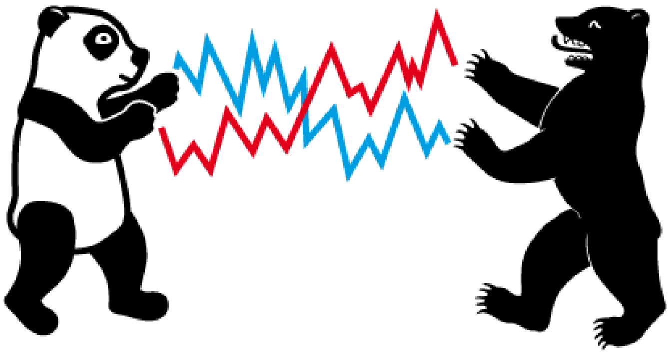
IRTG 1792 Discussion Paper 2018-051

Property Investment and Rental Rate under Housing Price Uncertainty: A Real Options Approach

Honglin Wang *
Fan Yu *[2]
Yinggang Zhou *[3]



* Hong Kong Institute for Monetary Research, People's Republic of China
*[2] Claremont McKenna College, United States of America
*[3] Xiamen University, People's Republic of China

This research was supported by the Deutsche Forschungsgemeinschaft through the International Research Training Group 1792 "High Dimensional Nonstationary Time Series".

http://irtg1792.hu-berlin.de
ISSN 2568-5619

International Research Training Group 1792

2018 V : pp. 1–33
DOI: 10.1111/1540-6229.12235
REAL ESTATE
ECONOMICS

Property Investment and Rental Rate under Housing Price Uncertainty: A Real Options Approach

Honglin Wang,* Fan Yu** and Yinggang Zhou***

The conventional wisdom that housing prices are the present value of future rents ignores the fact that unlike dividends on stocks, rent is not discretionary. Housing price uncertainty can affect household property investments, which in turn affect rent. By extending the theory of investment under uncertainty, we model the renter's decision to buy a house and the landlord's decision to sell as the exercising of real options of waiting and examine real options effects on rent. Using data from Hong Kong and mainland China, we find a significant effect of housing price on rent and draw important policy implications.

Introduction

From a standard financial asset perspective, housing prices are the present value of all future rents. This leads to conventional discounted cash flow analysis that begins with rent as the fundamental of property valuation. However, Shiller (2008) shows that it is difficult for rent or housing construction cost to explain the U.S. housing price in recent years. Lee, Seslen and Wheaton (2015) propose using an alternative comparison of housing price to an imputed rent based on predicted price. Moreover, the housing boom and bust cycle has called attention to the volatility of housing prices, as well as their connection to business and financial cycles and impact on other markets. Lai and Van Order (2017) find regime shifts in U.S. housing prices over the past 30 years. Another important dimension that remains largely unexplored in the academic literature is that rent is not discretionary as in the case of dividends on stocks, but is determined in the rental market. Thus, a new and interesting

*Former Researcher, Hong Kong Institute for Monetary Research or wanghonglinmail@yahoo.com.
**Robert Day School of Economics and Finance, Claremont McKenna College, Claremont, CA 91711 or fan.yu@claremontmckenna.edu.
***Department of Finance at School of Economics, and Wang Yanan Institute for Studies in Economics (WISE), Xiamen University, Xiamen 361005, China or yinggang.zhou@gmail.com.

Yinggang Zhou is the corresponding author of the paper.

question is whether the behavior of housing prices can exert an influence on rent. In this article, we examine how housing price uncertainty affects the decision making of household property investments, which in turn affects rent, and draw important policy implications for property bubbles and inflation.

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 house's 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 house value. The decision on the timing of a purchase becomes an optimal stopping problem for renters. A rational renter will delay the decision to buy if the housing price is higher than a threshold related to their private valuation of the house, but there is hope in waiting for the price to drop. Likewise, landlords own a call option on the housing value, which allows them to choose the optimal timing of sale. A rational landlord will delay the decision to sell if the housing price is lower than a threshold related to their private valuation, but there is hope in waiting for the price to recover. Further assuming that the private valuations of renters and landlords are drawn from known distributions, we can 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. An increase in rental demand is associated with a decrease in rental supply in a rising housing market because more renters are reluctant to buy and more landlords are willing to sell. In contrast, in a downward housing market, rental demand will decrease because more renters are willing to buy while 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, both renters and landlords are more eager to hold on to their real options given an increase in housing price volatility. This produces greater rental demand and supply. The effect on the equilibrium rental rate depends crucially on the relative size of the demand and supply increases. When the private valuations of the renters and landlords are similarly dispersed, we show that the expansion of rental demand plays a dominant role, yielding a normally positive relation between housing price volatility and rent. As the housing price falls, however, more renters depart the rental market to become homeowners, eventually leaving those who are insensitive to price and volatility shocks.[1] As this point, an increase in housing price

[1]This is analogous to the notion of "burnout" in mortgage prepayment (Richard and Roll 1989), which could be caused by financial constraints or heterogeneity in attention (Andersen *et al.* 2015).

volatility mostly expands the rental supply while the rental demand remains largely fixed, yielding a negative relation between housing price volatility and rent.

