sell for a price of 4.2% higher than comparable houses located outside the 400-m MRT station region. The interactive term ("aftdumMRT") is also statistically significant and has a positive sign, which implies that houses with the accessibility convenience to the new CL ("dumMRT" = 1) sell for 13.2% more expensive than other houses without the accessibility convenience to the new CL. The results confirm that the opening of CL generates positive housing wealth effects to households who live and own houses in close proximity to MRT stations along the CL.

We conduct a robustness test by reducing the sample coverage area from 4,000 meters to 2,000 meters, which cut the sample size from 81,316 observations to 57,417 observations. The adjusted R^2 of the model as shown in Column 3 of Table 3 decreases only marginally to 0.859. The estimated coefficients for the Model (3) are consistent with the estimated coefficients of the early Model (2). We find significant treatment effects, which show that the opening of the new CL increases prices for houses located within 400 meters from the closest CL MRT station by 12.2% in the post-opening period relative to price changes of other houses that are located outside the 400-m range. The results again support the story that the new CL opening generates positive economic effects on houses that are within an accessibility distance to the MRT stations along the line.

5.2. Effects on existing MRT stations

The CL is connected to other major MRT lines via six existing MRT stations, which are denoted by the dummy "MRTold". Except for the two terminating stations on the CL (Harbour Front in the west and Dhoby Ghaut in the centre), four of the existing stations serve as the interchanges that connect the CL to other major MRT lines. These four interchanges are Buona Vista station and Paya Lebar station on the East-West line, Bishan station on the North-South line, and Serangoon station on the North-East line. Commuters living in the city fringe areas could travel to the outskirts of the island and the CBD with MRT via these four interchanges. We first use the six existing stations to establish the cut-off distance for the MWTP in Table 2; and as additional robustness tests, we next test how the opening of new stations on the CL affects housing prices around these existing stations relative to other stations.

The results of the panel regressions with the spatial and time fixed effects are summarized in Table 4. Column 1 shows the results when all the six existing stations as identified by the dummy "MRTold" are included in the triple-interactive term, ("after×dumMRT×MRTold"); whereas Column 2 replaces the "MRTold" with the "interchg" dummy to capture the incremental effects of the four interchanges on the CL line (Buona Vista, Bishan, Serangoon and Paya Lebar stations). The estimated coefficients on the control variables are significant, and the overall results are consistent with those reported for Model 2 in Table 3. The results show an average growth in housing prices of 2.6% after the CL opening, and houses located within the 400-m radius from the CL stations enjoy significant price premiums of about 13.0% relative to other houses located outside the 400-m range. We find that the coefficients on the two triple-interactive terms—"after×dumMRT×MRTold" (Model 1) and "after×dumMRT×interchg" (Model 2)—are significant, but have negative values of -0.093 and -0.096, respectively. The results imply that while housing prices near the CL MRT stations in general increase following the opening of CL, housing prices increase at a faster rate in other CL stations than housing prices in the existing stations (both "MRTold" and "interchg") ("dumMRT|MRTold=0" and "dumMRT|interchg=0"). The new CL generates incrementally higher housing wealth effects to households, who were previously not served by the CL line, relative to households who have already had the access to the existing lines via the six stations.

Table 4. Treatment effects in existing MRT stations and inter-changes

		(1)	(2)
Floor level	floor	0.007***	0.007***
		(0.000)	(0.000)
Unit size	area	0.007***	0.007***
		(0.000)	(0.000)
Condominium dummy	dumcond	0.163***	0.163***
		(0.002)	(0.002)
Freehold dummy	dumfh	0.094***	0.094***
		(0.002)	(0.002)
Age	age	-0.009***	-0.009***
		(0.000)	(0.000)
Resale dummy	dumresale	-0.050***	-0.050***
		(0.002)	(0.002)
After the opening of MRT line	after	0.026***	0.026***
		(0.002)	(0.002)
Proximity to MRT (≤ 400m)	dumMRT	0.129***	0.130***
		(0.003)	(0.003)
After × Proximity × Existing MRT station	aftdumMRTold	-0.093***	
		(0.009)	
After × Proximity ×Interchange	aftdumMRTinterchg		-0.096***
			(0.009)
Constant	Constant	13.509***	13.511***
		(0.008)	(0.008)
Observations		81,316	81,316
R-squared		0.864	0.864
Planning Sector FE		Yes	Yes
Year of Sale FE		Yes	Yes

