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Aging like fine wine: a Singapore public housing story

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This paper examines the unique context of the public housing resale market in Singapore over a 29-year period (1990 to 2018). We find that, on average, there is a price premium for housing units with a longer-term lease. This premium effect is significant and nonlinear after controlling for size, floor level, macroeconomic conditions, as well as year and location fixed effects. Specifically, the town and street fixed effects address the concern that older (but established) districts are characterized by more reputable schools and infrastructure such as health care offerings and shopping malls, while developing districts have innovative facilities with a fresh contemporary outlook as that of modern satellite towns. We document a different lease premium in mature towns as compared to that of the new towns, which captures the different concerns of buyers in combination with location and other characteristics of the houses.

Keywords

Singapore, Public Housing, Resale Price, Lease Premium

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1. Introduction

1.1. Public Housing

The first rudiment of public housing dates back to the 19th century Industrial Revolution. A municipal housing project was carried out in 1865 when the City of London Corporation built the world's first large-scale housing project tenements on Farringdon Road in London to replace one of the most notorious slums – the Old Nichol (The London, 1896). Public housing projects were experimented in other European countries and the United States (US) in the 1930s and became widespread globally after the Second World War. Public housing started out to address the less privileged segment in the community with mixed success globally. In the Americas, housing assistance was aimed at the lower income segments with few success stories (Ling and Austin, 2015). Public housing in Denmark, Finland and Sweden are witnessing rising ownership with rising affluence; Ireland and the United Kingdom (UK) are also changing ownership schemes to accommodate changing population needs (Winther, 1996). The leading economies of Europe (France, Germany, Italy, the Netherlands and Spain) have low percentages of public housing at 2-5% (Housing Europe, 2019). The privatization of housing in the former Soviet Union began in 1991. Residents can occupy the premises should they choose not to privatize (Morton, 2017). Lately, the public housing system in Australia and New Zealand are changing in the attempts to meet the needs of an evolving population make-up ((Mills et al., 2015). Special housing projects are established to provide housing assistance for the low-income population – but have clearly demonstrated that successes vary and stigmatized in some of the cases.

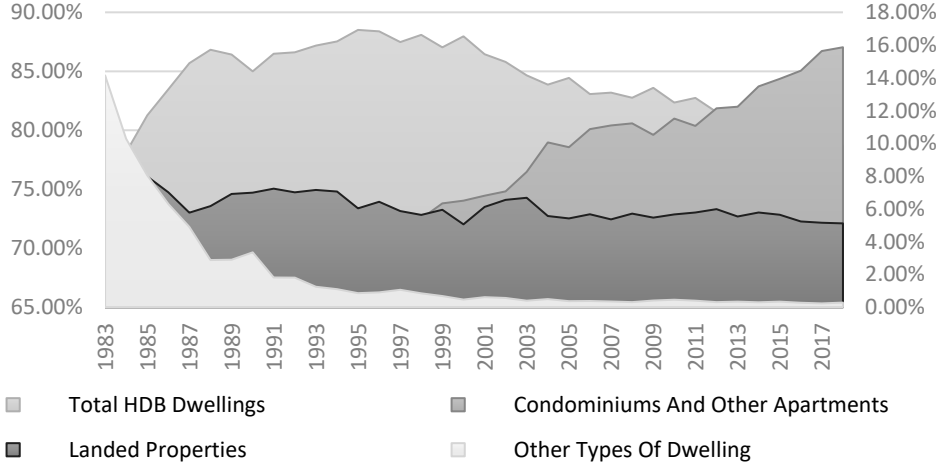
In Asia, China started its program in the 1950s and was first planned by and later relied on the market economy for its public housing (Wang and Shao, 2014). The rest of Asia (including Japan) has public housing in various states of progression. For example, public housing in Hong Kong can be rented or purchased (The Government of the Hong Kong Special Administrative Region, 2018). Indonesia is aiming for a target of 1 million public housing units (Nabila, 2019). The Japanese notion of public housing encompasses those who struggle with poverty, the ageing population, young immigrants and foreign worker families (Muramatsu and Akiyama, 2011). In engaging with contemporary discourses, Woo and Khoo (2020) argue for affordable housing in Penang, Malaysia to co-exist with nature in lieu of ecological changes. While many governments have focused on public housing programs for the poorest members of society, the public housing schemes in Singapore cater to the needs of not only low-income families, but also the middle-income group or young families. Thus Singapore has one of the highest rates of home ownership in the

world (88.9% as of 2021)[1]. The unusual and successful public housing policy in Singapore makes this public housing market worthwhile of further investigation.

1.2. Singapore Housing Market

Singapore is a city state in Southeast Asia with challenges to contend, including an aging population, high population density, strained infrastructure, and unwarranted property prices. Nevertheless, the city state prides itself on a top-down policymaking landscape, and one of the key policy milestones that was undertaken after independence from Malaysia (1965) was to build affordable public housing for the then population of 300,000 (Latif, 2009). As of 2019, flats under the public housing schemes provided by the Housing and Development Board (HDB) are home to about 80% of the resident population, of which, about 90% own their home, thus making Singapore one of the countries with the highest public housing penetration rate in the world.

Figure 1A Resident Households by Type of Dwelling (%)



HDB public housing in Singapore has morphed over the years, changing from extremely basic flats to the current focus on 'smart homes of the future'. What makes the Singapore housing public market even more interesting to study is the possibility of resale transactions on an open market. New housing units

[1] https://www.singstat.gov.sg/find-data/search-by-theme/households/households/latest-data

purchased directly from the HDB are balloted and successful applicants pay a heavily subsidized rate (relative to the public housing resale market). After occupying a unit directly purchased from the HDB for a minimum period of five years, the owner is permitted to sell the unit in the resale market at the market price. The public housing resale market has existed in Singapore since 1971 (Phang and Wong, 1997). In the 1990s, public policy and liberalization coupled with excess demand for housing gave a further boost to the resale market (Tu and Wong, 2002; Phang and Helble, 2016).

Figure 1B Resident Households by Tenancy (%)

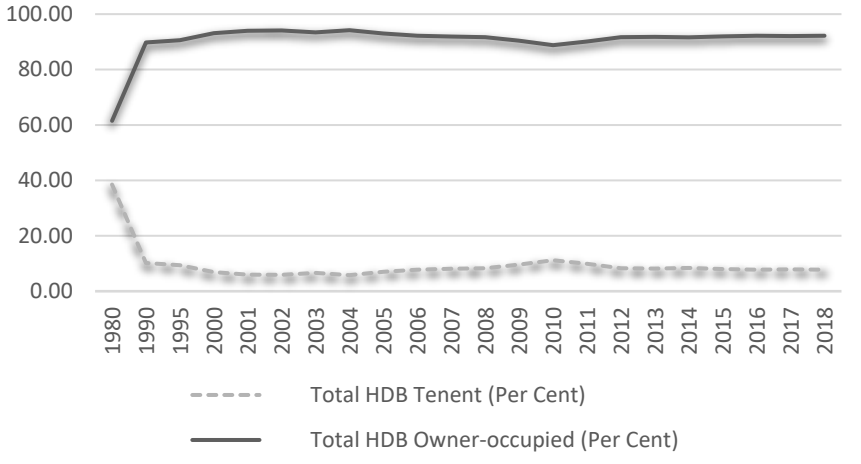
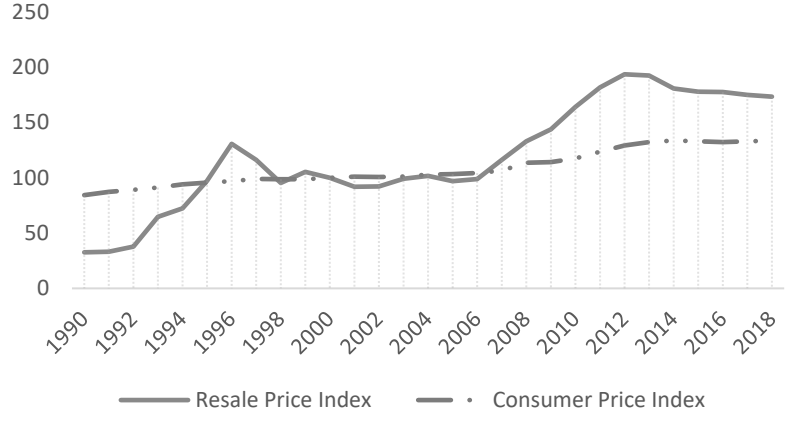