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 and Dixit and Pindyck 1994) as well as macro-level fluctuations in aggregate investments (Bernanke 1983). After the recent financial crisis, considerable attention has been given to the impact of uncertainty shocks.[2] For example, Bloom (2009) shows that a higher uncertainty increases the real option value of waiting, so that firms scale back their investments and hiring. In parallel with this argument, we show that uncertainty shocks in the property market have real options effects on the property investments of individual households as well as cyclical fluctuations in the rental market. More broadly, the real options approach has been used to value urban land (Titman 1985), lease contracts (Grenadier 1995) and other projects (Brennan and Schwartz 1985, Childs, Ott and Triantis 1998). We obtain a closed-form solution for the equilibrium rent that contains the option premium of waiting driven by housing price uncertainty. 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. We offer a new and richer explanation based on the "hold out" phenomenon. 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.

Our model also adds to the recent literature that has abandoned the traditional "rent drives price" view. One line of literature suggests that the housing price deviates from fundamentals largely due to strong (speculative) demand shocks in conjunction with supply constraints (*e.g.*, Hilber and Vermeulen 2016). Another line of recent research allows both rent and the housing

[2]See "How economic uncertainty dulls investment," *The Economist*, November 16, 2013.

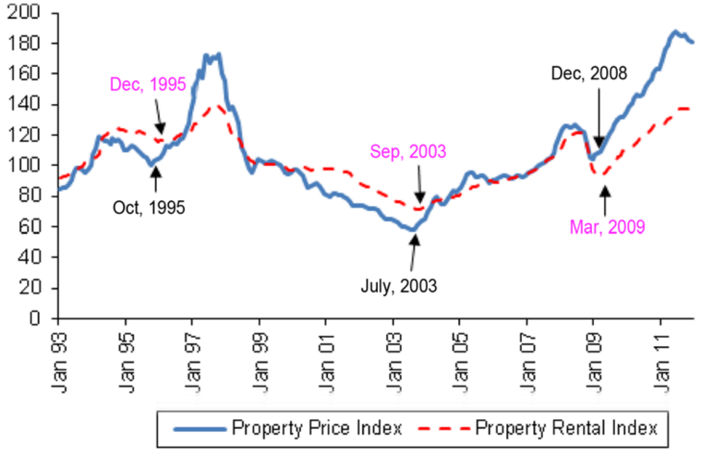
price to be simultaneously determined (Ayuso and Restoy 2006, Chambers, Garriga and Schlagenhauf 2009, Sommer, Sullivan, and Verbrugge 2013). In this article, we treat the housing price as exogenous. This is realistic in some circumstances because the property market is integrated into the capital market and is more easily exposed to external shocks such as large capital flow, which induces significant change of demand for housing, whereas the rental market is highly segmented and local. This is a partial equilibrium framework in which the effects of housing price dynamics on rent can be analyzed in a tractable way.

Empirically, we find strong real option effects of the housing price on rent for Hong Kong and mainland China's cities. In the literature, Yao and Pretorius (2014) analyze and test option values in ten detailed Hong Kong cases involving purchase, holding, converting and developing land. We argue that Hong Kong is an ideal laboratory to test our model predictions because it is a small open economy and its housing market is subject to external shocks.[3] Moreover, property rent tends to follow property price in Hong Kong, as shown in Figure 1. Besides Hong Kong, the model is also applicable to mainland China's largest cities where the rental and owner-occupied housing units are very similar and rent control is absent. Moreover, China is a large emerging market economy with unique setting to exploit various interesting questions and draw broader implications (*e.g.*, Bailey, Huang and Yang 2011). In particular, the property market of large cities in China attracts massive capital inflows so that housing price dynamics is relatively exogenous. Following the literature (Leahy and Whited 1996, Bloom, Bond and Reenen 2007), we measure housing price uncertainty with its return variance. Consistent with the model's implications, positive housing price shocks produce rapid rent growth while negative shocks reverse it. Moreover, rent growth increases with housing price variance shocks when the housing price is rising and decreases with variance shocks when the housing price is falling.

The conventional rental adjustment literature adopts a disequilibrium perspective by assuming that the rental rate does not adjust quickly enough to clear the market, giving rise to the vacancy rate as the main driver of rental rate changes (Smith 1974, Eubank and Sirmans 1979, Rosen and Smith 1983, Hendershott 1996). However, in the case of Hong Kong (for which we have vacancy rate data), the rental market was extremely tight with monthly vacancy rates always below 5% from 1993 to 2013. Therefore, rental rate changes are more

[3]Having soared by more than 90% since 2008, the Hong Kong property price is 84% overvalued according to the conventional gauge of the price-to-rent ratio, which ranks Hong Kong No. 1 in the world. See *The Economist*, August 31, 2013.

Figure 1 ■ Hong Kong housing price and rental price indices. [Color figure can be viewed at wileyonlinelibrary.com]



Note: This figure plots monthly housing price and rental price in Hong Kong from January 1993 to March 2013. Both indices are published by the Hong Kong Rating and Valuation Department.

likely to be driven by factors affecting the demand and supply of rental units, rather than by the disequilibrium adjustment induced by the deviation of the vacancy rate from its natural level. Indeed, we find that the vacancy rate does not explain rental rate changes in Hong Kong, while changes in the housing price and housing price volatility do.

Finally, our analysis carries important policy implications. Both our theoretical model and empirical findings suggest that housing price dynamics contribute to cyclical fluctuations in the rental market. Due to the large weight of rent in the Consumer Price Index (CPI) in most countries, rent inflation driven by housing price bubbles can therefore exert considerable influence on measures of overall and core inflation, giving another reason for regulators to target asset prices in general and stabilize the housing price dynamics in particular. Moreover, our findings are relevant for the detection of property bubbles: the conventional gauge of price-to-rent ratio may misstate the size of housing bubbles because rent can be driven up or down by housing price uncertainty. A more accurate measure should conceivably adjust for the option component of rent.

