# Rental Rate under Housing Price Uncertainty: A Real Options Approach

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**Abstract**

This paper extends the theory on investment under uncertainty by studying household property investment under housing price uncertainty. Specifically, we model the renter′s decision to buy a house and the landlord′s decision to sell as real options of waiting and examine real options effects on rental demand, supply, and thus the rental rate. Using unique data from Hong Kong, we empirically verify two predictions from our model. First is the monotonic price effect, i.e., positive housing price shocks produce rapid rental growth while negative price shocks reduce rental growth. Second is the regime-dependent volatility effect, i.e., rental growth increases with volatility when the housing price is rising and decreases with volatility when the housing price is falling. Our findings carry important policy implications for cyclical fluctuations in the rental market, inflation, and property bubbles.

**Key words:** investment under uncertainty, real options, rental adjustment, volatility

## 1. Introduction

Following extreme monetary easing in the developed world after the recent financial crisis, there has been a big concern about asset bubbles and imported inflation in emerging economies and small open economies. For example, the Managing Director of the IMF, Christine Lagarde, told the media at the close of the IMF and World Bank's annual meeting of 2012 that "accommodative monetary policies...could strain the capacity of those economies to absorb the potentially large flows and could lead to overheating asset price bubbles." As one of the world's most open economies, Hong Kong warned of fresh risks of an assets bubble when the third round of quantitative easing by the US Federal Reserve was launched. Having soared by 109.4% since the fourth quarter of 2007, the Hong Kong property price is 81% overvalued according to the conventional gauge of the price-to-rent ratio.[1]

More intriguing is the stylized fact that property rent tends to follow property price in Hong Kong, as shown in Chart 1. This is in contrast to conventional wisdom that rent affects housing price, but not the reverse. However, such an empirical finding is sensible because the Hong Kong property market is integrated with the world capital market and is more easily exposed to external shocks, while the rental market is highly segmented and local. In Hong Kong, the interest rate cannot deviate too much from its US counterpart under the linked exchange rate system. Thus US monetary shocks have a great impact on Hong Kong's capital and property markets. The relatively exogenous housing price dynamics will affect the decision making of

[1] "Global property markets: Bloom and gloom," *Economist*, May 18, 2013.

property investments, which in turn affects the rental demand, supply, and the rental rate. In this paper, we examine the rental rate under housing price uncertainty using a real options approach.

We begin by modeling both the renter′s decision to buy a house and the landlord′s decision to sell as the exercising of real options. Owning a house is risky because the housing price is volatile and its fluctuation can have a sizable effect on the owner′s wealth. Renting thus provides a hedge against housing price uncertainty by offering a put option on the housing value. The decision on the purchase timing becomes an optimal stopping problem for renters. Rational renters will delay their decision to buy if the housing price is higher than their private valuations of the house but there is hope in waiting for the price to drop. Landlords, by contrast, own a call option on the housing value which allows them to choose the optimal timing of sale. Rational landlords will delay their decision to sell if the housing price is lower than their private valuations but there is hope in waiting for the price to recover. Further assuming that the private valuations of renters and landlords are drawn from normal distributions, we can then derive the rental demand and supply, as well as the relation between the equilibrium rental rate and the housing price and housing price volatility.

The price effect in this model is straightforward to understand. This refers to an increase of the rental demand and a decrease of the rental supply in an up housing market because more renters are reluctant to buy and more landlords are willing to sell. By contrast, in a down housing market, the rental demand will decrease because more renters are willing to buy while the rental supply will increase because more landlords are reluctant to sell. This induces a positive relation between the equilibrium rental rate and the housing price.

Meanwhile, the volatility effect will increase both demand and supply in the rental market because with greater housing price volatility, both renters and landlords are more eager to hold on to their real options. The effect on the equilibrium rental rate depends crucially on the relative size of the demand and supply increases. When the private values of the renters are more widely dispersed, the expansion in rental demand induced by higher housing price volatility will be smaller, and it is possible for the expansion of rental supply to play a more important role, leading to lower equilibrium rental rates. We discuss various scenarios that might lead to such a negative relation between the rental rate and housing price volatility, including a case in which a falling housing market gradually removes renters who become homeowners, eventually leaving only renters who are insensitive to price changes (this is analogous to the notion of "burnout" in mortgage prepayment).

Our model contributes to the literature on investments under uncertainty, which recognizes irreversibility and the possibility of delay as key characteristics of most investments. A firm or household with an opportunity to invest in a real asset is holding a "real option" analogous to a financial option—the right but not the obligation to buy or sell an asset at some future time of its choosing. The option value of waiting is highly sensitive to uncertainty about the future value of investments and has a significant impact on firm-level investment decisions (Henry, 1974; Bernanke, 1983; Majd and Pindyck, 1987; Brennan, 1990; Triantis and Hodder, 1990; Dixit and Pindyck, 1994; Aguerrevere, 2009) as well as macro-level cyclical fluctuations in aggregate investments (Bernanke, 1983). After the recent financial crisis, considerable attention is paid to the impact of uncertainty shocks. Bloom (2009) shows that higher uncertainty, especially regarding government policy, increases the real options value to waiting so that firms scale back their investments and hiring. We demonstrate that uncertainty shocks in the property market (especially caused by monetary easing) also have real options effects on the property investments of individual households and the cyclical fluctuations in the rental market.

In the real estate context, the real options approach has been used to value urban land (Titman, 1985) and lease contracts (Grenadier, 1995; 2005). We obtain a closed-form solution for the equilibrium rent that contains the option premium of waiting driven by housing price uncertainty, and offer a new and richer explanation based on the "hold out" phenomenon. Qian (2013) examines the real options effect of sellers holding out in a down housing market. In her model, the option value of waiting is driven by the exogenous rent uncertainty and the "reservation value" depends on the current value of the rent and is identical for everyone. Her model can explain why homeowners would delay selling, but then every homeowner would sell at the same time. In our model, both renters and landlords hold out in a volatile housing market, and their aggregate effect on the equilibrium rental rate depends on the distributions of their private valuations.

Empirically, we find strong evidence of a monotonic housing price effect and a regime-dependent volatility effect on the rental rate using a unique dataset from the Hong Kong residential rental and property market. As a small open economy, there is strong (Granger) causality from the Hong Kong housing price change to its rental rate change, supporting our model's assumption of relatively exogenous housing price dynamics. Besides, Hong Kong is an ideal place to test our model predictions because its housing and rental markets are fairly homogenous, with rent free from control and constructed from fresh lettings. Consistent with the modeling described above, positive housing price shocks produce rapid rental growth while negative price shocks reduce rental growth. Moreover, rental growth increases with housing price volatility when the housing price is rising and decreases with volatility when the housing price is falling. Our empirical evidence contributes to the conventional rental adjustment literature where the vacancy gap between the "natural" (or equilibrium) and actual rate is the sole driver of rental rate changes (Smith, 1974; Eubank and Sirmans, 1979; Rosen and Smith, 1983; Hendershott, 1996). More interestingly, in our empirical model, vacancy becomes insignificant in explaining the change of the rental rate after controlling for the housing price change and volatility. This suggests that vacancy is an endogenous driver of rental adjustment and its micro foundation could be the real options cross-market effect on the rental demand and supply.