*Note: This table summarizes the OLS regression results with the ln-housing price (lnprice) as the dependent variables. The Models are estimated using a sample of 81,316 transactions found within a 4,000-meter boundary from the closest CL MRT stations. The models include a vector of control variables that include floor level ("floor"), unit size ("area"), condominium dummy ("dumcond"), freehold dummy ("dumfh"), age, and resale dummy ("dumresale"). "After" is the treatment dummy that have a value of 1, if a sale occurs after the CL opening; and otherwise 0 for a sale occurs before the CL opening. "dumMRT" is the proximity dummy that has a value of 1, if a house is located within 400 meters from the closest CL MRT station; and 0 otherwise; and "aftdumMRT" is the interactive term of the two treatment variables. The triple-interactive terms "aftdumMRTold" and "aftdumMRTinterchg" interact "aftdumMRT" with the two station-related variables, where "MRTold" is used to identify six of the existing MRT stations ((Buona Vista, Paya Lebar (East-West line), Bishan, Dhoby Ghaut interchange (North-South line), Serangoon and Harbour Front (North-East line)), and "interchg" identifies four of them that are used as the inter-changes on the CL line (Buona Vista, Paya Lebar (East-West line), Bishan (North-South line), Serangoon (North-East line). The planning sector fixed effects (FE) is defined by the first 2 digits of the postal code, and the year of sale fixed effect is also included in the model. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.*

5.3. Heterogeneity Tests

We run some heterogeneity tests to further identify if the differential economic spillovers effects of the new CL between new sales (consist mainly of pre-completion sales by developers) and resales (completed), and private buyers and public housing upgraders. The results are summarized in Table 5. Column 1 shows the incremental effects of the new CL line on the resale housing market vis-à-vis the new (pre-completion) sale markets. We find that the new CL have larger incremental on the treatment group of houses in the new sale markets than those in the resale market. The differential price effects associated with the accessibility benefits of the CL are about 6.4% with the developers' new houses enjoy the greater price increases relative to houses sold in the secondary market. There is anecdotal evidence showing that private developers capitalize on the opening of the CL in the launch of new projects, such as Sky Habitat[11] that was labelled as the most expensive suburban residential project when it was launched in April 2012 by CapitaLand, one of the largest listed developers in Singapore.[12]

By buyer type, we separately identify new private housing buyers, who previously live in HDB flats identified with public housing addresses, and other housing buyers with private housing addresses. We denote the "public housing upgraders" group by a new dummy variable, "HDBbuyer"; and they make up about 34.3% of the sample buyers. We observe a significant increase in the number of upgraders from 30.0% to 37.4% in the two periods "before" and "after" opening of the CL. In Column 2, the triple-interactive term shows that HDB upgraders pay 4.3% more than other private housing buyers for houses located within 400 meters from the closest MRT stations after the CL opening, ceteris paribus. Public housing buyers, who are more likely to use MRT to commute on daily basic, place higher MWTP premiums for accessibility benefits to the CL MRT stations.

5.4. Temporal variations of the MRT line opening

As the CL opened in stages over a 2.5-year period from May 2009 to Jan 2012, we test the temporal variations in the treatments associated with the CL opening events. Based on the gradual information diffusion argument, we expect the earliest phase of CL opening (the stretch from Bartley station to Marymount station) to have larger incremental price impact than the last phase of the CL line extension from Promenade station to Marina Bay station. We represent each of the four phases of CL opening with a dummy "Ph_k", where k = (1, 2, 3, 4), and replace the treatment term "after" in Equation (1) with the four new interactive terms: "aftPh_k" and "aftPh_k×dumMRT". The regression results are reported in Column 1 of Table 6.