The rest of the article is organized as follows. Section 2 presents our theoretical model. Section 3 describes our testable hypotheses, data and preliminary analyses. Section 4 discusses the empirical results. Section 5 provides concluding remarks.

Theoretical Model

In contrast to the traditional literature that treats rent as the fundamental of property valuation and the housing price as the present value of all future rents, we model the housing price dynamics as exogenously given and consider a real options model of the renter's decision to purchase and the landlord's decision to sell.

Specifically, we assume that the market value of housing, S, is described by a geometric Brownian motion with volatility σ and drift $\mu < r$, the risk-free rate.[4] At the same time, we allow each agent to hold a subjective private valuation of the house, denoted by K, which is assumed to be a constant that can differ across individuals. In the spirit of modeling rational asset bubbles, one can view the housing price as the sum of two components—the first part being driven by fundamentals such as the present value of future rents, and the second part being a bubble component associated with a market-wide sentiment. Similarly, the private valuation held by each agent can be considered as the sum of the same fundamental component and another component associated with an individual-specific sentiment. This conveniently allows for market and individual valuations to move together with less than perfect correlation. Yet, when examining the difference between S and K, which is needed in solving agents' optimizing decisions, the common fundamental component drops out and one only needs to model market-wide and individual sentiments, which can be reinterpreted as S and K, respectively. Our modeling assumptions are appropriate if individual sentiments move much more slowly than market-wide sentiments.

To finish specifying the model, we assume that τ represents the stopping time of switching from renting to buying for the renter, or from renting to selling for the landlord. While the renter is renting, he pays rent at the rate of R and derives enjoyment from living in the rented house at the rate of c.[5] In parallel, before the landlord decides to sell the house, she collects rent at the rate of R and spends c per unit time to maintain the house as a rental unit. All agents take the constant rent R as given.

[4]We assume this simple dynamic for the housing price so that the real options problem can be solved analytically.

[5]We normalize the enjoyment from living in an owned house as zero. It is likely that $c < 0$, reflecting a general preference for home ownership over renting.

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 τ to maximize his utility:

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

The first part of Equation (1) captures the utility gain from buying the house at the market price. 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 incurring a penalty.[6]

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

$$\tau = \inf\{t : \; S_t \le S_c\}, \tag{2}$$

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

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

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):

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

where

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

[6]From the renter's perspective, his landlord could sell her house before he decides to stop renting. When this happens (likely when the housing price rises significantly before falling), the renter must negotiate a new rental agreement with another landlord. A parallel scenario can occur for a landlord when her tenant stops renting before she decides to sell (say, when the housing price falls significantly before rising), in which case she must negotiate a new rental agreement with another tenant. These considerations significantly complicate the optimization problems for the renter and the landlord because the new rent level is determined by market clearing at an uncertain future date (see the discussion in Section 2.3). For simplicity and tractability, we abstract away from these issues in our model.

we have:

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

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:

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

To better understand the renter's decision, we note that when $r \ll \sigma^2$ and $\mu \ll \sigma^2$, we can approximate γ 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 confirms 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 σ is higher.

Landlord's Problem

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

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

The first part of Equation (9) captures the utility gain from selling the house (which the landlord privately values at K) for the market price of S_τ, and the second part represents the value from receiving rental payment and maintaining the house before it is sold.

Conjecturing an optimal stopping policy of:

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

we have:

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

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

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

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 $\mu \ll \sigma^2$, we can approximate β using Taylor's expansion and rewrite S_c^L as:

$$S_c^L = \left(1 + \frac{\sigma^2}{2(r-\mu)}\right)\left(K + \frac{R-b}{r}\right). \tag{16}$$

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 σ is higher.

Equilibrium

Suppose that all landlords' rental units are occupied by renters at time t with rental agreements entered into prior to t. Because of the changing housing price over the next time interval Δt, some renters and landlords will find it optimal to renege on their current rental agreements in order to buy/sell a house. These "broken matches" produce "fresh" renters and landlords who need to negotiate a new set of rental agreements. Generally speaking, the size of this effect is difficult to estimate because it depends on the set of existing rental contracts at time t, which were initiated at various times prior to t. Since we will show later on that the housing price is an important determinant of rent, this implies that the rental demand and supply can be related to the past history of the housing price.[7]

While this component of the rental demand/supply is difficult to quantify, the rental demand is also affected by people moving into the area as renters (Saiz 2003), and so is the rental supply by people who have accumulated enough wealth to purchase properties in the area. For simplicity, we assume that there are potential renters and landlords, each with mass one, endowed with private valuations normally distributed as $K_R \sim N(\mu_R, \sigma_R^2)$ and $K_L \sim N(\mu_L, \sigma_L^2)$, respectively. Assuming that the rental demand and supply are driven solely by this exogenous channel, we can determine the equilibrium rent as follows:

From Equation (7), given a housing price of S and when offered a rental contract with rent R, a potential renter with private valuation K will decide 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 potential 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, according to Equation (15), given a housing price of S and when offered a rental contract with rent R, a potential landlord will decide to rent out her house if $S \leq S_c^L$ or, equivalently, if her private valuation K satisfies:

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

[7]For example, if all existing rental contracts were initiated one year ago, then the rent level in these contracts was determined by the housing price at that time, among other things. Since the thresholds for buying and selling are related to the rent, the rental supply and demand today will be a function of today's housing price as well as the housing price a year ago. Another way in which the past housing price can affect the current rent is through its effect on the distribution of private valuations. For example, if the housing price has been steadily rising over time, then landlords with relatively lower private valuations would have already sold their houses, leaving behind only those with relatively higher valuations.