Lastly, our findings carry important policy implications for cyclical fluctuations in the rental market. It is apparent in our model that housing price dynamics in general and uncertainty in particular play important roles in rental adjustments and contribute to cyclical fluctuations in the rental market. Property bubbles may spill over to rent inflation and the burst of a bubble may cause rent deflation. Moreover, due to the large weight of rent in the CPI (accounting for 26% in Hong Kong), rent inflation exerts considerable influence on measures of overall and core inflation. To curb inflation or prevent an economy from falling into deflation, it is important to stabilize the housing price dynamics and reduce housing price uncertainty. In particular, policy actions are needed to deal with capital inflow in the era of quantitative easing and capital outflow when it comes to the end. The findings also have another important implication for detecting property bubbles: the conventional gauge of price-to-rent ratio may underestimate a bubble because rent can be driven up by housing price uncertainty. A better measure should be adjusted for the option component of rent.

The rest of the paper is organized as follows. Section 2 presents our theoretical model and derives testable implications. Section 3 discusses data of rental and property markets in different countries and relevant background. Section 4 reports the results from our empirical model. Section 5 provides concluding remarks.

## 2. Theoretical Model

In contrast to the traditional literature that treats the rent as fundamental and the housing price as the present value of all future rents, we model the housing price dynamics as exogenously given and consider the following real options model of the renter and landlord's decisions. The model uses the following variables:

$K$ : Private valuation of the house held by the renter or landlord.

$S_t$ : Market value of the house at time $t$, described by a geometric Brownian motion with volatility $\sigma$ and drift $r-\delta$ where $\delta$ captures the market-wide property yield.

$r$ : Risk-free interest rate.

$\tau$ : Stopping time of switching from renting to buying for the renter, or from renting to selling for the landlord.

$c$ : The renter's enjoyment (per unit time) derived from living in the house.

$b$ : The landlord's cost (per unit time) of maintaining the house as a rental unit.

$R$ : Cost (per unit time) of renting the house.

### 2.1. Renter's Problem

First, we consider the renter's decision to rent or buy a house. The renter solves an optimal stopping-time problem. He (assumed to be risk-neutral) chooses $\tau$ to maximize his utility:

$$U = \max_{\tau} E\left[ e^{-r\tau}\left(K - S_{\tau}\right) + \int_0^{\tau} e^{-ru}\left(c - R\right)du \right] \tag{1}$$

The first part of equation  captures the utility gain from buying the house. The second part captures the utility derived from the period that he rents before buying. For simplicity, we assume that the rental agreement has an infinite maturity and both the renter and the landlord can walk away from the agreement at any time without suffering a penalty.

Following the literature on valuing American put options (Kim, 1990; Bunch and Johnson, 2000), we conjecture that the optimal stopping policy is given by:

$$\tau = \inf\{t : S_t \le S_c\}, \qquad (2)$$

where $S_c$, the early exercise boundary, is a constant. We then have:

$$U = \max_{S_c} \int_0^\infty \left[ e^{-r\tau}\left(K - S_c\right) + \frac{c-R}{r}\left(1 - e^{-r\tau}\right) \right] f(\tau)\, d\tau, \qquad (3)$$

where $f(\cdot)$ is the density of the first passage time of $S_t$ from an initial value of $S_0 = S$ down to a lower threshold of $S_c$. Using the following result from Kim (1990):

$$\int_0^\infty f(t) e^{-rt} dt = \left(\frac{S_c}{S}\right)^\gamma, \qquad (4)$$

where

$$\gamma = \frac{1}{\sigma^2}\left[ \sqrt{\left(r - \delta - \frac{1}{2}\sigma^2\right)^2 + 2\sigma^2 r} + \left(r - \delta - \frac{1}{2}\sigma^2\right) \right], \qquad (5)$$

we have:

$$U = \max_{S_c} \left(K - S_c - \frac{c-R}{r}\right)\left(\frac{S_c}{S}\right)^\gamma + \frac{c-R}{r}. \qquad (6)$$

Solving the first order condition with respect to $S_c$, we find that the renter will choose to buy the house if the housing price $S_t < S_c^R$, where:

$$S_c^R = \frac{\gamma}{\gamma+1}\left(K - \frac{c-R}{r}\right). \qquad (7)$$

To better understand the renter's decision, we note that when $r \ll \sigma^2$ and $\delta \ll \sigma^2$, we can approximate $\gamma$ using Taylor's expansion and rewrite $S_c^R$ as:

$$S_c^R = \frac{2r}{2r+\sigma^2}\left(K - \frac{c-R}{r}\right). \tag{8}$$

This shows that the renter is more likely to remain renting when his private valuation of the house $K$ is lower, when the rent $R$ is lower, when his enjoyment of renting the house $c$ is greater, and when the housing price volatility $\sigma$ is higher.

## 2.2. Landlord's Problem

In comparison, the landlord chooses the optimal timing to sell her house. Her utility is given by:

$$U = \max_{\tau} E\left[e^{-r\tau}\left(S_\tau - K\right) + \int_0^\tau e^{-ru}\left(R-b\right)du\right]. \tag{9}$$

The first part of equation  captures the utility gain from selling the house (which the landlord privately values at $K$ ) for the market price of $S_\tau$, and the second part represents the value from receiving rent payment and maintaining the house from 0 to $\tau$.

Conjecturing an optimal stopping policy of:

$$\tau = \inf\left\{t \ : \ S_t \geq S_c\right\}, \tag{10}$$

we have:

$$U = \max_{S_c} \int_0^\infty \left[e^{-r\tau}\left(S_c - K\right) + \frac{R-b}{r}\left(1-e^{-r\tau}\right)\right] g\left(\tau\right) d\tau, \tag{11}$$

where $g(\cdot)$ is the density of the first passage time of $S_t$ from an initial value of $S_0 = S$ up to a higher threshold of $S_c$. Using the following result from Kim (1990):

$$\int_0^\infty g(t)e^{-rt}dt = \left(\frac{S}{S_c}\right)^\beta, \tag{12}$$

where

$$\beta = \frac{1}{\sigma^2}\left[\sqrt{\left(r-\delta-\frac{1}{2}\sigma^2\right)^2 + 2\sigma^2 r} - \left(r-\delta-\frac{1}{2}\sigma^2\right)\right], \tag{13}$$

we have:

$$U = \max_{S_c}\left(S_c - K + \frac{R-b}{r}\right)\left(\frac{S}{S_c}\right)^\beta + \frac{R-b}{r}. \tag{14}$$

Solving the first order condition with respect to $S_c$, we find that the landlord will choose to sell the house if the housing price $S_t > S_c^L$, where:

$$S_c^L = \frac{\beta}{\beta-1}\left(K + \frac{R-b}{r}\right). \tag{15}$$

To better understand the landlord's decision, we note that when $r \ll \sigma^2$ and $\delta \ll \sigma^2$, we can approximate $\beta$ using Taylor's expansion and rewrite $S_c^L$ as:

$$S_c^L = \frac{2\delta+\sigma^2}{2\delta}\left(K + \frac{R-b}{r}\right). \tag{16}$$

This shows that the landlord is more likely to remain a landlord when her private valuation of the house $K$ is higher, when the rent $R$ is higher, when her cost of maintaining the house as a rental unit $b$ is lower, and when the housing price volatility $\sigma$ is higher.