Figure 2 Resale Price Index of Public Housing and Consumer Price Index in Singapore



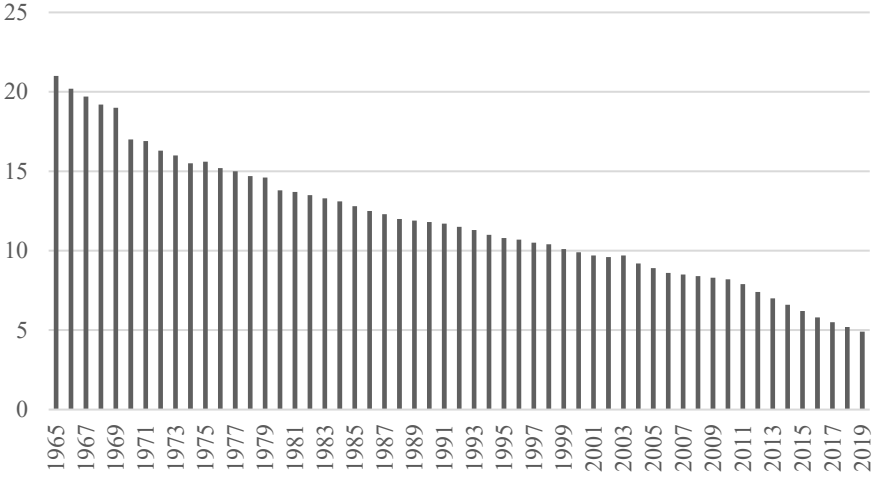
The main goal of this paper is to add to the literature on public housing market, leveraging on the unique set up of the public housing resale market in Singapore. Various studies on housing price dynamics in Singapore can be found in the literature. Bardhan et al. (2003) find that increases in the rate of change of public housing prices has a significantly positive impact on the number of private housing units transacted. The wealth generated from private property contributes to economic health, and Phang (2004) documents a significantly negative effect on consumption from falling private housing wealth. The converse is true where aggregate consumption in Singapore increases at a larger scale and is relatively more permanent from public housing wealth (Edelstein and Lum, 2004). This explains the imperative public housing pricing effects (although lagged) on price changes in the private housing markets in Sing et al. (2006). The effects are lagged due to transaction and search costs. Tu (2003) argues that the impacts of the public housing resale market on the private housing market prices can affect the equitable distribution of public resources. Hence, maintaining the stability of public housing prices in Singapore is critical in lieu of the large ramifications on a small open economy.

Public housing monopolizes residential housing in Singapore. As the literature shows, public housing price stability plays a key role that should not be undermined. The HDB has built more than one million units of housing since its establishment in 1960 (Housing & Development Board, 2022), and naturally, most of the aged premises are owned by the elder generation. Furthermore, Singapore is an aging society with population shifts in the young (age zero to 14 years old) and the elders (65 years old and over), as shown in Figure 3. The old-age support ratio is calculated as the ratio of the population aged 15-64 years old per person aged 65 years old and over in Singapore. This would imply that older housing units need to hold its value for the longer-term in relying on appreciating house prices to finance retirement (Phang, 2012; Mah, 2011).

To meet future retirement needs, the market value of public flats must necessarily increase to exceed annual inflation in order to preserve the capital invested. However, relatively low liquidity to flat owners and depreciating value of aged public flats have been observed, despite the continuous efforts of the HDB to upgrade programs. Therefore, this study mainly investigates the sensitivity of the public housing resale market buyers relative to the remaining years of the lease. In general, using the HDB resale transaction prices over a 29-year period of time (1990 to 2018), it is found that an inversed U-shape trend can be observed when explaining the resale prices based on the years left on the remaining lease. Furthermore, this finding has been controlled for in size, floor level, macroeconomic conditions, as well as town or street fixed effects. Specifically, there is a price discount for shorter lease housing units and this discount persists even in mature towns and estates. These findings indicate that even though shorter lease housing units may be larger in size and located in favorable locations, they seem to suffer from price handicap relative to longer

lease units - this could probably be attributed to poor liquidity which can be a compounding factor to even further illiquidity. One may argue that investment in maintenance of leasehold properties (HDB flats) might be lower compared to private freehold properties because capital investment is lost upon expiry of the lease and there is no incentive for households to improve or maintain the flat quality. This may be the potential reason for the exponential deterioration of the flats built on leased land as compared to those on freehold land. Despite the above observations, the HDB has strategies in place to tackle the sustainability issue of HDB flats through upgrading strategies, and these include improving the physical conditions of the estate as well as the façade and flat interior.

Figure 3 Population Shift in Singapore



Notes: Old-age Support Ratio: Number of Residents Aged 15-64 Years per Resident Aged 65 Years & Over

The findings of this study will contribute to the housing literature by furthering understanding of the price factor of residential property tenure, particularly in the setup of the Singapore real estate market where leasehold public housing holds a significant role in residential properties. Studies in this literature focus on explaining varying discount rates. Wong et al. (2008) find a lower intergenerational discount rate compared to the intragenerational discount rate by comparing different lease tenure transactions (999-year vs. 99-year tenures) in Hong Kong. Giglio et al. (2015) report similar findings in the UK and Singapore housing markets. Bracke et al. (2018) use transaction data in the prime central London (PCL) area of 2 distinct periods to document a declining discount rate as a function of tenure length and time. Fesselmeyer et al. (2021) focus on the private housing market in Singapore and develop an empirical

model that explains for the price premium of freehold properties as compared to 999-year leasehold properties. Even though both types (freehold and 999-year tenures) are considered "long-lived" property assets, declining discount rates are still estimated from 100 to 400 years. Our results based on the public housing market in Singapore complement the literature by demonstrating price discounts for leasehold properties with shorter tenures.

Joo and Wong (2008) provide three analysis dimensions on sustainable public housing in Singapore, namely social, economic, and environmental sustainability. The outcomes of our study may also shed light towards the sustainable development of public housing at this critical juncture of an aging population (25% of the population is predicted to be 65 and older by 2030 in Singapore) (Phang and Helble, 2016). If the value of HDB wealth is expected to be "unlocked" during retirement for the majority of public homeowners as source of income, then theoretically the appreciation of housing price should be sufficient for retirement needs and provide both social and economic sustainability for a household and even beyond for future generations. However, the finding of a price discount in this study indicates that, with rising living costs and an aging society, housing policies will face challenges.

Due to data availability, this study focuses on the standard features of HDB resale units without capturing other important features such as renovated interior, or aspect/facing and scenic views from the unit. We control for street and town together with year fixed effects. This attempt minimizes the variations based on proximity of schools, shopping malls and Mass Rapid Transit (MRT) train stations by incorporating street and town fixed effects in the regression analysis. However, there are cases where developments at the fringe of a one-kilometer radius to a top school show price differences for neighboring blocks. The profile of home buyers is also critical such as ethnic group (Agarwal et al., 2019) which could be incorporated in future studies.