The results show significant negative price changes after the phase 1 ("aftPh_1": May 2009), phase 3 ("aftPh_3": October 2011) and phase 4 ("aftPh_4": January 2012); and the only period that show positive price growth is after the phase 2 of the CL opening ("aftPh_2": April 2010). The first period decline could be caused by the negative sentiment from the aftermath of the Subprime Crisis in 2007–2008; whereas the negative growth in October 2011 and January 2012 could be caused by the impact of cooling measures introduced by the government during the periods. We next examine

11. "CapitaLand sells 125 units at Sky Habitat", by Kalpana Rashiwala, The Business Times, 16th Apr 2012.

12. "Sky Habitat effect' lifts sales in other estates", by Esther Teo, The Straits Times, 16th Jun 2012.

the treatment effects shown by the triple "diff-in-diff" variables in Model 1, and find that stronger price increases when the phase 1 CL opened in May 2009, which creates positive price effects of 19.2% for houses located within 400 meters from the stations along the Bartley and Marymount stretch. The incremental price effects are still positive in the phases 2 and 3 of the CL opening, but with a weaker magnitude of 12.5% and 3.4%, respectively. There is no significant price effect shown in the phase 4 extension of the CL to the Marina Bay in January 2012. The results are consistent with the information diffusion hypothesis, which predicts strong price effects when the CL opening event was first revealed in the market.

Table 5. Effects on developers' sales and public housing upgraders

		(1)	(2)
Floor level	floor	0.007***	0.007***
		(0.000)	(0.000)
Unit size	area	0.007***	0.007***
		(0.000)	(0.000)
Condominium dummy	dumcond	0.164***	0.163***
		(0.002)	(0.002)
Freehold dummy	dumfh	0.096***	0.095***
		(0.002)	(0.002)
Age	age	-0.009***	-0.009***
		(0.000)	(0.000)
Resale dummy	dumresale	-0.048***	-0.052***
		(0.002)	(0.002)
After the opening of MRT line	after	0.026***	0.024***
		(0.002)	(0.002)
Proximity to MRT (≤ 400m)	dumMRT	0.134***	0.111***
		(0.003)	(0.003)
After × Proximity × Resale	aftdumMRTresale	-0.064***	
		(0.006)	
After × Proximity × HDB buyer	aftdumMRThdbbuyer		0.043***
			(0.006)
Constant		13.507***	13.514***
		(0.008)	(0.008)
Observations		81,316	81,316
R-squared		0.864	0.864
Planning Sector FE		Yes	Yes
Year of Sale FE		Yes	Yes

*Note: This table summarizes the OLS regression results with the ln-housing price (lnprice) as the dependent variables. The Models are estimated using a sample of 81,316 transactions found within a 4000 meters boundary from the closest CL MRT stations. The models include a vector of control variables that include floor level ("floor"), unit size ("area"), condominium dummy ("dumcond"), freehold dummy ("dumfh"), age, and resale dummy ("dumresale"). "After" is the treatment dummy that have a value of 1, if a sale occurs after the CL opening; and otherwise 0 for a sale occurs before the CL opening. "dumMRT" is the proximity dummy that has a value of 1, if a house is located within a 400meter from the closest CL MRT station; and 0 otherwise; and "aftdumMRT" is the interactive term of the two treatment variables. The triple-interactive terms "aftdumMRTresale" and "aftdumMRThdbbuyer" interact "aftdumMRT" with the two new dummies, which include "dumresale" that indicates non-developers' sales, and "hdbbuyer" identifies public housing upgraders. The planning sector fixed effects (FE) is defined by the first 2 digits of the postal code, and the year of sale fixed effect is also included in the model. . Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1*

Like McDonald and Osuji (1995) and McMillen and McDonald (2004), we test if "anticipative" effects occur around the CL opening event. We use a 6-month pre-opening dummy, "bef6mth", which has a value of 1 if a house were sold in less than 180 days (6 months) before the opening of the closest CL MRT stations, to capture the "anticipative" effects, alongside the post-opening effects in the Model 2. Our results show no "anticipative" effects associated with the CL opening, but prices of houses located close to the MRT stations were 4.4% lower than prices of other houses located outside the 400m cut-off boundary in the pre-opening of CL. However, houses located in the treatment zone increase by 14.3% more than prices of comparable houses outside the treatment zone in the post-CL opening period. We next replace the "after" dummy by "Ph_k", which captures different opening event time effects, and estimate the regression model as shown in Column 3 of Table 6. The results are consistent with the earlier findings, where we observe negative price changes in the pre-opening period, and the information impact is positive in the next three phases of the CL opening but at a declining rate. The news of the extension of the CL (phase 4) has no incremental impact on housing prices in the treatment zone.