Given the distribution of private valuations of the potential 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:[8]

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

To interpret Equation (21), we first note an unambiguously positive relation between the equilibrium rent and the housing price, because

$$\frac{1+\gamma}{\gamma} = \frac{\sqrt{\left(\mu - \frac{1}{2}\sigma^2\right)^2 + 2\sigma^2 r} + \left(\mu + \frac{1}{2}\sigma^2\right)}{\sqrt{\left(\mu - \frac{1}{2}\sigma^2\right)^2 + 2\sigma^2 r} + \left(\mu - \frac{1}{2}\sigma^2\right)} > 0,$$

$$\frac{\beta-1}{\beta} = \frac{\sqrt{\left(\mu - \frac{1}{2}\sigma^2\right)^2 + 2\sigma^2 r} - \left(\mu + \frac{1}{2}\sigma^2\right)}{\sqrt{\left(\mu - \frac{1}{2}\sigma^2\right)^2 + 2\sigma^2 r} - \left(\mu - \frac{1}{2}\sigma^2\right)} > 0. \tag{22}$$

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 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, σ_R and σ_L. To see this, we first follow earlier derivations to assume that $r \ll \sigma^2$ and $\mu \ll \sigma^2$, yielding the following approximations by Taylor's expansion:

$$\frac{1+\gamma}{\gamma} \approx \frac{2r + \sigma^2}{2r},$$

[8]As this is mainly a partial equilibrium model of the effect of housing price dynamics on the rental market, we abstract away from any feedback from rent into the housing price. Indeed, Equation (21) presents the equilibrium rent as a function of both the housing price and housing price volatility, which makes it possible for the housing price to be influenced by its own dynamic properties via the present value relation between the housing price and future rents. The treatment of this "feedback loop" is beyond the scope of our paper.

$$\frac{\beta-1}{\beta} \approx \frac{2(r-\mu)}{2(r-\mu)+\sigma^2}. \tag{23}$$

Given this approximation, Equations (18) and (20) 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 σ_R and σ_L are similar in magnitude, it is evident that R^* will be increasing in σ, because $(1+\gamma)/\gamma$ clearly dominates $(\beta-1)/\beta$ in size.

The above setting assumes that all renters and landlords are utility maximizers who can freely buy and sell properties. However, financial constraints can be a significant consideration for many people in the housing market (Bajari, Chan, Krueger and Miller 2013). In reality, some renters will keep renting even if the housing price decreases substantially. For instance, some people may not have saved enough for a down payment, and others may have ruled out buying because of expected job-related migration. The optimal stopping problem probably does not describe the behavior of these agents. This is akin to the concept 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:

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

and the equilibrium rent is:

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

which is increasing in S and decreasing in σ according to Equation (23).

Our model abstracts away from several important features in the housing market. First, our notion of equilibrium considers only the decisions of "fresh" renters and landlords who arrive during each time interval for exogenous reasons. We have chosen to ignore the effect of existing renters and landlords who exit the rental market by purchasing or selling a house. As explained at the beginning of this subsection, this effect is likely to induce a dependence of the equilibrium rent on lagged housing prices. The extension of our model to account for this effect is beyond the current article. Second, we do not consider the searching and matching process in the rental market (Wheaton 1990), which allows the vacancy rate to play an important role in the rental adjustment process. This dimension has been deliberately left out of our model so that we can stay focused on the real options effects on rent determination. Our empirical analysis, however, includes the vacancy rate as a control variable whenever such data are available. Finally, our model assumes that renters and landlords are risk-neutral. When agents are risk-averse, their hedging motives might also predict a complex relation between rental rates and housing volatility.[9] Our theoretical explanation, however, is independent of the hedging motives of rental market participants.

Empirical Design

Testable Hypotheses

Combining insights from the equilibrium analysis, we have the following comparative statics:

$$\frac{\partial R}{\partial S} > 0,$$

$$\frac{\partial R}{\partial \sigma} > 0 \quad \text{unless } \Delta S < 0,$$

which summarizes the monotonic price effect and the regime-dependent volatility effect. This motivates the following empirical specification:

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

where $\%\Delta R_t$ is the real rental growth rate, $vacancy_{t-1}$ is the lagged vacancy rate, $\%\Delta S_{t-1}$ is the lagged growth rate of the real housing price, V_t is the variance of the real housing price growth and ΔV_t its first difference, d_t is a dummy variable for housing price trend that equals one if the housing price is rising and zero otherwise, and $\%\Delta r_t$ denotes the percentage change of the real risk-free interest rate.[10]

[9]For example, when the housing price is rising, renters' hedging concern might play a dominant role, causing them to pay a higher rent when the housing volatility is high. In contrast, when the housing price is falling, landlords' hedging concern might dominate, causing them to accept a lower rent when the housing volatility is high. For discussions of the effect of hedging demand in the housing market, see Han (2010, 2013).