### 2.3. Equilibrium

We assume that there are renters and landlords, each with mass one, endowed with private valuations normally distributed as $K_R \sim N\left(\mu_R, \sigma_R^2\right)$ and $K_L \sim N\left(\mu_L, \sigma_L^2\right)$, respectively.

Given a housing price of $S$, a current renter will continue to rent if $S \geq S_c^R$ or, equivalently, if his private valuation $K$ satisfies:

$$K \leq \frac{1+\gamma}{\gamma} S + \frac{c-R}{r}. \tag{17}$$

Given the distribution of private valuations of the renters, the demand for rental units is:

$$\text{Demand} = \Phi\left(\frac{\frac{1+\gamma}{\gamma} S + \frac{c-R}{r} - \mu_R}{\sigma_R}\right), \tag{18}$$

where $\Phi(\cdot)$ is the standard normal CDF.

Similarly, a current landlord will continue to rent out her house if $S \leq S_c^L$ or, equivalently, if her private valuation $K$ satisfies:

$$K \geq \frac{\beta-1}{\beta} S - \frac{R-b}{r}. \tag{19}$$

Given the distribution of private valuations of the landlords, the supply for rental units is:

$$\text{Supply} = \Phi\left(\frac{-\frac{\beta-1}{\beta} S + \frac{R-b}{r} + \mu_L}{\sigma_L}\right). \tag{20}$$

Equating demand and supply for rental units, the equilibrium rent is determined as:

$$R^* = \frac{1}{\sigma_L + \sigma_R}\left[r\left(\sigma_L \frac{1+\gamma}{\gamma} + \sigma_R \frac{\beta-1}{\beta}\right) S + \sigma_L\left(c - r\mu_R\right) + \sigma_R\left(b - r\mu_L\right)\right]. \tag{21}$$

To interpret equation , we first note an unambiguously positive relation between the equilibrium rent and the housing price, since

$$
\begin{aligned}
\frac{1+\gamma}{\gamma} &= \frac{\sqrt{\left(r-\delta-\frac{1}{2}\sigma^2\right)^2+2\sigma^2 r}+\left(r-\delta+\frac{1}{2}\sigma^2\right)}{\sqrt{\left(r-\delta-\frac{1}{2}\sigma^2\right)^2+2\sigma^2 r}+\left(r-\delta-\frac{1}{2}\sigma^2\right)} > 0, \\
\frac{\beta-1}{\beta} &= \frac{\sqrt{\left(r-\delta-\frac{1}{2}\sigma^2\right)^2+2\sigma^2 r}-\left(r-\delta+\frac{1}{2}\sigma^2\right)}{\sqrt{\left(r-\delta-\frac{1}{2}\sigma^2\right)^2+2\sigma^2 r}-\left(r-\delta-\frac{1}{2}\sigma^2\right)} > 0.
\end{aligned}
\tag{22}
$$

The intuition for this result is clear. When $S$ increases, the demand for rental units increases while the supply shrinks. Hence $R$ must increase to restore the equilibrium. When $S$ decreases, the demand for rental units drops while the supply expands. Therefore $R$ must decrease to restore equilibrium.

The relation between the equilibrium rent and housing price volatility is more complex and depends crucially on the standard deviations of the private value distributions, $\sigma_R$ and $\sigma_L$. To see this, we first follow earlier derivations to assume that $r \ll \sigma^2$ and $\delta \ll \sigma^2$, yielding the following approximations by Taylor's expansion:

$$
\begin{aligned}
\frac{1+\gamma}{\gamma} &\approx \frac{2r+\sigma^2}{2r}, \\
\frac{\beta-1}{\beta} &\approx \frac{2\delta}{2\delta+\sigma^2}.
\end{aligned}
\tag{23}
$$

Given this approximation, equations  and  then show that both the demand and supply of rental units will increase with housing price volatility. Moreover, the expansion of rental demand and supply will be larger when the private values are more tightly distributed. When $\sigma_R$ and $\sigma_L$ are similar in magnitude, it is clear that $R^*$ will be increasing in $\sigma$ (since $(1+\gamma)/\gamma$ clearly dominates $(\beta-1)/\beta$ ). However, if for any reason the renters' private valuations are much more widely dispersed than those of the landlords′, it is possible for the increase in rental demand to be outstripped by the increase in rental supply, resulting in $R^*$ decreasing in $\sigma$.

One such possibility could arise after a fresh drop in housing prices. Since landlords are generally more optimistic about the housing market, they tend to discount the drop as temporary fluctuation and keep subscribing to their favorable views at least for a while. Renters, on the other hand, tend to be more pessimistic. Given the recent drop in housing prices, some renters are likely to drastically reduce their subjective valuation. This could result in $\sigma_R > \sigma_L$ and the equilibrium rent declining with housing price volatility.

The above setting assumes that all renters and landlords are utility maximizers who can buy and sell properties without constraints. In reality, however, some renters will remain renting even if the housing price decreases substantially. For instance, some renters may not have saved enough for a down payment, and some renters may have ruled out buying because of expected job-related migration. The optimal stopping problem probably does not capture the behavior of these renters. This is akin to the notion of "burnout" in mortgage prepayment, which refers to borrowers who do not refinance following a drop in interest rates.

To allow for this possibility, we assume that the demand for rental units is fixed at $D_1$ once the housing price has fallen sufficiently. In other words, all unconstrained renters who can afford and are willing to buy a house have already done so, leaving only constrained renters who have no other alternative but continuing to rent. In this case, the equilibrium condition is given by:

$$\Phi^{-1}\left(D_1\right) = \frac{-\frac{\beta-1}{\beta}S + \frac{R-b}{r} + \mu_L}{\sigma_L}, \tag{24}$$

and the equilibrium rent is:

$$R^* = \frac{r(\beta - 1)}{\beta} S - r\left(\mu_L - \sigma_L \Phi^{-1}\left(D_1\right)\right) + b, \tag{25}$$

which is increasing in $S$ and decreasing in $\sigma$.

Lastly, our notion of equilibrium considers only the rational decisions of *existing* renters and landlords to exit the rental market by purchasing or selling a house. Clearly, the rental demand is also affected by people moving into the area as renters, and so is the rental supply by people who have accumulated enough wealth to purchase multiple properties. We leave the modeling of these market participants to future extensions of our model.