Table 6. Temporal effects of the opening of CL

		(1)	**(2)**	**(3)**
Floor level	floor	0.007***	0.007***	0.007***
		(0.000)	(0.000)	(0.000)
Unit size	area	0.007***	0.007***	0.007***
		(0.000)	(0.000)	(0.000)
Condominium dummy	dumcond	0.168***	0.165***	0.168***
		(0.002)	(0.002)	(0.002)
Freehold dummy	dumfh	0.099***	0.098***	0.098***
		(0.002)	(0.002)	(0.002)
Age	age	-0.009***	-0.009***	-0.009***
		(0.000)	(0.000)	(0.000)
Resale dummy	dumresale	-0.052***	-0.053***	-0.053***
		(0.002)	(0.002)	(0.002)
Proximity to MRT (≤ 400m)	dumMRT	0.038***	0.031***	0.028***
		(0.005)	(0.005)	(0.005)
6 months before MRT opening	bef6mth		-0.007**	-0.017***
			(0.003)	(0.003)
6 months before MRT opening x Proximity to MRT	bef6mthdumMRT		-0.044***	-0.037***
			(0.010)	(0.010)
After the opening of MRT line	after		0.021***	
			(0.003)	
After×Proximity to MRT	aftdumMRT		0.143***	
			(0.007)	
AfterxPhase 1	aftph1	-0.041***		-0.028***
		(0.005)		(0.006)
AfterxPhase 2	aftph2	0.046***		0.058***
		(0.003)		(0.003)
AfterxPhase 3	aftph3	-0.007*		-0.001
		(0.004)		(0.004)
AfterxPhase4	aftph4	-0.022***		-0.020**
		(0.008)		(0.008)
After×Phase1×Proximity to MRT	aftph1dumMRT	0.192***		0.202***
		(0.008)		(0.008)
After×Phase2×Proximity to MRT	aftph2dumMRT	0.125***		0.134***
		(0.008)		(0.008)
After×Phase3×Proximity to MRT	aftph3dumMRT	0.034***		0.044***
		(0.011)		(0.011)
After×Phase3×Proximity to MRT	aftph4dumMRT	-0.080		-0.070
		(0.054)		(0.054)
Constant		13.545***	13.535***	13.549***
		(0.008)	(0.008)	(0.008)
Observations		81,316	81,316	81,316
R-squared		0.866	0.865	0.866
Planning Sector FE		Yes	Yes	Yes
Year of Sale FE		Yes	Yes	Yes

*Note: The table summarizes the regression with the ln-housing price (lnprice) as the dependent variable. The Models are estimated using a sample of 81,316 transactions found within a 4,000-meter boundary from the closest CL MRT stations. "Phase 1" = 28 May, 2009: (Bartley–Marymount); "Phase 2" = 17 April, 2010: (Dhoby Ghaut–Bartley) (eastern stretch); "Phase 3" = 8 October, 2011: (Marymount–Harbour Front) (western stretch); "Phase 4"= 14 January, 2012: CL Extension (CLe) (Promenade–Marina Bay). Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1*

6. Conclusion

The bid-rent theory of Alonso (1964), Muth (1969), and Mills (1972) has shaped urban growth of monocentric cities for decades. Household preference for bigger space and tranquillity of living environment in suburban areas induces them to live further away from central areas. The trade-off between commuting costs and housing consumption results in a negative bid-rent curve, which predicts that housing price declines with respect to distance from the CBD. However, with large public investments in transit and MRT networks that improve connectivity and accessibility to suburban areas, the Alonso-Muth-Mill's bid-rent theory has become less relevant in the urban structure in today's modern cities. There are two competing hypotheses that explain possible positive rent gradient from the CBD: First, Richardson (1977) argues that less congested and low-density living environment in suburbs creates externality rents for high income households, who pay higher housing prices in areas located further away from the CBD. Second, the decentralisation trend also reduces the CBD effect. The emergence of multiple regional centres changes a monocentric city structure to a poly-centric one. Richardson *et al.* (1990) show that the distance-to-CBD effects on bid rent is still statistically significant but weak in 1970, and the distance effects disappeared in 1980 in some US cities.