The remainder of the paper is organized as follows. In the next section, the main hypotheses of the paper will be provided. Section Three describes the empirical settings of this study including the data and methodology used. Discussions from the empirical findings will then be presented. The final section concludes the paper.

2. Hypothesis Development

After a new flat purchased directly from the HDB is occupied by the first owner for the Minimum Occupation Period (MOP) of five years, it can be sold in the resale market to eligible buyers. Although there are still a set of other eligibility conditions to fulfill, the resale transaction price of the flat is largely driven by the supply and demand of public housing available for resale. Transactions are price sensitive, and demographics are just as critical as economic fundamentals

when it comes to driving public house resale prices in Singapore (Chia et al., 2017). The current consensus is that flats (including the HDB and private flats) with a remaining lease less than 50 years are very illiquid in the resale market, even though they could be very well maintained, or even newly renovated or upgraded. Amongst the studies on HDB flats, Thang (2014) has discussed the living conditions of HDB flats for different demands and emphasized the importance of lease on the housing price to senior citizens. We focus on depreciating lease and develop the following hypotheses to understand the perceived value of an HDB flat in the resale market:

H1: On average, the remaining year of the lease tenure is positive and significant in explaining resale property transaction prices, after controlling for size, floor level, location, and year fixed effects.

We test the lease premium with the use of transaction prices in terms of the price per square feet (PSF) and total transaction price. The total transaction price-to-annual median income-ratio is also used as a robustness check. The analysis controls for size, floor level, the consumer price index (CPI), year and location fixed effects (estate/town or street fixed effect). A shorter remaining lease term means greater uncertainty of expected cash flow that can be generated by the property, thus resulting in higher discount rates. However, a higher discount rate is not proportionally compensated by higher returns, which is inconsistent with the asset pricing theory which predicts a positive relationship between return and risk. Unlike stocks that are normally viewed as perpetual or bonds that will receive a face value at maturity, market participants seem to value HDB flats that are on a 99-year lease term differently. This is because upon expiry of the leasehold, ownership of the land will revert back to the state with the rights of any property owners effectively extinguished. As such, we propose the following hypothesis:

H2: When the remaining lease is relatively short, there will be a significant discount in the transaction price, despite premium location or upgrading scheme.

To test the hypothesis, we group the data into two subsamples with a cutoff of 60 years in the remaining lease. Controlling for size, floor level, CPI, year and location fixed effects (estate/town or street fixed effects), we expect to see a significant difference between the factor loadings of the remaining lease factor in the regressions of the two subsamples.

Once the HDB flat is eligible to be sold on the resale market, the transaction price will have a period of value appreciation despite the depreciating lease. However, this phenomenon does not last throughout the course as buyers ultimately become more sensitive to the remaining years of the lease, and therefore will start to place discounts on these older units. As such, we expect to see a non-linear relationship (a third hypothesis) between the remaining lease

of the property and the resale transaction prices, which is measured by the PSF, total transaction price and total transaction price-to-annual median income-ratio.

H3: There is a non-linear relationship between the remaining lease and the resale transaction prices.

This hypothesis will be tested based on a polynomial model where the remaining lease, as one of the explanatory factors of transaction price and the key focus of this study, will no longer be just in its first order. Other factors that are fixed includes size, floor level, CPI, as well as time and location effects.

3. Empirical Analysis

3.1. Data

Data on public housing resale prices were obtained directly from select official public housing data websites in Singapore including the Housing Development Board (HDB) and Department of Statistics (DOS), Singapore on data.gov.sg. The range of data covers all registered HDB resale transacted prices from 1990 to 2020. Chosen factors of location of the flat, floor level range, floor area and remaining lease period are analyzed to understand the changes in resale housing prices in a timeseries setup. Economic proxies have been used with the Singapore CPI indicating associated living costs and annual household median income to adjust for economic development over the observed time period.

As an overview of the data, we present Figure 4A which shows the average prices of HDB flats versus private housings over the past three decades. HDB resale transaction prices are in general more stable relative to private housing prices but have also become more volatile in the recent decade.

Figure 4B shows the differences of HDB resale transaction prices relative to private housing prices within the same neighborhood. The figures vary across towns and in select towns (Bishan, Central Area, Choa Chu Kang, Hougang, Jurong West, Pasir Ris, Punggol, Sembawang, Sengkang, Woodlands and Yishun), HDB flats have experienced more volatile resale prices over the recent decade as compared to other towns where the transaction prices are more stable.

As the paper focuses on the HDB resale transactions, Figure 4C describes the joint distribution of HDB resale transaction prices and their corresponding leases (in terms of remaining number of years). We observe a general trend where a longer lease translates into higher transaction prices, which supports H1. However, the joint distribution is clustered in certain areas as shown in the figure and the relationship between the two variables does not show a strong linear pattern, which is in line with H3.