## 3. Data

In order to test our theory, a well-matched dataset is prerequisite to get a sensible result since there are several salient features about housing and rental markets. First, housing units are always heterogeneous, and units for sale could be quite different to units for rent in the same area. For example, in the US units for sale are mostly single-family homes while the rental market is dominated by condos and apartments (Dales, 2011). The heterogeneity suggests that the ideal sample for this study is from a large metropolitan city where units for sale and for rent are homogenous. Second, about 40-50 percent of the world′s urban population lives in rental housing of one kind or another and most of these households live in units subject to controls on rent paid (Turner and Malpezzi, 2003). Many large cities such as London, New York and Los Angeles have rent controls in different regimes for many years. Third, from the theoretical model, we need rental prices constructed by fresh lettings in the rental market, and rental costs from the Consumer Price Index (CPI) is not appropriate because it has significant time lags. Unfortunately, the CPI rental indicators are much easier to obtain compared with the indices constructed from fresh lettings.

Given the above data requirements, Hong Kong is an ideal place to study the link between housing price and rent for at least three reasons: first, units for sale and units for rent are homogenous in Hong Kong because most housing units are apartments and condos in this metropolis with very high population density.[2] Second, Hong Kong has been free from rent control for many years (Wang et al, 2012). Third, the rental price indices are constructed from fresh lettings in Hong Kong. Therefore, we collect and construct the following data from Hong Kong residential rental and property markets.

a) **Housing price index**

The housing price index is published by the Hong Kong Rating and Valuation Department (R&VD), and covers five categories of private residential units according to size.[3] The R&VD publishes two types of price indices at both the aggregate level and the size category level, and the price indices are designed to measure price changes with quality kept constant, which means that they have been adjusted for variations in the quality of the different housing units.

b) **Rental price index**

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[2] Hong Kong is one of the most densely populated areas in the world, with a land mass of 1,104 km2 (426 sq mi) and a population of seven million people. Most residential housing units in the city are apartments and condos with size less than 100 Square meters, which account for 92% of total housing units in 2011 (R&VD, 2012). Housing is the most important form of savings to most households in the city and about half of domestic credit goes to various mortgage loans in the property market and taxes from the real estate industry have been a significant source of government revenue (Peng et al. 2002).

[3] The five categories are from the smallest Class A to the largest Class E, representing floor areas of 39.9 $m^2$ and below (A), 40.0 to 69.9 $m^2$ (B), 70.0 to 99.9 $m^2$ (C), 100,0 to 159.9 $m^2$ (D), and over 159.9 $m^2$ (E), respectively.

Similar to housing prices, the R&VD also publishes rental price indices constructed by fresh lettings for different categories. Rents are based on an analysis of rental information recorded by the R&VD for fresh lettings effective in the quarter being analyzed, and rents are analyzed on a net basis, i.e., exclusive of rates, management, and other charges. The rental indices are designed to measure rent changes with constant quality since rents at a certain period depend to a large extent on the special characteristics of the premises, including quality and location.

c) **Volatility of the housing price growth**

From the theoretical model, the housing price uncertainty plays an important role in rental adjustment. To proxy for uncertainty, we estimate the volatility of the housing price growth. Following the volatility literature, we choose the Exponential Generalized Autoregressive Conditional Heteroskedasticity (EGARCH) model (Nelson, 1991) to better capture the volatility asymmetry in the property markets (Michayluk et al. 2006 and Liow et al., 2009). The detailed information about volatility estimates can be found in Table 2.

d) **Real risk-free interest rate**

Since 1983, Hong Kong dollar has been pegged to the US dollar under the linked exchange rate system, suggesting that the risk-free interest rate in Hong Kong should be closely in line with its counterpart in the US. In the real estate literature, long-term Treasury bond yields are often used as a proxy for the risk-free interest rate (Poterba, 1991, Himmelberg, et al., 2005). We select the ten-year US Treasury bond yield as an appropriate risk-free interest rate in Hong Kong because the long-term domestic government bond market in Hong Kong is quite illiquid (Wang et al., 2012).

e) **Vacancy rate**

The vacancy rate is also from the RV&D reports and the vacant unit is defined as a unit not physically occupied when the survey is conducted at the end of the year from management offices, owners, occupiers, or by inspection (RV&D, 2011). Premises under decoration are classified as vacant and some vacancies could be due to units not yet issued with certificates by the government, which therefore could not have been occupied. It should be clear that vacancy bears no relationship to whether the property has been sold by the developers, and units sold may remain vacant, pending occupation by the owner or tenant. Vacancy figures cover the entire stock in the residential market and are not just confined to new developments.

The data used in this paper is quarterly and monthly from 1980Q1 to 2011Q4. As shown in Chart 1, the Hong Kong property market has been very volatile in the last three decades. Since 2009, property prices have increased sharply in Hong Kong, and the housing price index rose above its 1997 peak and is almost 40% higher than the previous peak in the first quarter of 2013. Meanwhile, the rental price index has also increased dramatically. For example, rent increased 35% between 2009Q3 and 2010Q4, while property price rose more than 50% in the same period. More importantly, rent tends to follow the housing price in Hong Kong. For example, in October 1995, the housing price index came to its turning point and began its two-year rally. Two months later, the rent followed the housing price and came to its own trough and increased persistently till housing price collapsed at the end of 1997. We can observe the same pattern in both 2003 and 2008.

[Chart 1 here]

Table 1 shows the summary statistics of housing price growth, rental price growth, interest rate change, and vacancy rate. It can be easily observed that housing price growth is more volatile than rental growth in both quarterly and monthly data, which is consistent with what we observed in Chart 1. The vacancy rate is quite low, only 4.7% on average in quarterly data between 1980 and 2011, and the rate is even smaller in recent years, only 3.5% on average, suggesting that the rental market has been extremely tight in Hong Kong.

[Table 1 here]

Table 2 reports the ARMA-EGARCH estimation results of the housing price growth. According to the Akaike Info Criterion (AIC) and the Schwarz Criterion (SC), we choose ARMA (1,2)-EGARCH (2,3,2) for the quarterly data and ARMA(1,2)-EGARCH(2,2,2) for the monthly data. The results show a strong EGARCH effect. We derive the series of estimated volatility from the ARMA-EGARCH models, which are then superimposed over the real rental growth as shown in Chart 2.

[Chart 2]

From Chart 2, the housing price has become more volatile since the late 1980s, especially during the Asian financial crisis of 1997 and the recent global financial crisis of 2008. The forecasted volatility reached the highest level in 1994Q3 due to the sudden price jump at the end of 1994. Correspondingly, the real rental growth also became quite strong, which suggests that housing price volatility might play a role in rental adjustment.