[10]While our model predicts a contemporaneous relation between rent and the housing price and housing price uncertainty, we follow the traditional rental adjustment

In Model 1, we consider the lagged vacancy rate as the only determinant of rental growth, which is not present in our theoretical model but in line with the traditional rental adjustment literature. The purpose is to compare predictive powers between the traditional model and our model. In the benchmark Model 2, we use the lagged housing price growth and the first difference of housing growth variance as explanatory variables to test our model predictions, which can be structured as two hypotheses. The first is the monotonic price effect hypothesis (H1):

$$\beta_2 > 0, \tag{27}$$

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

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

which argues that rental growth increases/decreases with housing growth variance shocks when the housing price is rising/falling. Moreover, if the housing price dynamics plays a more important role in the rental adjustment process than the vacancy rate, the explanatory power of Model 2 will be higher than that of Model 1.

In Model 3, our purpose is to examine whether these two hypotheses still hold after controlling for interest rate changes, because the latter are an important part of the user cost of housing. Therefore, we expect $\beta_5 > 0$.[11] Finally, we include all variables in Model 4. We expect the monotonic price effect and regime-dependent variance effect to still be significant after controlling for the vacancy rate. At the same time, it is interesting to see whether the vacancy rate remains significant in explaining rental growth after controlling for the housing price growth and its variance shocks.

---

literature to include the lagged vacancy rate as a control. Moreover, we use lagged housing price growth in our empirical specifications to show a predictive relation. Results are robust when the contemporaneous housing price growth is included in lieu of or in addition to the lagged version. The nonlinear relation between volatility change and rental growth is simplified as a piece-wise linear relation in the regression. Interest rate change is added as a control since it is implied in our theoretical model. We do not include other control variables, such as migration, because the data is not readily available.

[11]On the other hand, lower interest rates are usually associated with a relaxation of credit constraints, which gives renters more money to consume and to pay rent. Therefore, the effect of interest rate on rent could be ambiguous. This might account for the insignificant results on interest rates that we present later.

Data

To test our model, a carefully selected dataset is key because of several salient features of the housing and rental market data. First, housing units are always heterogeneous, and units for sale could be quite different from units for rent in the same area. For example, in the United States, units for sale are mostly single-family homes while the rental market is dominated by condominiums and apartments (Dales 2011). This heterogeneity suggests that the ideal sample for this study is from a large metropolitan area where units for sale and units for rent are similar. Second, many large cities such as London, New York and Los Angeles have had rent controls under different regimes for many years. There is a consensus that rent controls generally short-circuit the market mechanism for housing (Arnott 1995). Third, our theoretical model speaks to rental rates obtained from fresh lettings in the rental market, and rental costs from the CPI are inappropriate proxies because they are subject to significant time lags. Unfortunately, CPI rental indicators are much easier to obtain compared to 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. First, units for sale and units for rent are homogenous in Hong Kong because most are apartments and condominiums given the very high population density in the city.[12] Second, Hong Kong has been free from rent control for many years (Wang, Zhang and Dai 2012). Third, the rental price indices are constructed from fresh lettings in Hong Kong. Therefore, we have collected the following data from the Hong Kong residential rental and property markets.

First, 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.[13] 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 holding quality constant, which means that

---

[12]Hong Kong is one of the most densely populated areas in the world, with a land mass of 1,104 km^2 (426 mi^2) 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. Housing is the most important form of savings to most households in the city and about half of Hong Kong credit goes to various mortgage loans in the property market.

[13]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.

they have already been adjusted for variations in the quality of the housing units.

Second, similar to housing prices, the R&VD also publishes rental price indices constructed from fresh lettings at the aggregate level and for the different size categories. Rents are based on an analysis of rental information recorded by the R&VD for fresh lettings effective during the quarter being analyzed. 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 because rents in a certain period depend to a large extent on the special characteristics of the premises, such as quality and location.

Third, the Hong Kong dollar has been pegged to the U.S. dollar since 1983 under the linked exchange rate system, suggesting that the risk-free interest rate in Hong Kong should be very close to its counterpart in the U.S. 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, Mayer and Sinai 2005). We select the 10-year U.S. 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, Zhang and Dai 2012).

Fourth, the vacancy rate is also taken from RV&D reports; vacant units are defined as those not physically occupied when the survey is conducted at the end of the year.[14] Premises under decoration are classified as vacant. Some vacancies could be due to units not having been issued occupation certificates by the government. It should be clear that vacancy does not necessarily correlate with whether the property has been sold by its developer, because units sold may remain vacant, pending occupation by the owner or tenant. Finally, vacancy figures cover the entire stock in the residential market and are not just confined to new developments.

The data used in this article are quarterly from 1980Q1 to 2011Q4 and monthly from January 1993 to March 2013. As shown in Figure 1, the Hong Kong property market has been very volatile during the last three decades. Since 2009, property prices have increased sharply in Hong Kong. The housing price index rose above its 1997 peak and is almost 40% higher than the previous peak during the first quarter of 2013. Meanwhile, the rental price index has also increased dramatically. For example, rent increased 35% between 2009Q3 and 2010Q4, while the property price rose more than 50% during the same period. More importantly, a casual inspection of Figure 1

[14]Rating and Valuation Department (R&VD), Hong Kong Property Review 2012, available at http://www.rvd.gov.hk/en/publications/hkpr.htm.

shows that rent tends to follow the housing price in Hong Kong. For example, in October 1995, the housing price index reached a turning point and began a two-year rally. Two months later, rent began its own sustained increase until the housing price collapsed at the end of 1997. Similar patterns are also observed in 2003 and 2008.