Figure 4A Average Price: Private vs. HDB

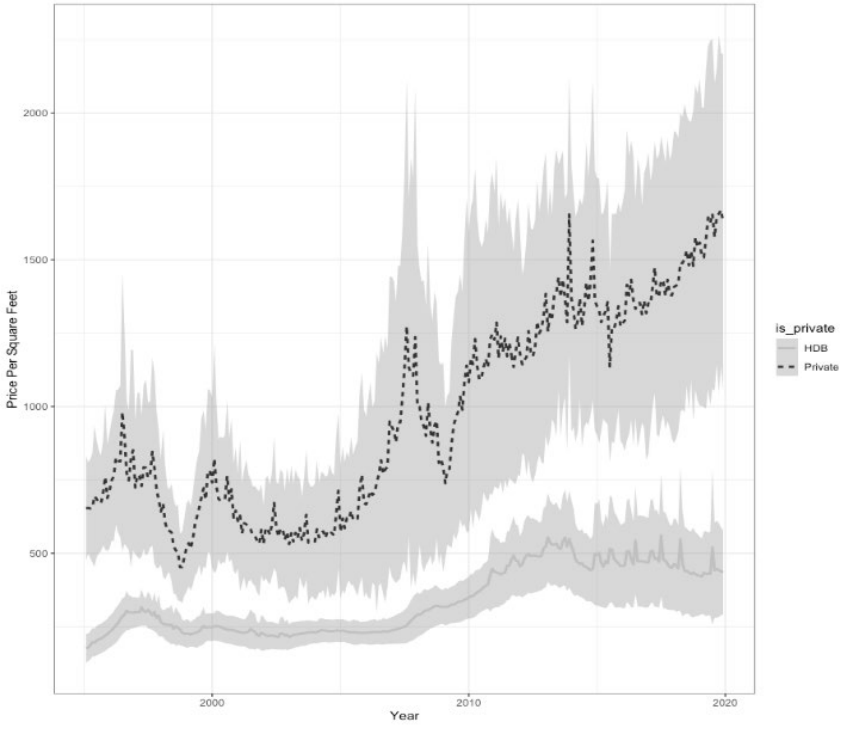


Figure 4B Average Price: Private vs. HDB by Town

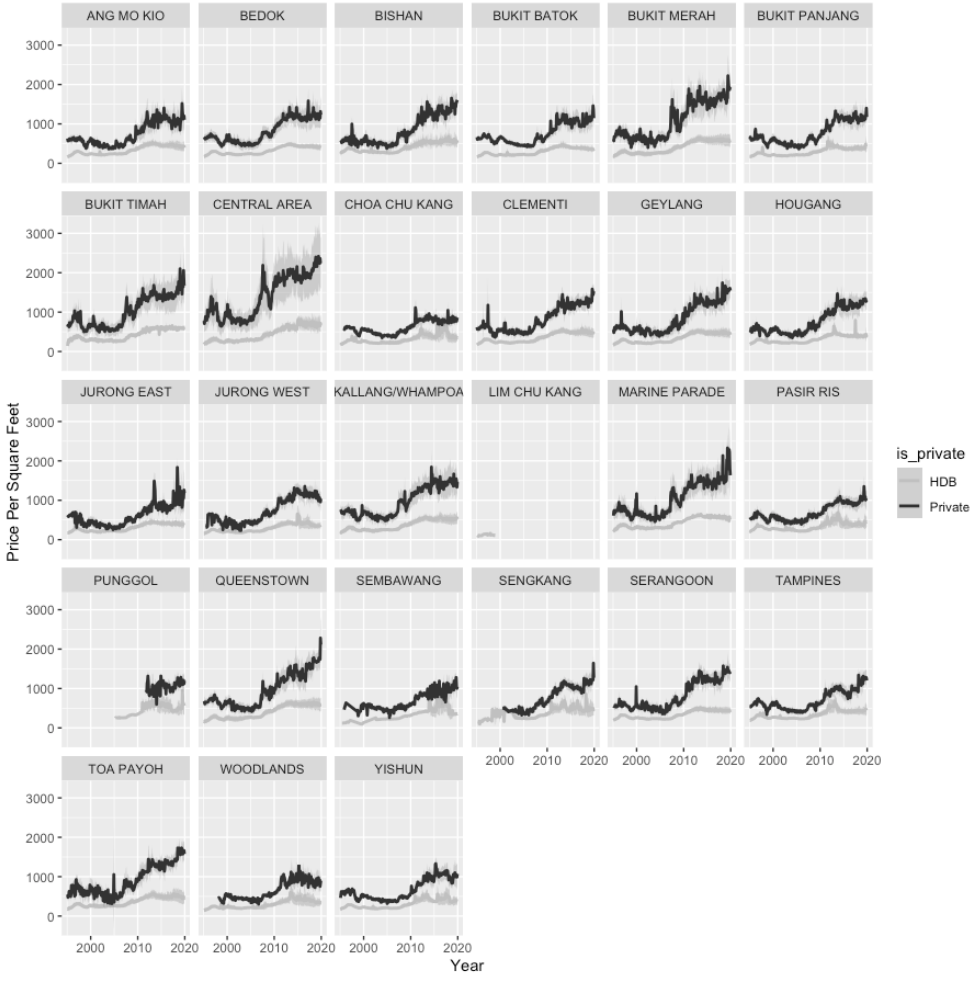
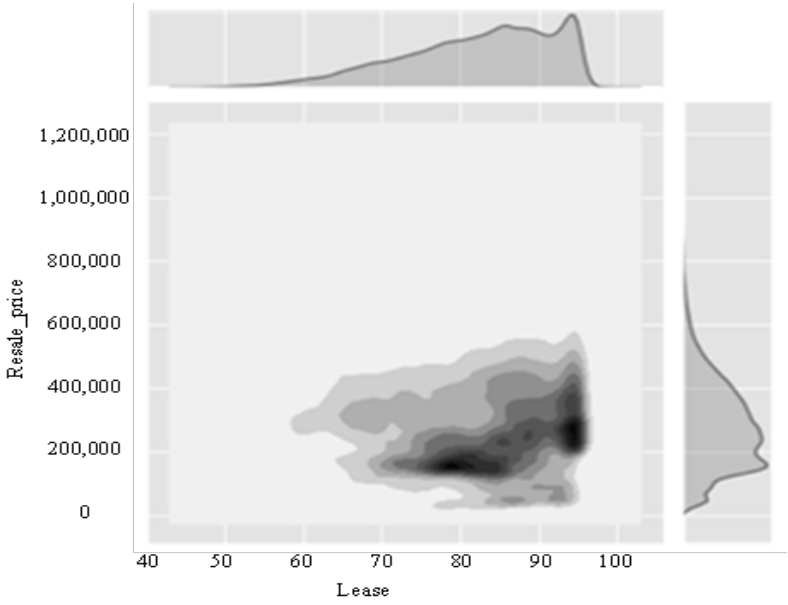


Figure 4C Joint Distribution of HDB Resale Transaction Prices and Lease



***Notes*:** Lease is reported in terms of remaining number of years left on the lease

3.2. Empirical results and discussion

Table 1 are the summary statistics in which all the transactions for the HDB resale units are presented from January 1995 to January 2020 (inclusive).

The minimum transaction price is SGD25,000 (USD/SGD 1.40) and maximum transaction price is SGD 1.205 million. The PSF is calculated by dividing price by the total square feet with a unit of SGD 1000. The logPrice is calculated by using the logarithm of the transaction price (in SGD). Price/Median Income is calculated by dividing price by the annual median income per household in Singapore during the transaction year. Lease is defined as 99 years minus the number of years between the lease commence date and the transaction year for any HDB resale unit. The minimum lease is 45 years while the maximum lease is 99 years. Floor is the level of the HDB unit and reported as the lower level for every level range reported in a resale transaction. The Consumer Price Index is reported for each year. MatureTown is defined as one if the transaction is in an established town and zero otherwise. In Panel B, we report the number of observations and the mean of each variable by separating the sample based on every 10 years of remaining lease: less than 55 years, between 55 and 64 years, between 65 and 74 years, between 75 and 84 years, and more than 85 years.

The group of units with the longest remaining lease accounts for the largest portion of our sample.

To study the effect of lease and test the main hypothesis *(H1)*, we use four different price measurements in the panel regressions, including the PSF, total transaction price, logarithm of the total transaction price, and total transaction price-to-annual median income-ratio. Year and street fixed effects are controlled for in the panel regressions with robust standard errors and HDB town clustering effects. As such, we can handle the variations such as HDB upgrading schemes, distance to shopping malls, schools, and public transport stations by controlling for street and year fixed effects together. The following equation is used to explain for the transaction prices in terms of the corresponding remaining number of years in the lease (*lease*), and the control variables, including size of the transaction unit, floor level, and CPI as a proxy for associated living costs.

$$y_{i,t} = \alpha + \beta_1 lease_{i,t} + \beta_2 Controls + \varepsilon_{i,t} \quad (1)$$

Table 2 reports the results of the panel regressions, with standard errors kept robust, and clustering effect allowed within each specific town. In Columns (1), (3), (5) and (7), the results are based on Year and Street fixed effects, while in Columns (2), (4), (6) and (8), the Year and Town fixed effects are used instead. The first two columns report the impact of the lease by using PSF as the resale price measurement. They show that for every additional year of remaining lease, the average PSF increases by around SGD 28 if we control for Street FE and SGD 29 for Town FE, with t-statistics of 34.99 and 23.17 respectively. In Columns (3) and (4), the average price is reported to increase by around SGD 3000 for every additional year of the remaining lease based on the total transaction price with t-statistics of 37.99 and 22.32. Similarly, the estimated coefficients of lease in Columns (5) to (8) are all positive and statistically significant at the 1% level, either by taking a logarithm of the total price o by scaling the total price with household median income.

While Table 2 provides direct evidence for HI on the lease premium, we further study the impact of lease by separating the sample into two subsamples: one with shorter lease, defined as when the transaction unit has a remaining lease less than 60 years, and the other with longer lease (transaction unit with a remaining lease of 60 years and more). We use the same regression (1) above and compare the estimated coefficients of lease between the two subsamples.