[Table 2 here]

We also conduct a Granger causality test for the housing price growth and rental price growth using both quarterly and monthly data. From results in Table 3, we can reject the null hypothesis that the rental price growth does not Granger cause the housing price growth at the 5% significance level, while we can also reject the null hypothesis that price growth does not Granger cause rent growth at the 1% significance level. However, if we examine monthly data, we cannot reject that rent growth does not Granger cause price growth even at the 10%

significance level. Yet, we can still reject that price growth does not Granger cause rent growth at the 1% significance level. These results clearly show that housing price growth could Granger cause rent growth, but not the other way around.

[Table 3 here]

# 4. Empirical Analysis

## 4.1. Empirical Model

According to the above discussion, we can write down the following empirical models:

$$\%\Delta R_t = \beta_0 + \beta_1 Vacancy_{t-1} + \beta_2 \%\Delta S_{t-1} + \beta_3 Vol_t + \beta_4 Vol_t \times d_t + \beta_5 \%\Delta r_t + \varepsilon_t, \quad (26)$$

where $\%\Delta R_t$ is the percentage change of the real rent at period *t*, $vacancy_{t-1}$ is the lagged vacancy rate, $\%\Delta S_{t-1}$ is the lagged percentage change of the real housing price, $Vol_t$ represents the volatility of the real housing price growth, $d_t$ is a dummy for housing price trend where $d_t = 1$ if the housing price is rising and zero otherwise, and $\Delta r_t$ denotes the percentage change of the real risk-free interest rate.

In the benchmark model (Model 1), we consider the lagged vacancy rate as the only determinant of rental growth, which is in line with the traditional literature of rental adjustment. Alternatively, Model 2 uses lagged housing price growth and volatility as explanatory variables to test our theoretical model predictions, which can be structured as two hypotheses. The first one is the monotonic price effect hypothesis (H1):

$$\beta_2 > 0 \quad (27)$$

which expects rental growth to be increasing with housing price growth. The second one is the regime-dependent volatility effect hypothesis (H2):

$$\beta_4 > 0 \ \beta_3 < 0 \, , \ \beta_4 + \beta_3 > 0 \tag{28}$$

which argues that rental growth increases with housing price volatility when the housing price is rising and decreases with housing price volatility when the housing price is falling (see our discussion on page 11 which justifies these predictions). Moreover, if housing price dynamics and uncertainty play more important roles in the rental adjustment process than the vacancy rate, the R-squared of Model 2 will be higher than that of Model 1.

In Model 3, we want to examine whether these two hypotheses (monotonic price effect and regime-dependent volatility effect) still hold after controlling for interest rate changes. Also, we are interested in the impact of interest rate changes on the rental growth. The sign of $\beta_5$ is not so straightforward because the first order derivative of the real rent with respect to the real interest rate is complicated from equation . Intuitively, however, when the interest rate is low, credit constraint is relaxed and housing demand would increase. This seems to imply a lower rental demand and lower rental rates. Therefore, we expect to see a positive $\beta_5$.

In Model 4, we put all variables into the regression. We expect that the monotonic price effect and regime-dependent volatility effect are still significant and robust after controlling for the vacancy rate. On the other hand, it is interesting to see whether the vacancy rate is still significant in explaining the rental growth after controlling for house price dynamics and uncertainty. If vacancy rate becomes insignificant, it suggests that vacancy rate is an endogenous driver of rental adjustment and its micro-foundation could be the housing price effect and volatility effect in the rental market.

### 4.2 Empirical Results

We test the above empirical models using quarterly and monthly data at the aggregate level. Table 4 presents the results estimated by Ordinary Least Squares (OLS) using quarterly data. In Model 1, vacancy rate is significant, which suggests that the conventional rental adjustment explanation is valid for Hong Kong data. In Model 2, As the monotonic price effect predicts, the housing price has a significantly positive impact on the rental growth, and a one percent housing price hike would push the rental rate up about 0.28%. Since rent could also affect the housing price, here we use the lagged housing price instead of the contemporaneous price.[4]

The results in Table 4 show that housing price volatility has a positive impact on the rental growth when the housing price is rising ( $\beta_4 + \beta_3 > 0$ ), while it has an opposite impact on the rental growth when the housing price is decreasing ( $\beta_3 < 0$ ), confirming the regime-dependent volatility effect. These results suggest that the expansion of rental supply due to higher housing price volatility dominates the expansion of rental demand when the housing market is trending downward, leading to lower rental rates. Hence, it seems that Hong Kong landlords have a strong desire not to sell off their properties when the housing price drops sharply; instead, they are choosing to rent out their properties.

In Model 3, we add real interest rate changes as another explanatory variable. The results suggest that interest rates seem to have a positive impact on rental growth, but the estimated coefficient is not statistically significant. Interest rates could impact rental growth in at least two ways: First, a lower interest rate leads to a higher housing price, which can be passed on to rent. Since we control for the housing price in our model, the impact from this channel should have been already accounted for. Second, a higher interest rate implies that renters can obtain higher

[4] The impact is still significantly positive if we use the contemporaneous price.

returns from investing in alternative assets instead of owning a house. This suggests that renters are willing to pay more rent as the interest rate rises. In this sense, a higher interest rate might lead to a higher rent. However, the results suggest that the impact from the second channel might not be strong enough to produce significant estimates.

In Model 4, we include all the explanatory variables in one model, and interestingly, the vacancy rate becomes insignificant while the impact from housing price changes and its volatility are still significant. As we discussed before, it suggests that vacancy rate is an endogenous indicator of demand and supply in the rental market, and what really drives rental demand and supply are the housing price change and housing price volatility as our theoretical model illustrates. The higher R-squared after adding these theoretically motivated variables also supports our assessment.

[Table 4 here]

Furthermore, we employ monthly data to test our theory. The monthly results in Table 5 are quite consistent with what we find in Table 4: both the price effect and the volatility effect are still significant in the rental adjustment process, and the coefficient for the real interest rate change is not significant, though the sign is consistent with our expectation. We find that a one percent housing price increase will push the rental rate up about 0.29%, which is similar to what we estimate using quarterly data. Finally, the lagged vacancy rate alone cannot explain rental adjustments in Hong Kong, which is not surprising because the slow movement of the vacancy rate is incapable of explaining rental rate changes at the monthly frequency.

[Table 5 here]

### 4.3. Robustness check

For robustness, we construct a panel dataset using observations from five categories to estimate the empirical models by fixed-effect regressions. The results shown in Table 6 are quite similar to what we find using aggregate-level data: the price effect is positive and significant, and housing price volatility boosts rental growth as the housing price rises, while it pushes the rent down when the housing price falls. The size of the volatility effect is smaller than that in Table 4, presumably because the category-level data is more noisy compared to the aggregate-level data.

The real interest rate change remains positive and insignificant, which is consistent with previous results. The lagged vacancy rate is negative and significant in Model 1, which suggests that the conventional rental adjustment explanation is valid in category-level data. However, the lagged vacancy rate become insignificant after controlling for the price effect and the volatility effect, which is consistent with what we find using aggregate-level data in Table 4.