We extend our analysis to large cities in mainland China for three reasons. First, China is a large emerging market economy from which we can draw broader implications. Second, the rental and owner-occupied housing units are very similar and there is a lack of rent control, which fits the rental adjustment mechanism described in our model. Third, the property market of large cities in mainland China is easily subject to external capital flows, which is consistent with our assumption of relatively exogenous housing price dynamics.

From the WIND database, we collect the available monthly housing price, rent and interest rate data of the following five large cities: Beijing, Shanghai, Guangzhou, Shenzhen and Tianjin.[15] Figure 2 plots the real housing price and rental price indices of these five cities from January 2008 to December 2013. In the sample period, housing price indices follow a general upward trend with some small decreases and rental price indices follow a similar, albeit smoother, pattern. Since the period of falling housing prices for different cities does not completely coincide, we may obtain better explanatory power in our empirical analysis by pooling the cities together. However, the vacancy data for mainland cities are not available.

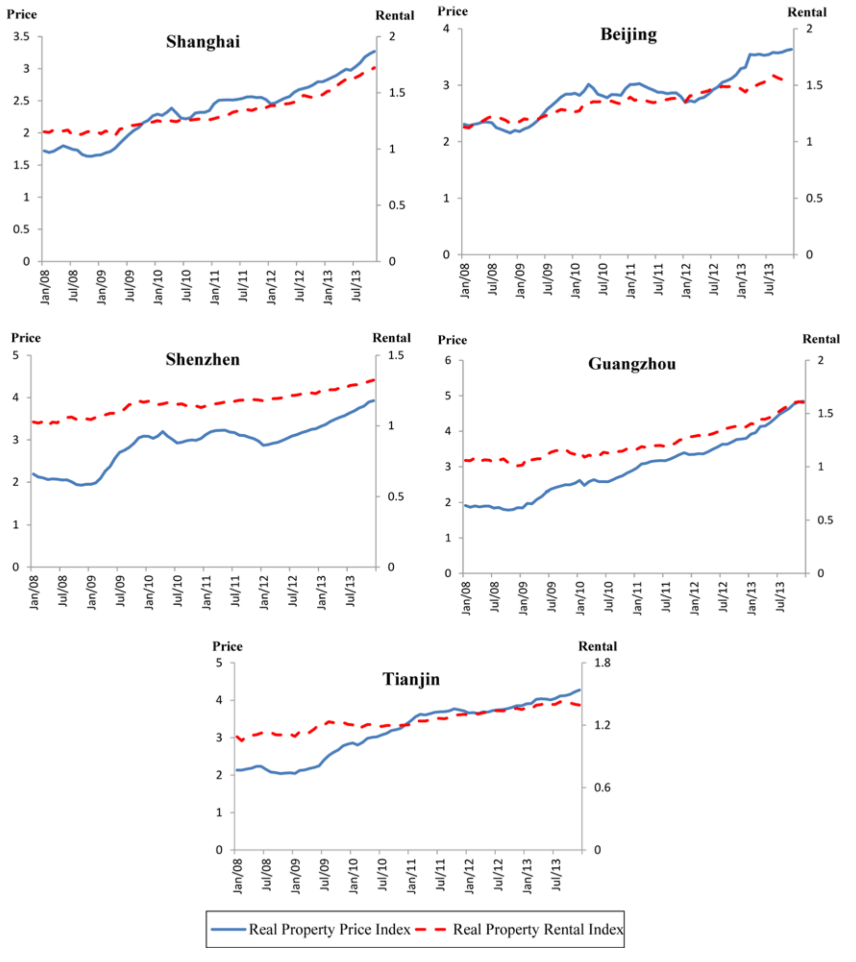
Preliminary Analysis

Table 1 shows the summary statistics of Hong Kong housing price growth, rental price growth, interest rate changes and vacancy rates. Housing price growth is more volatile than rental price growth in both quarterly and monthly data, which is consistent with Figure 1. The vacancy rate averages 4.7% between 1980 and 2011, which is quite low. It is even lower between 1993 and 2013, being only 3.5% on average, suggesting that the rental market has been extremely tight in Hong Kong.

Table 2 reports the summary statistics of the same variables (note the absence of vacancy rates due to data unavailability) for the five large cities

[15]Interestingly, by some media account the vacancy rate for Beijing reached as much as 30% in recent years (http://news.xinhuanet.com/fortune/2012-06/06/c_112132817.htm). Nevertheless, panel data on vacancy rates are generally not available for Chinese cities.

Figure 2 ■ Real housing price and rental price indices for mainland China's cities. [Color figure can be viewed at wileyonlinelibrary.com]



Note: This figure plots the monthly real housing price and rental price indices of five large cities in mainland China from January 2008 to December 2013. Both indices are published by Wind Info.

in mainland China. Compared to Hong Kong, the Chinese cities have seen larger and less volatile growth of the housing price and rent. Consistent with the general upward trend in Figure 2, the minimum housing and rental growth rates are significantly smaller in magnitude than their maximum counterparts.

Table 1 ■ Summary statistics of Hong Kong.