This study empirically tests housing wealth effects associated with the opening of new CL MRT Line in Singapore. Using non-landed private housing transactions for the period from January 2009 to May 2013, we find that the opening of the new CL MRT line increases housing prices by 1.6%, on average. Houses in the treatment zone, which is within 400 meters from the CL MRT stations, sell for 4.2% higher in price than comparable houses located outside the 400-m MRT zone. Housing price increases in the MRT treatment region are 13.2% more than housing price increases of houses located outside the treatment regions after the CL opening. Based on 6,564 houses sold for an average price of S$1,416,896 in the post-CL opening period, which is translated into an aggregate value of S$9.30 billion, we estimate the housing wealth of S$1.23 billion accrued to households living in 400-m radius from the closest MRT stations after the opening of the CL. We also find that the accessibility premiums are larger in developers' market, and for public housing buyers (HDB upgraders) who pay relatively higher accessibility premiums relative to private housing buyers.

When we test temporal variations in the treatment effects, we find no significant "anticipative" effects in the six-month window prior to the opening of the new CL. Housing price in the treatment zone increases by more than 14.3% relative to housing prices outside the treatment zone after the CL opening. We find significant positive treatment effects in the first three phases of the CL opening, but the treatment intensity diminishes after phase 1. The results are consistent with the information diffusion hypothesis, and the results find no sentiment-driven momentum effects.

Governments of rapidly expanding cities invest heavily in public transit projects to meet increasing transportation demand. In countries including Singapore, new public transit lines are seen as a key driver for economic and employment growth.[13] There are also other non-pecuniary benefits associated with public transit lines, which include reductions in road congestion and greenhouse

13. Mr Ngiam Tong Dow, the then permanent secretary of the Ministry of Communications, used the economic motivations to persuade the government to commit on the MRT project in Singapore. Sources: "Success and Failure of Public Policies: The Singapore Experience, 1960-2000". In A Mandarin and the Making of Public Policy: Reflections by Ngiam Tong Dow. Singapore: NUS Press, 2006, pp 150.

emission to the environment. For households, public transit lines cut down commuting costs; and for residents living in close proximity to transit stations, they also generate significant housing wealth effects. There are three implications for the positive housing wealth effects created by the new MRT line: First, the location of new MRT stations creates significant housing wealth effects for surrounding houses; therefore, central planners' decisions in selecting sites for future MRT projects should be objective and equitable. Second, MRT network has been an effective tool to drive developments and urban growth; the intensifying land uses around MRT nodes in city centre,[14] and also suburbs and city fringes, should be strategically incorporated into urban development plans. And third, MRT rail network is a capital intensive public infrastructure project; the government has already used various land recapture mechanisms, such as sales of land parcels surrounding the MRT stations, or imposition of betterment levies on redevelopment of lands near MRT stations, among others, to generate public revenue to fund more MRT extension projects. This is a sustainable and viable model of tapping into private capital for funding future MRT projects.

The "diff-in-diff" approach in this study establishes the causality relationship that runs from the accessibility to the CL MRT stations to housing prices. It disentangles price effects that are uncorrelated with the accessibility to the CL MRT stations. However, subject to the availability of micro-level car ownership data, we hope in the future studies to be able to empirically test if households, who pay higher prices for living near MRT stations, do switch to using public transport.

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14. When persuading the Singapore's Cabinet to endorse the MRT project proposal in 1982, Mr Ong Teng Cheong, the then Minister for Communications, argued for the importance of the MRT network as an essential part to drive the development of the future downtown in Marina South. (Source: page 44, the Urban Systems Studies (USS) report "Financing a city: developing foundations for sustainable growth," published by the Centre for Liveable Cities (CLC) Singapore, First Edition, 2014.

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