In Table 7, for each category we include all explanatory variables to run the same regressions and the results are quite robust across categories and similar to what we document in previous Tables. One notable finding is that as the unit size increases, the price effect is becoming slightly larger. This suggests that for luxury apartments, their rent and price are more closely integrated.

The more interesting finding is that, for categories with larger unit sizes (Category D: unit size between 100 $m^2$ and 160 $m^2$, and Category E: 160 $m^2$ and above), rent increases with volatility when the housing price is rising. However, rent does not decrease with volatility when the housing price is falling. This actually makes perfect sense in light of our earlier discussions: the buyers for these luxury housing units are not constrained renters; they are in fact very wealthy people. Therefore, when the price volatility of these luxury units is falling, those rich people are more willing to buy, and demand for rental units drops (it no longer stays fixed as in the case with constrained renters). This causes the rent to decrease.

## 5. Conclusion

This paper is motivated by housing bubbles and inflation in emerging markets and small open economies following extreme monetary easing of developed countries. We demonstrate that uncertainty shocks in the property market have great impacts on property investments of individual households and can lead to cyclical fluctuations in the rental market. Specifically, we model the renters′ decision to buy a house and landlords′ decision to sell as real options of waiting and examine real options effects on rental demand, supply, and the rental rate. The predictions derived from the theoretical model are supported empirically using Hong Kong data.

Both the theoretical and empirical results show that housing price shocks could affect rent through two effects. The first one is the monotonic price effect: rent increases with the housing price. The empirical results show that a one percent housing price spike would push the rental rate up about 0.28%. The second effect is the regime-dependent volatility effect: rent increases with the housing price volatility when the housing market is rising and decreases with volatility when the market is falling.

The policy implications of the paper are important given the large weights of rent in the CPI: Property bubbles may spill over to rent inflation and pricking the bubble may cause rent deflation. Also, rent is not just driven by fundamentals; housing price shocks and its volatility also play important roles in rental adjustments. Therefore, the price-to-rent ratio could underestimate the size of housing bubbles.

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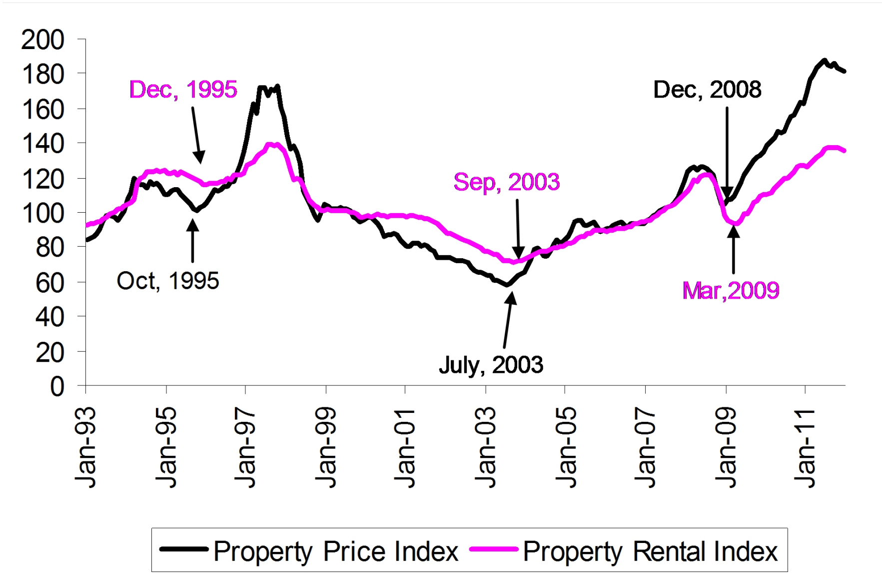
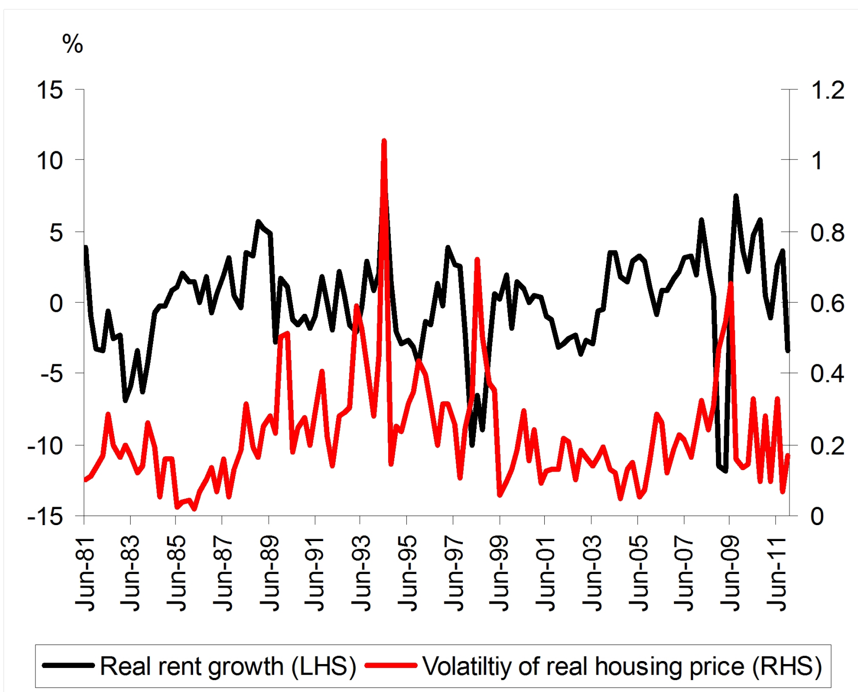
## Chart 1: Hong Kong housing price and rental price indices




## Chart 2: Rent growth and volatility of housing price in Hong Kong



## Table 1: Summary statistics

This table reports summary statistics of Hong Kong's real housing price growth, rental price growth, interest rate change, and vacancy rate. Housing price index, rental price index, and vacancy rate are from the Hong Kong Rating and Valuation Department (R&VD). Real housing price growth and real rental growth are percentage change of housing price index and rental price index adjusted for Hong Kong inflation rate, respectively. US 10-year Treasury bond yield is used for the Hong Kong risk-free interest rate, which is closely aligned with its US counterpart under the linked exchange rate system. Real interest rate change is the percent change of the US 10-year Treasury bond yield adjusted for the Hong Kong inflation rate.

| Variables | Obs | Mean | Std. dev | Min | Max |
|---|---|---|---|---|---|
| Quarterly data (Sample period: 1980Q1-2011Q4) | | | | | |
| Real housing price growth | 124 | 0.747 | 5.813 | -16.66 | 17.95 |
| Real rental price growth | 124 | 0.020 | 3.462 | -11.80 | 9.05 |
| Real interest rate change | 124 | -0.022 | 0.080 | -0.237 | 0.213 |
| Vacancy rate | 124 | 4.712 | 1.023 | 2.9 | 6.8 |
| Monthly data (Sample period: January 1993- March 2013) | | | | | |
| Real housing price growth | 242 | 0.291 | 2.865 | -11.66 | 9.418 |
| Real rental price growth | 242 | 0.036 | 1.671 | -8.648 | 7.587 |
| Real interest rate change | 242 | -0.005 | 0.057 | -0.312 | 0.204 |
| Vacancy rate | 239 | 3.532 | 0.822 | 1.8 | 4.7 |