Variables	Obs.	Mean	Std. dev.	Min.	Max.
Quarterly data (Sample period: 1980Q1–2011Q4)					
Real housing price growth	124	0.75	5.81	–16.66	17.95
Real rental price growth	124	0.02	3.46	–11.80	9.05
Real interest rate change	124	–2.2	8.0	–23.7	21.3
Vacancy rate	124	4.7	1.0	2.9	6.8
Monthly data (Sample period: January 1993 to March 2013)					
Real housing price growth	242	0.29	2.87	–11.66	9.418
Real rental price growth	242	0.04	1.67	–8.65	7.59
Real interest rate change	242	–0.5	5.7	–31.2	20.4
Vacancy rate	239	3.5	0.8	1.8	4.7

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

From our theoretical model, the housing price uncertainty plays an important role in rental adjustment. Measuring uncertainty accurately, however, could be rather tricky. For example, Leahy and Whited (1996) and Bloom, Bond and Reenen (2007) suggest using stock return volatility as a proxy for firm-level uncertainty. In our empirical work, we simply use the square of the housing price growth to measure housing price uncertainty, which is model-independent and not affected by estimation errors. For robustness, we have also used volatility forecasts based on several GARCH models.

Results

Evidence from Hong Kong

First, we estimate the above empirical models and test the hypotheses using Hong Kong data at the aggregate level. Table 3 presents the results obtained with Ordinary Least Squares (OLS) using quarterly data. In Model 1, the coefficient for the vacancy rate is not significant (though the negative sign is expected), which suggests that the conventional rental adjustment explanation does not seem to fit the Hong Kong data. As we discussed in the preliminary analysis, this is likely because the Hong Kong rental market has been

Table 2 ■ Summary statistics of mainland China's cities.

Variables	Obs.	Mean	Std. dev.	Min.	Max.
All five cities					
Real housing price growth	355	0.93	1.95	–5.45	8.00
Real rental price growth	355	0.46	1.37	–4.41	6.71
Real interest rate change	350	0.26	4.76	–16.32	10.93
Shanghai					
Real housing price growth	71	0.92	1.74	–3.92	4.34
Real rental price growth	71	0.60	1.29	–4.07	5.13
Real interest rate change	70	0.26	4.77	–15.97	10.52
Beijing					
Real housing price growth	71	0.64	1.97	–3.91	6.70
Real rental price growth	71	0.43	1.37	–2.36	4.77
Real interest rate change	70	0.26	4.73	–15.85	10.43
Shenzhen					
Real housing price growth	71	0.82	2.28	–3.55	8.00
Real rental price growth	71	0.36	0.94	–2.62	2.84
Real interest rate change	70	0.26	4.75	–16.13	10.93
Guangzhou					
Real housing price growth	71	1.31	2.00	–5.45	6.46
Real rental price growth	71	0.58	1.73	–4.41	6.71
Real interest rate change	70	0.27	4.88	–16.32	10.92
Tianjin					
Real housing price growth	71	0.98	1.67	–3.68	6.57
Real rental price growth	71	0.35	1.42	–3.53	4.02
Real interest rate change	70	0.26	4.81	–16.12	10.53

Note: This table reports summary statistics of real housing price growth, rental price growth and interest rate change for five large cities in mainland China: Beijing, Shanghai, Guangzhou, Shenzhen and Tianjin. The data are monthly from January 2008 to December 2013 and obtained from Wind Info. Real housing price growth and real rental growth are log changes in the housing price index and rental price index adjusted for five cities' CPI, respectively. The Chinese 10-year Government bond yield is used for the mainland cites' risk-free interest rate. Real interest rate changes are represented by the percentage change of the Chinese 10-year Government bond yield adjusted for the five cities' CPI, respectively. The numbers in the table are in percentage points.

extremely tight in the last 30 years and the vacancy rate fluctuates in a very narrow band.[16] Consistent with the vacancy rate's lack of significance, the adjusted R-squared of the regression is only 2%.

[16]Hendershott, Lizieri and Matysiak (1999) find vacancy rate to be highly significant in their analysis of London's office market. However, the range of London vacancy rates during their sample period of 1977–1996 lies between 2% and 20%, which is much wider than what we have witnessed in the Hong Kong residential market during 1980–2013.

Table 3 ■ Rental determinants with quarterly Hong Kong aggregate data.

Dependent Variable: $\%\Delta R_t$				
Variables	Model (1)	Model (2)	Model (3)	Model (4)
$Vacancy_{t-1}$	–0.534			0.040
	(0.464)			(0.253)
$\%\Delta S_{t-1}$		0.456^{***}	0.446^{***}	0.448^{***}
		(0.062)	(0.058)	(0.057)
ΔV_t		-2.066^{***}	-2.034^{***}	-2.036^{***}
		(0.467)	(0.462)	(0.463)
$\Delta V_t \times d_t$		3.103^{***}	3.080^{***}	3.086^{***}
		(0.559)	(0.549)	(0.552)
$\%\Delta r_t$			0.042	0.042
			(0.039)	(0.040)
Constant	2.541	–0.371	–0.268	–0.458
	(2.193)	(0.276)	(0.253)	(1.274)
Obs	124	123	123	123
Adjusted R^2	0.02	0.57	0.57	0.57
$\beta_3 + \beta_4$		1.037	1.046	1.050
F-test for $\beta_3 + \beta_4 = 0$		9.75^{***}	11.08^{***}	10.99^{***}

Note: This table presents the results of estimating the following model using quarterly Hong Kong aggregate data from Quarter 1 of 1980 to Quarter 4 of 2011: $\%\Delta R_t = \beta_0 + \beta_1 Vacancy_{t-1} + \beta_2\%\Delta S_{t-1} + \beta_3\Delta V_t + \beta_4\Delta V_t \times d_t + \beta_5\%\Delta r_t + \varepsilon_t$, 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, V_t is the squared demeaned real housing price growth, ΔV_t is the first difference of V_t, d_t is a price trend dummy equal to 1 for $\%\Delta S_t > 0$ and $\%\Delta r_t$ is the real interest rate growth. The numbers in the parentheses are Newey-West robust standard errors. The symbols *,**,***denote statistical significance at 10%, 5% and 1% level, respectively.