Table 1 Summary Statistics

We obtain the data from the Housing Development Board (HDB) and Department of Statistics (DOS), Singapore on data.gov.sg. The range of data covers all registered HDB transacted resale prices from 1990 to 2020. In Panel B, we report the number of observations and the mean of each variable for different groups by separating the sample according to remaining leases of less than 55 years, between 55 and 64 years, between 65 and 74 years, between 75 and 84 years, and more than 85 years.

	Panel A: HDB samples				
Variable	Obs	Mean	Std. Dev.	Min	Max
psf	728,322	3.208	1.149	0.577	11.809
price	728,322	0.311	0.140	0.025	1.205
logPrice	728,322	12.547	0.456	10.127	14.002
price/income	728,322	4.489	1.719	0.495	16.945
Size	728,322	96.300	25.882	28.000	307.000
Lease	728,322	81.353	9.846	45.000	99.000
Floor	728,322	6.535	4.628	1.000	49.000
CPI	718,602	73.842	12.444	60.605	101.136
MatureTown	728,322	0.507	0.500	0.000	1.000
Variable	728,322	3.208	1.149	0.577	11.809

	Panel B: by every 10 years of lease									
	<55		[55,65)		[65,75)		[75,85)		>85	
Variable	Obs	Mean	Obs	Mean	Obs	Mean	Obs	Mean	Obs	Mean
psf	4015	4.746	40077	4.536	135281	3.576	232124	2.873	316825	3.109
price	4015	0.301	40077	0.340	135281	0.307	232124	0.279	316825	0.333
logPrice	4015	12.578	40077	12.660	135281	12.511	232124	12.424	316825	12.638
price/income	4015	2.810	40077	3.610	135281	3.787	232124	4.073	316825	5.227
size	4015	63.355	40077	74.160	135281	83.434	232124	93.752	316825	106.878
Lease	4015	51.813	40077	60.756	135281	70.081	232124	79.781	316825	90.298
Floor	4015	5.830	40077	6.588	135281	6.181	232124	6.324	316825	6.843
CPI	3559	92.061	38002	88.032	133000	80.530	229795	72.185	314246	70.301

Table 2 HDB Lease Premium in Linear Regression Analysis

Table 2 reports the results based on four different price measurements in panel regressions according to:

$$y_{i,t} = \alpha + \beta_1 lease_{i,t} + \beta_2 Controls + \varepsilon_{i,t}$$

with robust standard errors and clustering effect. Columns (1) and (2) use PSF as the resale transaction price measurement, while total transaction price is used in Columns (3) and (4), logarithm of the total transaction price in Columns (5) and (6), and total transaction price-to-annual median income-ratio in Columns (7) and (8), respectively. Associated t-statistics are reported in parentheses while ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

	(1) psf	(2) psf	(3) price	(4) price	(5) logPrice	(6) logPrice	(7) Price/ Income	(8) Price/ Income
Lease	0.028***	0.029***	0.003***	0.003***	0.008***	0.009***	0.037***	0.033***
	(34.99)	(23.17)	(37.99)	(22.32)	(38.58)	(30.99)	(35.35)	(26.76)
Size	0.004***	0.003***	0.004***	0.003***	0.012***	0.012***	0.056***	0.055***
	(23.03)	(6.32)	(224.97)	(83.57)	(190.65)	(67.26)	(161.51)	(58.08)
Floor	0.023***	0.029***	0.002***	0.003***	0.007***	0.008***	0.033***	0.040***
	(96.18)	(36.49)	(90.93)	(38.24)	(115.34)	(47.31)	(92.39)	(51.81)
CPI	2.709***	2.727***	0.250***	0.250***	0.757***	0.768***	3.166***	3.209***
	(44.26)	(15.22)	(43.06)	(14.62)	(39.18)	(13.99)	(36.39)	(13.16)
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Street FE	YES	NO	YES	NO	YES	NO	YES	NO
Town FE	NO	YES	NO	YES	NO	YES	NO	YES
Intercept	-1.614***	-1.655***	-0.481***	-0.467***	10.174***	10.082***	-6.436***	-6.123***
	(-21.16)	(-10.28)	(-61.03)	(-26.39)	(491.34)	(218.58)	(-60.11)	(-29.52)
Obs	704209	704209	704209	704209	704209	704209	704209	704209
adj. R^2	0.922	0.866	0.945	0.908	0.943	0.913	0.907	0.863

Table 3 reports the subsample analysis results for the HDB, with Panel A reporting the transaction units that have a long remaining lease (60 years and more) while Panel B reporting the transaction units that have a short lease (less than 60 years). In general, the regression coefficients of *lease* – which indicate a lease premium, and are estimated by using the short lease sub-sample (Panel B) are only of one third of the coefficients in the long lease sample (Panel A). Statistically, the estimated lease premium in the short lease sample is significant but the t-statistics are much smaller as compared to those of the long lease sample. In Columns (1) and (2), for every additional year of remaining lease, the average PSF increases by around SGD 30 and SGD 31, respectively in the short lease sample but the increments are only SGD 9 and SGD 10 per square feet in the long lease sample. In Columns (3) and (4), the average total transaction price increases by around SGD 3000 in the short lease sample but SGD 1000 in the long lease sample if the unit is newer by one additional year (longer remaining lease). The pattern is similar when the logarithm of price and price per median income are used instead, after controlling for size, floor, CPI, Year, Street (Columns 1, 3, and 5) and Town (Columns 2, 4, and 6) fixed effects.

Based on the above observations, we believe that the lease premium is unlikely to be a linear function of the remaining leases for the resale transactions of HDB flats and thus a linear regression would not be optimal for accurately understanding the effect of lease premiums. Hence, we proceed with a polynomial model to better understand the pricing mechanism of the resale transactions for the HDB flats by using the equation below and report the results in Table 4.

$$y_{i,t} = \alpha + \beta_1 Lease_{i,t} + \beta_2 Lease_{i,t}{}^2 + \beta_3 Lease_{i,t}{}^3 + \beta_4 Controls + \varepsilon_{i,t} \qquad (2)$$

As shown in Table 4 Panel A, a non-linear result is observed. The coefficients of all three remaining lease variables, Lease, {{Lease}_{i,t}}^2 and {{Lease}_{i,t}}^3, are statistically significant at 1% level in explaining the resale transaction prices throughout the four different measures. While the estimated coefficient for {{Lease}_{i,t}}^3 is too small to interpret in Panel A, we adjust the unit of Lease by dividing the number of years by 5 so the variable Lease_5y is measuring the remaining lease of a transaction with a unit of 5 years in Panel B. The rationale of choosing a 5-year scale is that there is a minimum occupation period (MOP) of 5 years required for any HDB flat transactions, be it a direct purchase from HDB or a resale in the open market. Control variables include size, floor level, macroeconomic conditions (CPI), as well as year and location fixed effects.

To facilitate with the interpretation of the results in Table 4, a visualization of the polynomial function along the remaining dimension based on the coefficients in Column (3) of Panel A of Table 4, is given in Figure 5.

As shown in Figure 5, when the remaining lease is shorter (less than 60 years), we observe a larger slope of the lease premium function. However, when the remaining lease is longer (60 years and more), the slope is gentler. Combining both Table 4 and Figure 5, we document the lease premium as a positive and nonlinear factor in explaining for the HDB resale transaction prices.