## Table 2: Estimation results of ARMA-EGARCH models

This table reports the results of the ARMA-EGARCH models for the housing price growth. The conditional mean is specified as ARMA(1,2) based on the AIC and Schwarz criteria. The conditional variance is the EGARCH(q,p,r) model as follows:

$$\ln\sigma_t^2 = \omega + \sum_{j=1}^{q}\beta_j \ln\sigma_{t-j}^2 + \sum_{k=1}^{p}\alpha_i \left|\frac{\varepsilon_{t-i}}{\sigma_{t-i}}\right| + \sum_{k=1}^{r}\gamma_k \frac{\varepsilon_{t-k}}{\sigma_{t-k}},$$

where the left-hand side is the logarithm of the conditional variance, which implies that the leverage effect is exponential, rather than quadratic, and that forecasts of the conditional variance are guaranteed to be nonnegative. The parameters q, p, and r are chosen according to the AIC and Schwarz criteria.

| Dependent variable: Real housing price growth | | | | | | |
|---|---|---|---|---|---|---|
| | Quarterly data (EGARCH(2,3,2)) | | | Monthly data (EGARCH(2,2,2)) | | |
| Variables | Coefficient | St. Error | Z-statistics | Coefficient | St. Error | Z-statistics |
| Constant | 0.001 | 0.008 | 0.015 | 0.004 | 0.002 | 1.755 |
| AR(1) | 0.088 | 0.312 | 0.283 | -0.043 | 0.348 | -0.123 |
| MA(1) | 0.662 | 0.306 | 2.162 | 0.564 | 0.350 | 1.611 |
| MA(2) | 0.228 | 0.191 | 1.193 | 0.200 | 0.172 | 1.161 |
| Variance Equation | | | | | | |
| $\omega$ | -0.286 | 0.227 | -1.260 | -0.205 | 0.028 | -7.298 |
| $\beta_1$ | 0.336 | 0.432 | 0.777 | 0.032 | 0.061 | 0.525 |
| $\beta_2$ | -0.537 | 0.383 | -1.403 | -0.002 | 0.062 | -0.034 |
| $\alpha_1$ | -0.067 | 0.186 | -0.359 | -0.019 | 0.033 | -0.566 |
| $\alpha_2$ | -0.334 | 0.263 | -1.269 | 0.025 | 0.032 | 0.770 |
| $\alpha_3$ | 0.453 | 0.197 | 2.302 | | | |
| $\gamma_1$ | 1.226 | 0.370 | 3.311 | 1.930 | 0.021 | 91.93 |
| $\gamma_2$ | -0.297 | 0.348 | -0.856 | -0.954 | 0.021 | -45.75 |
| $R^2$ | 0.318 | | | 0.204 | | |
| AIC | -3.268 | | | -4.629 | | |
| SC | -2.994 | | | -4.470 | | |

## Table 3: Granger causality test between price growth and rent growth

The table reports the results of Granger causality tests for the real housing price growth $y_t$ and real rent growth $x_t$ as follows:

$$y_t = \alpha_0 + \alpha_1 y_{t-1} + .... + \alpha_k y_{t-k} + \beta_1 x_1 + ... + \beta_k x_{t-k} + \varepsilon_t$$
$$x_t = \alpha_0^{'} + \alpha_1^{'} x_{t-1} + .... + \alpha_k^{'} x_{t-k} + \beta_1^{'} y_1 + ... + \beta_k^{'} y_{t-k} + u_t.$$

where the number of lags is 8 in both quarterly and monthly data according to the AIC criterion. The null hypothesis is that $x_t$ does not Granger cause $y_t$ in the first regression, and $y_t$ does not Granger cause $x_t$ in the second regression. The reported F-statistics are the Wald statistics for the joint hypothesis:

$$\beta_1 = \beta_2 = \cdots = \beta_k = 0$$

| | **Obs** | **F-statistics** | **Prob** |
|---|---|---|---|
| | | **Quarterly Data** | |
| Null hypothesis: Rent growth does not Granger cause price growth | 116 | 2.224 | 0.031 |
| Null hypothesis: Price growth does not Granger cause rent growth | | 5.680 | 0.000 |
| | | **Monthly Data** | |
| Null hypothesis: Rent growth does not Granger cause price growth | 234 | 1.572 | 0.134 |
| Null hypothesis: Price growth does not Granger cause rent growth | | 74.79 | 0.000 |

## Table 4: Quarterly results of rental determinants with aggregate Data

This table presents the results of the following models using aggregate quarterly data from Quarter 1 of 1980 to Quarter 4 of 2011

$$\%\Delta R_t = \beta_0 + \beta_1 Vacancy_{t-1} + \beta_2 \%\Delta S_{t-1} + \beta_3 Vol_t + \beta_4 Vol_t \times d_t + \beta_5 \%\Delta r_t + \varepsilon_t ,$$

where $\%\Delta R_t$ is real rental growth, $Vacancy_{t-1}$ is the lagged vacancy rate, $\%\Delta S_t$ is the lagged real housing price growth, $Vol_t$ is the volatility of real housing price growth, $d_t$ is the price trend dummy for $\%\Delta S_t > 0$, and $\%\Delta r_t$ is the real interest rate growth.

Numbers in parentheses are standard errors. The symbols *, **, *** denote statistical significance at 10%, 5% and 1% level respectively.

| Dependent Variable: $\%\Delta R_t$ | | | | |
|---|---|---|---|---|
| Variables | Model (1) | Model (2) | Model (3) | Model (4) |
| $Vacancy_{t-1}$ | -0.534* | | | 0.035 |
| | (0.314) | | | (0.221) |
| $\%\Delta S_{t-1}$ | | 0.280*** | 0.280*** | 0.281*** |
| | | (0.042) | (0.042) | (0.043) |
| $Vol_t$ | | -7.696*** | -7.607*** | -7.554*** |
| | | (1.855) | (0.167) | (1.904) |
| $Vol_t \times d_t$ | | 10.05*** | 9.823*** | 9.842*** |
| | | (1.774) | (1.829) | (1.840) |
| $\%\Delta r_t$ | | | 1.425 | 1.342 |
| | | | (2.621) | (2.682) |
| Constant | 2.541 | 0.181 | 0.223 | 0.039 |
| | (1.514) | (0.375) | (0.384 | (1.218) |
| Obs | 124 | 123 | 123 | 123 |
| Adjusted R-sq | 0.02 | 0.58 | 0.58 | 0.58 |

## Table 5: Monthly results of rental determinants with aggregate Data

This table presents the results of the following models using aggregate monthly data from January 1993 to March 2013:

$$\%\Delta R_t = \beta_0 + \beta_1 Vacancy_{t-1} + \beta_2 \%\Delta S_{t-1} + \beta_3 Vol_t + \beta_4 Vol_t \times d_t + \beta_5 \%\Delta r_t + \varepsilon_t \,,$$

where $\%\Delta R_t$ is real rental growth, $Vacancy_{t-1}$ is the lagged vacancy rate, $\%\Delta S_t$ is the lagged real housing price growth, $Vol_t$ is the volatility of real housing price growth, $d_t$ is the price trend dummy for $\%\Delta S_t > 0$, and $\%\Delta r_t$ is the real interest rate growth.