Aside from the non-linearity of the lease premium as a factor in explaining for the HDB resale transactions, another concern is that the remaining lease might not be a good enough proxy for the actual conditions of the property. The HDB has implemented several upgrading programs to enhance the overall living environment of the estates, which can potentially break the relationship between the remaining lease and housing quality. To address this concern, we analyze the non-linearity of the lease premium based on subsamples of mature HDB towns versus new HDB towns. We believe that this is one way to hold the impact of upgrading programs constant, given that most of the upgrading programs take place in the mature HDB towns.

Figure 5 Polynomial Function along Lease Dimension

X-axis is lease with a unit of one year and y-axis is the corresponding HDB transaction price with a unit of one million SGD, holding the rest of the control variables unchanged. The figure is drawn based on the coefficients in Column 3 of Panel A in Table 4:

$$y_{i,t} = .0996212 * Lease_{i,t} - 1.2569 * 10^{-3}\ Lease_{i,t}{}^{2} + 5.38 * 10^{-6}\ Lease_{i,t}{}^{3}$$

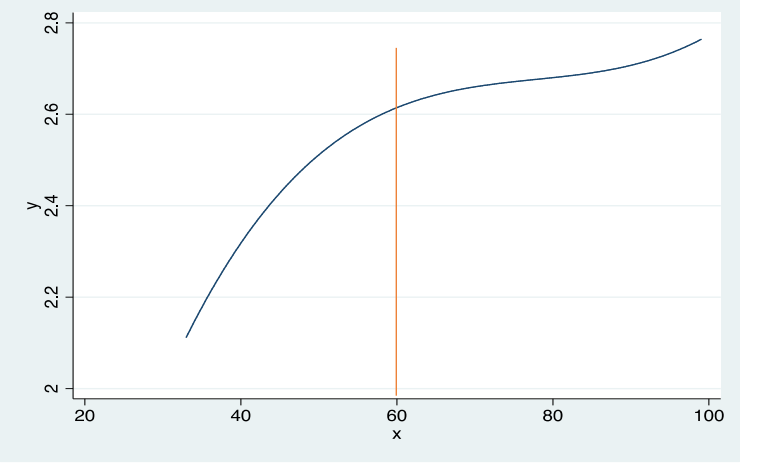


Table 3 Subsample Analysis for HDB: Long vs. Short Lease

Table 3 reports the results based on 2 subsamples in panel regressions according to:

$$y_{i,t} = \alpha + \beta_1 lease_{i,t} + \beta_2 Controls + \varepsilon_{i,t}$$

with robust standard errors and clustering effect. Transaction units with a remaining lease of 60 years and longer are classified under the "Long Lease" group and reported in Panel A. Transaction units with a remaining lease less than 60 years are classified under the "Short Lease" group and reported in Panel B. Columns (1) and (2) use PSF as the resale transaction price measurement, while total transaction price is used in Columns (3) and (4), logarithm of the total transaction price in Columns (5) and (6), and total transaction price-to-annual median income-ratio in Columns (7) and (8), respectively. Related t-statistics are reported in parentheses ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

	Panel A: HDB with Long Lease							
	(1) psf	(2) psf	(3) price	(4) price	(5) logPrice	(6) logPrice	(7) Price/ Income	(8) Price/ Income
Lease	0.030***	0.031***	0.003***	0.003***	0.009***	0.011***	0.047***	0.043***
	(34.45)	(26.89)	(29.77)	(23.92)	(32.88)	(30.85)	(29.83)	(26.57)
Size	0.005***	0.004***	0.003***	0.003***	0.012***	0.012***	0.057***	0.056***
	(27.14)	(8.01)	(206.15)	(77.31)	(176.48)	(64.87)	(152.62)	(56.54)
Floor	0.022***	0.027***	0.002***	0.003***	0.007***	0.008***	0.033***	0.039***
	(92.50)	(40.24)	(88.90)	(42.60)	(107.70)	(47.95)	(88.04)	(51.19)
CPI	2.497***	2.517***	0.249***	0.248***	0.721***	0.731***	3.124***	3.170***
	(37.39)	(12.93)	(37.83)	(12.93)	(32.62)	(11.65)	(30.91)	(11.26)
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Street FE	YES	NO	YES	NO	YES	NO	YES	NO
Town FE	NO	YES	NO	YES	NO	YES	NO	YES
Intercept	-1.891***	-1.976***	-0.460***	-0.450***	9.991***	9.853***	-7.389***	-7.100***
	(-21.97)	(-11.43)	(-50.29)	(-24.83)	(355.92)	(178.01)	(-48.48)	(-28.29)
Obs	614744	614744	614744	614744	614744	614744	614744	614744
adj. R^2	0.918	0.865	0.950	0.921	0.943	0.916	0.907	0.867

(Continued…)

(Table 3 Continued)

	Panel B: HDB with Short Lease							
	(1) psf	(2) psf	(3) price	(4) price	(5) logPrice	(6) logPrice	(7) Price/ Income	(8) Price/ Income
Lease	0.009***	0.010***	0.001***	0.001***	0.003***	0.005***	0.005**	0.008***
	(3.93)	(3.08)	(2.86)	(3.59)	(5.34)	(6.33)	(2.21)	(2.65)
Size	-0.002***	-0.001**	0.004***	0.004***	0.011***	0.011***	0.046***	0.048***
	(-6.81)	(-1.98)	(103.32)	(60.73)	(129.07)	(74.52)	(98.21)	(55.80)
Floor	0.030***	0.031***	0.003***	0.003***	0.007***	0.008***	0.032***	0.034***
	(50.89)	(24.39)	(40.97)	(22.29)	(55.93)	(30.16)	(38.88)	(22.68)
CPI	3.659***	3.730***	0.263***	0.268***	0.919***	0.939***	3.389***	3.450***
	(29.31)	(13.61)	(25.94)	(12.69)	(28.06)	(14.13)	(26.89)	(12.86)
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Street FE	YES	NO	YES	NO	YES	NO	YES	NO
Town FE	NO	YES	NO	YES	NO	YES	NO	YES
Intercept	0.451***	0.209	-0.288***	-0.319***	10.766***	10.574***	-3.245***	-3.605***
	(2.66)	(0.70)	(-16.32)	(-12.98)	(258.96)	(145.03)	(-19.00)	(-12.49)
Obs	89465	89465	89465	89465	89465	89465	89465	89465
adj. R^2	0.914	0.849	0.940	0.905	0.958	0.930	0.914	0.866

Table 4 HDB: Polynomial Model Using Lease, Lease Square and Lease Cube

This table reports the results of a polynomial model based on the following equation:

$$y_{i,t} = \alpha + \beta_1 Lease_{i,t} + \beta_2 Lease_{i,t}{}^2 + \beta_3 Lease_{i,t}{}^3 + \beta_4 Controls + \varepsilon_{i,t}$$

with robust standard errors and clustering effect. Columns (1) and (2) use PSF as the resale transaction price measurement, while total transaction price is used in Columns (3) and (4), logarithm of the total transaction price in Columns (5) and (6), and total transaction price-to-annual median income-ratio in Columns (7) and (8), respectively. Related t-statistics are reported in parentheses ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