Numbers in parentheses are standard errors. The symbols *, **, *** denote statistical significance at 10%, 5% and 1% level respectively.

| Dependent Variable: $\%\Delta R_t$ | | | | |
|---|---|---|---|---|
| Variables | Model (1) | Model (2) | Model (3) | Model (4) |
| $Vacancy_{t-1}$ | 0.001 | | | -0.001 |
| | (0.005 | | | (0.001) |
| $\%\Delta S_{t-1}$ | | 0.294*** | 0.287*** | 0.288*** |
| | | (0.032) | (0.033) | (0.033) |
| $Vol_t$ | | -3.640** | -3.622** | -3.844** |
| | | (1.797) | (1.796) | (1.907) |
| $Vol_t \times d_t$ | | 4.082* | 4.211* | 4.306* |
| | | (2.254) | (2.256) | (2.278) |
| $\%\Delta r_t$ | | | 0.018 | 0.018 |
| | | | (0.016) | (0.016) |
| Constant | -0.003 | 0.001 | 0.001 | -0.001 |
| | (0.019) | (0.001) | (0.001) | (0.001) |
| Obs | 239 | 241 | 241 | 239 |
| Adjusted R-sq | 0.01 | 0.30 | 0.30 | 0.30 |

## Table 6: Quarterly results of rental determinants with panel data

This table presents the results of the following models estimated by fixed-effect regressions using a panel data including five categories of housing units: Category A, B, C, D and E have a floor area of 39.9 $m^2$ and below, between 40.0 and 69.9 $m^2$, between 70.0 and 99.9 $m^2$ , between 100.0 and 159.9 $m^2$ and 160 $m^2$ above respectively.

$$\%\Delta R_t = \beta_0 + \beta_1 Vacancy_{t-1} + \beta_2 \%\Delta S_{t-1} + \beta_3 Vol_t + \beta_4 Vol_t \times d_t + \beta_5 \%\Delta r_t + \varepsilon_t ,$$

where $\%\Delta R_t$ is real rental growth, $Vacancy_{t-1}$ is the lagged vacancy rate, $\%\Delta S_t$ is the lagged real housing price growth, $Vol_t$ is the volatility of real housing price growth, $d_t$ is the price trend dummy for $\%\Delta S_t > 0$, and $\%\Delta r_t$ is the real interest rate growth.

Numbers in parentheses are standard errors. The symbols *, **, *** denote statistical significance at 10%, 5% and 1% level respectively.

| Dependent Variable: $\%\Delta R_t$ | | | | |
|---|---|---|---|---|
| Variables | Model (1) | Model (2) | Model (3) | Model (4) |
| $Vacancy_{t-1}$ | -0.375** | | | 0.043 |
| | (0.167) | | | (0.123) |
| $\%\Delta S_{t-1}$ | | 0.277*** | 0.340*** | 0.341*** |
| | | (0.027) | (0.021) | (0.021) |
| $Vol_t$ | | -4.420*** | -3.054*** | -3.055*** |
| | | (0.824) | (0.756) | (0.756) |
| $Vol_t \times d_t$ | | 4.450*** | 5.398*** | 5.416*** |
| | | (0.912) | (0.709) | (0.712) |
| $\%\Delta r_t$ | | | 2.484 | 2.402 |
| | | | (1.558) | (1.579) |
| Constant | 1.784** | 0.347 | -0.261 | -0.469 |
| | (0.799) | (0.247) | (0.236) | (0.639) |
| Obs | 590 | 585 | 585 | 585 |
| Overall R-sq | 0.01 | 0.37 | 0.49 | 0.49 |

**Table 7: Quarterly results of rental determinants for each housing category**

This table presents the results of the following model using quarterly data from each housing category: Category A, B, C, D and E have a floor area of 39.9 $m^2$ and below, between 40.0 and 69.9 $m^2$, between 70.0 and 99.9 $m^2$, between 100.0 and 159.9 $m^2$, and 160 $m^2$ and above, respectively.

$$\%\Delta R_t = \beta_0 + \beta_1 Vacancy_{t-1} + \beta_2 \%\Delta S_{t-1} + \beta_3 Vol_t + \beta_4 Vol_t \times d_t + \beta_5 \%\Delta r_t + \varepsilon_t$$

where $\%\Delta R_t$ is real rental growth, $Vacancy_{t-1}$ is the lagged vacancy rate, $\%\Delta S_t$ is the lagged real housing price growth, $Vol_t$ is the volatility of real housing price growth, $d_t$ is the price trend dummy for $\%\Delta S_t > 0$, and $\%\Delta r_t$ is the real interest rate growth.

Numbers in parentheses are standard errors. The symbols *, **, *** denote statistical significance at 10%, 5% and 1% level respectively.

| Dependent Variable: $\%\Delta R_t$ | | | | | |
|---|---|---|---|---|---|
| Variables | Category A | Category B | Category C | Category D | Category E |
| $Vacancy_{t-1}$ | 0.029 | -0.061 | 0.048 | 0.108 | 0.077 |
| | (0.222) | (0.255) | (0.263) | (0.294) | (0.348) |
| $\%\Delta S_{t-1}$ | 0.296*** | 0.312*** | 0.312*** | 0.359*** | 0.375*** |
| | (0.047) | (0.046) | (0.048) | (0.053) | (0.052) |
| $Vol_t$ | -3.691*** | -3.063** | -5.503*** | -2.931 | -0.247 |
| | (1.971) | (1.233) | (1.786) | (1.822) | (5.219) |
| $Vol_t \times d_t$ | 6.259*** | 5.488*** | 8.164*** | 5.296*** | 3.934*** |
| | (2.189) | (1.715) | (1.844) | (1.577) | (1.651) |
| $\%\Delta r_t$ | 0.592 | 4.538 | 2.057 | 2.757 | 1.763 |
| | (2.852) | (3.241) | (3.464) | (3.759) | (4.438) |
| Constant | -0.296 | 0.178 | -0.331 | -0.772 | -1.699 |
| | (1.191) | (1.336) | (1.309) | (1.558) | (2.937) |
| Obs | 117 | 117 | 117 | 117 | 117 |
| Adjusted R-sq | 0.44 | 0.46 | 0.56 | 0.51 | 0.42 |