	Panel A: Lease in unit of 1 year							
	(1) psf	(2) psf	(3) price	(4) price	(5) logPrice	(6) logPrice	(7) Price/ income	(8) Price/ income
Lease	0.736***	0.842***	0.100***	0.120***	0.162***	0.165***	0.800***	1.095***
	(11.52)	(7.76)	(16.00)	(12.77)	(10.89)	(5.74)	(11.10)	(9.72)
$Lease^2$	-0.010***	-0.011***	-0.001***	-0.002***	-0.002***	-0.002***	-0.012***	-0.016***
	(-12.19)	(-8.14)	(-15.51)	(-12.42)	(-11.82)	(-6.20)	(-12.19)	(-10.36)
$Lease^3$	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	(13.17)	(8.69)	(15.42)	(12.30)	(13.12)	(6.86)	(13.60)	(11.15)
Size	0.004***	0.003***	0.004***	0.003***	0.012***	0.012***	0.056***	0.055***
	(24.23)	(7.22)	(226.97)	(85.92)	(195.31)	(71.60)	(165.31)	(61.94)
Floor	0.023***	0.028***	0.002***	0.003***	0.007***	0.008***	0.032***	0.039***
	(98.30)	(37.91)	(91.59)	(38.39)	(116.48)	(52.43)	(93.38)	(55.44)
CPI	2.699***	2.701***	0.250***	0.248***	0.754***	0.760***	3.149***	3.160***
	(44.12)	(14.89)	(42.89)	(14.44)	(38.94)	(13.61)	(36.14)	(12.65)
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Street FE	YES	NO	YES	NO	YES	NO	YES	NO
Town FE	NO	YES	NO	YES	NO	YES	NO	YES

(Continued…)

(Table 4 Continued)

	Panel A (Continued)							
Intercept	-17.709***	-20.532***	-2.918***	-3.411***	6.903***	6.807***	-21.957***	-29.157***
	(-10.86)	(-7.36)	(-18.47)	(-14.41)	(18.58)	(9.55)	(-12.43)	(-10.49)
Obs	704209	704209	704209	704209	704209	704209	704209	704209
adj. R^2	0.923	0.871	0.945	0.911	0.944	0.916	0.909	0.870
	Panel B: Lease in unit of 5 years							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	psf	psf	price	price	logPrice	logPrice	Price/ income	Price/ income
Lease_5y	3.678***	4.211***	0.498***	0.598***	0.812***	0.826***	3.999***	5.476***
	(11.52)	(7.76)	(16.00)	(12.77)	(10.89)	(5.74)	(11.10)	(9.72)
$Lease\_5y^2$	-0.252***	-0.285***	-0.031***	-0.038***	-0.058***	-0.059***	-0.294***	-0.391***
	(-12.19)	(-8.14)	(-15.51)	(-12.42)	(-11.82)	(-6.20)	(-12.19)	(-10.36)
$Lease\_5y^3$	0.006***	0.006***	0.001***	0.001***	0.001***	0.001***	0.007***	0.009***
	(13.17)	(8.69)	(15.42)	(12.30)	(13.12)	(6.86)	(13.60)	(11.15)
Size	0.004***	0.003***	0.004***	0.003***	0.012***	0.012***	0.056***	0.055***
	(24.23)	(7.22)	(226.97)	(85.92)	(195.31)	(71.60)	(165.31)	(61.94)
Floor	0.023***	0.028***	0.002***	0.003***	0.007***	0.008***	0.032***	0.039***
	(98.30)	(37.91)	(91.59)	(38.39)	(116.48)	(52.43)	(93.38)	(55.44)
CPI	2.699***	2.701***	0.250***	0.248***	0.754***	0.760***	3.149***	3.160***
	(44.12)	(14.89)	(42.89)	(14.44)	(38.94)	(13.61)	(36.14)	(12.65)
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Street FE	YES	NO	YES	NO	YES	NO	YES	NO
Town FE	NO	YES	NO	YES	NO	YES	NO	YES
Intercept	-17.709***	-20.532***	-2.918***	-3.411***	6.903***	6.807***	-21.957***	-29.157***
	(-10.86)	(-7.36)	(-18.47)	(-14.41)	(18.58)	(9.55)	(-12.43)	(-10.49)
Obs	704209	704209	704209	704209	704209	704209	704209	704209
adj. R^2	0.923	0.871	0.945	0.911	0.944	0.916	0.909	0.870

The subsample analysis results of matured towns and new towns are reported in Table 5. Mature towns include Ang Mo Kio, Bedok, Bishan, Bukit Merah, Bukit Timah, Central Area, Clementi, Geylang, Kallang/Whampoa, Marine Parade, Pasir Ris, Queenstown, Serangoon, Tampines and Toa Payoh. New towns include Bukit Batok, Bukit Panjang, Choa Chu Kang, Hougang, Jurong East, Jurong West, Punggol, Sembawang, Sengkang, Tengah, Woodlands and Yishun. The same polynomial model based on equation (2) above is adopted. Panel A contained the results for the matured towns, either based on a remaining lease in unit of a single year (Panel A1), or a remaining lease in unit of 5 years (Panel A2) as the coefficients of {{Lease}_{i,t}}^3 is too small in Panel A1. The results for the new towns are reported in Panel B (Panel B1 in 1-years unit and Panel B2 in 5-year unit). Control variables include size, floor level, macroeconomic conditions (CPI), as well as year and location fixed effects. The coefficients of the control variables are omitted for reporting purpose. As indicted by the sign of the coefficients of Lease, {{Lease}_{i,t}}^2 and {{Lease}_{i,t}}^3, the non-linearity of the lease term holds in both matured and new towns. However, the magnitudes of the coefficients differ, and Figure 6 clearly present the differences.

While the pricing functions are both polynomial with statistically significant slopes for lease and its second and third powers, the economical significance level varies at different stages. The slope of lease of matured town is 22 times of that of new towns. The slopes of lease square of both matured and new towns are negative, and again, the value of the slope of matured town is 21 times of that of the new towns. However, for the slopes of the lease cube, both are positive, and the magnitude is about the same. For matured towns (Figure 6A), when the remaining lease decreases (moving along the x-axis from right to left), the price decreases at a lower rate prior to decreasing at a higher rate. For new towns (Figure 6B), although the pattern of the curve looks similar to that in Figure 6B, however, the magnitude of the y-axis is different. In general, the variation in the price relative to the lease of the units is larger for mature towns than for new towns. A possible explanation for this phenomenon is that buyers are willing to pay for a premium for the units in the mature towns with the expectation that the value of the house can be preserved. Matured facilities and upgrading programs have enhanced the overall living environment but it has not fundamentally change how buyers perceived the value of shorter lease HDB units.

Table 5 HDB Price Nonlinearity Subsample Analysis: Mature vs. New Towns

Table 5 reports the results based on 2 subsamples of a polynomial model by using the following equation:

$$y_{i,t} = \alpha + \beta_1 Lease_{i,t} + \beta_2 Lease_{i,t}{}^2 + \beta_3 Lease_{i,t}{}^3 + \beta_4 Controls + \varepsilon_{i,t}$$

with robust standard errors and clustering effect. Columns (1) and (2) use PSF as the resale transaction price measurement, while total transaction price is used in Columns (3) and (4), logarithm of the total transaction price in Columns (5) and (6), and total transaction price-to-annual median income-ratio in Columns (7) and (8), respectively. Related t-statistics are reported in parentheses ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

	Panel A1: Mature Town, and Lease in unit of 1 year							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	psf	psf	price	price	logPrice	logPrice	Price/ income	Price/ income
Lease	0.865***	0.788***	0.106***	0.118***	0.177***	0.111***	0.885***	0.966***
	(11.05)	(5.43)	(15.18)	(8.97)	(9.36)	(2.93)	(10.87)	(5.64)
$Lease^2$	-0.012***	-0.011***	-0.001***	-0.002***	-0.003***	-0.002***	-0.013***	-0.014***
	(-11.57)	(-5.52)	(-14.69)	(-8.44)	(-9.99)	(-3.10)	(-11.99)	(-5.98)
$Lease^3$	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	(12.32)	(5.76)	(14.56)	(8.14)	(10.85)	(3.41)	(13.32)	(6.41)
	Panel A2: Mature Town, and Lease in unit of 5 years							
	psf	psf	price	price	logPrice	logPrice	Price/ income	Price/ income
Lease_5y	4.325***	3.941***	0.532***	0.588***	0.884***	0.556***	4.426***	4.829***
	(11.05)	(5.43)	(15.18)	(8.97)	(9.36)	(2.93)	(10.87)	(5.64)
$Lease\_5y^2$	-0.300***	-0.269***	-0.034***	-0.038***	-0.064***	-0.040***	-0.334***	-0.355***
	(-11.57)	(-5.52)	(-14.69)	(-8.44)	(-9.99)	(-3.10)	(-11.99)	(-5.98)
$Lease\_5y^3$	0.007***	0.006***	0.001***	0.001***	0.002***	0.001***	0.008***	0.009***
	(12.32)	(5.76)	(14.56)	(8.14)	(10.85)	(3.41)	(13.32)	(6.41)

(Continued…)

(Table 5 Continued)

	Panel B1: New Town, Lease in unit of 1 year							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	psf	psf	price	price	logPrice	logPrice	Price/ income	Price/ income
Lease	0.327***	0.307**	0.048***	0.060***	0.069***	0.056	0.392***	0.426**
	(3.81)	(1.98)	(5.23)	(4.21)	(2.60)	(0.98)	(3.22)	(2.21)
$Lease^2$	-0.005***	-0.005**	-0.001***	-0.001***	-0.001***	-0.001	-0.007***	-0.008***
	(-4.65)	(-2.57)	(-5.41)	(-4.33)	(-3.50)	(-1.55)	(-4.49)	(-3.09)
$Lease^3$	0.000***	0.000***	0.000***	0.000***	0.000***	0.000**	0.000***	0.000***
	(5.64)	(3.24)	(5.77)	(4.57)	(4.59)	(2.23)	(5.81)	(4.00)
	Panel B2: New Town, lease in unit of 5 years							
	psf	psf	price	price	logPrice	logPrice	Price/ income	Price/ income
Lease_5y	1.635***	1.536**	0.239***	0.300***	0.347***	0.279	1.958***	2.131**
	(3.81)	(1.98)	(5.23)	(4.21)	(2.60)	(0.98)	(3.22)	(2.21)
$Lease\_5y^2$	-0.128***	-0.127**	-0.016***	-0.020***	-0.030***	-0.028	-0.178***	-0.195***
	(-4.65)	(-2.57)	(-5.41)	(-4.33)	(-3.50)	(-1.55)	(-4.49)	(-3.09)
$Lease\_5y^3$	0.003***	0.003***	0.000***	0.000***	0.001***	0.001**	0.005***	0.005***
	(5.64)	(3.24)	(5.77)	(4.57)	(4.59)	(2.23)	(5.81)	(4.00)

Figure 6A Polynomial Function along Lease Dimension in Mature Towns

The X-axis is lease with a unit of one year and y-axis is the corresponding HDB transaction price with a unit of one million SGD, holding the rest of the control variables unchanged. The figure is drawn based on the coefficients in Column 3 of Panel A1 in Table 5:

$$y_{i,t} = .1064457 * Lease_{i,t} - 1.3652 * 10^{-2}\ Lease_{i,t}{}^{2} + 5.92 * 10^{-6}\ Lease_{i,t}{}^{3}$$

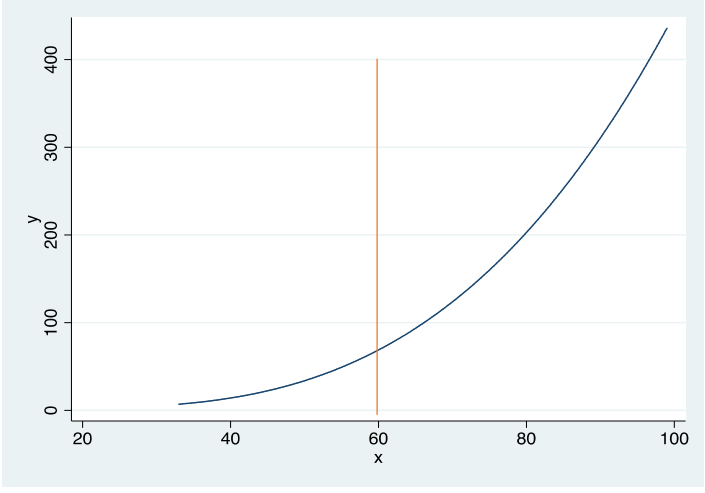
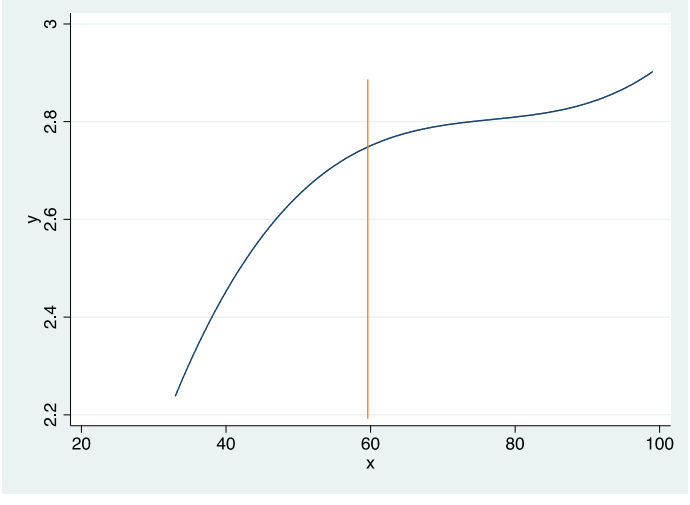


Figure 6B Polynomial Function along Lease Dimension in New Towns

X-axis is lease with a unit of one year and y-axis is the corresponding HDB transaction price with a unit of one million SGD, holding the rest of the control variables unchanged. The figure is drawn based on the coefficients in Column 3 of Panel B1 in Table 5:

$$y_{i,t} = 0.0477575 * Lease_{i,t} - 6.377 * 10^{-4}\ Lease_{i,t}{}^{2} + 2.9 * 10^{-6}\ Lease_{i,t}{}^{3}$$



4. Conclusion

This study aims to examine the public housing resale market to determine the significance of remaining leases as one of the most impactful factors on transaction prices. This paper concludes that (after controlling for size, floor level, macroeconomic conditions, and fixed effects) there is a significant price premium for housing units with a longer-term lease and this premium effect is nonlinear and polynomial. We use town and street fixed effects to address the concerns that older (but established) districts are characterized by more reputable schools and infrastructures such as health care offerings and shopping malls, while developing districts have innovative facilities with a fresh contemporary outlook as that of modern satellite towns. We also document a different lease premium in mature towns as compared to that of the new towns, which captures the different concerns and preferences of buyers in combination with location and other characteristics of the houses.

The HDB has come a long way since the independence of Singapore, and Chua (2014) highlights three points for a balanced and sustainable public housing model of the HBD in Singapore: i. monetizing public housing for retirement; ii. public housing prices must keep pace with inflation and rising costs of living; and iii. new subsidized flats must be kept affordable for new entrants into the housing market. The results from this paper have reinforced the first two points. The public housing market in Singapore has its unique features. The market has been undergoing various challenges in recent decades due to rising prices as well as debates revolving around 99-year leaseholds. As flats age, their market value drops which may impact the retirement plans of the flat owner. This issue is intensified when many of the owners of these older flat are elderlies whose wealth is largely dependent on the value of their owned real estate.

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