In Model 2, which incorporates the housing price growth as well as its variance, the adjusted R-squared increases substantially to 57%. Moreover, as the monotonic price effect predicts, housing price has a significantly positive correlation with the rental rate. Specifically, a 1% housing price increase is associated with a 0.46% increase in the rental rate. The F-tests in Table 3 show that the housing price variance has a positive impact on the rental rate when the housing price is rising ($\beta_3 + \beta_4 > 0$), while it has a negative impact on the rental rate when the housing price is falling ($\beta_3 < 0$), confirming the regime-dependent variance effect. These results suggest that the expansion of rental supply due to a greater housing price uncertainty dominates the expansion of rental demand when the housing market is trending downward, leading to lower rental rates. Therefore, it seems that Hong Kong landlords as a group are more sensitive to real options effects of uncertainty than renters are when the housing price drops sharply, while the opposite is true when the housing price rises.

In Model 3, we add real interest rate changes as another explanatory variable. Consistent with the user cost of housing model, the results suggest that interest rates have a positive impact on rental growth, but the estimated coefficient is not statistically significant (recall Footnote 11). In Model 4, we include all explanatory variables. Notably, the coefficients for both the vacancy rate and the interest rate remain insignificant while the effects of the housing price and its variance are almost unchanged from Model 2. A comparison of the adjusted R-Squared across the regressions shows that the housing price growth and its variance account for most of the explanatory power for rental growth.

Additionally, we conduct the same estimations using monthly data. The results in Table 4 are consistent with what we find in Table 3. Specifically, both the price effect and the variance effect are still significant in the rental adjustment process, and the coefficient for the real interest rate is not significant. We find that a 1% housing price increase is associated with a rental rate increase of about 0.31%, which is similar to what we find using quarterly data. Finally, the explanatory power of the lagged vacancy rate weakens further, which is not surprising because the slow-moving vacancy rate is even less likely to explain rental rate changes at the monthly frequency.

For robustness, we construct a panel dataset using observations from the five size categories to estimate the empirical models by fixed effects regressions with two-way cluster-robust standard errors of Petersen (2009). The results shown in Table 5 are similar to what we find using aggregate-level data: the price effect is positive and significant, and the housing price variance boosts rental growth as the housing price rises, while it pushes the rent down when the housing price falls. The size of the variance effect is smaller than that in Table 3, presumably because the category-level data contain more noise than the aggregate-level data.

Table 5 also shows that the coefficient for the lagged vacancy rate is negative and significant in Model 1, which suggests that the conventional rental adjustment explanation is valid in the category-level data. However, the lagged vacancy rate is no longer significant after controlling for the price effect and the variance effect, which is consistent with what we find using the aggregate-level data in Table 3. For the real interest rate, Table 5 shows that its effect on the rental rate is positive and marginally significant, which is supportive of the user cost of housing model.

Table 4 ■ Rental determinants with monthly Hong Kong aggregate data.

Dependent Variable: $\%\Delta R_t$				
Variables	Model (1)	Model (2)	Model (3)	Model (4)
$Vacancy_{t-1}$	0.0004			0.001
	(0.002)			(1.019)
$\%\Delta S_{t-1}$		0.313***	0.312***	0.314***
		(0.048)	(0.049)	(0.048)
ΔV_t		–1.383	–1.381	–1.428
		(1.206)	(1.206)	(1.207)
$\Delta V_t \times d_t$		4.872***	4.860***	5.003***
		(1.451)	(1.451)	(1.427)
$\%\Delta r_t$			0.000	0.000
			(0.0002)	(0.0002)
Constant	–0.001	–0.001	–0.001	–0.005
	(0.007)	(0.001)	(0.001)	(0.004)
Obs	239	241	241	239
Adjusted R^2	–0.004	0.36	0.36	0.36
$\beta_3 + \beta_4$		3.489	3.479	3.575
F-test for $\beta_3 + \beta_4 = 0$		45.55***	41.20***	42.80***

Note: This table presents the results of estimating the following model using monthly Hong Kong aggregate data from January 1993 to March 2013: $\%\Delta R_t = \beta_0 + \beta_1 Vacancy_{t-1} + \beta_2\%\Delta S_{t-1} + \beta_3\Delta V_t + \beta_4\Delta V_t \times d_t + \beta_5\%\Delta r_t + \varepsilon_t$, 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, V_t is the squared real demeaned housing price growth, ΔV_t is the first difference of V_t, d_t is a price trend dummy equal to 1 for $\%\Delta S_t > 0$ and $\%\Delta r_t$ is the real interest rate growth. The numbers in the parentheses are Newey-West robust standard errors. The symbols *,**,***denote statistical significance at 10%, 5% and 1% level, respectively.

Evidence from China

Given our previous results from using a unique dataset from the Hong Kong residential rental and property market, a natural question is whether similar results can be estimated using mainland China's cities.

To increase the power of statistical tests, we estimate the following dynamic panel data fixed effects regression for all five cities with two-way cluster-robust standard errors of Petersen (2009):

$$\%\Delta R_t = \beta_0 + \beta_1\%\Delta R_{t-1} + \beta_{21}\%\Delta S_{t-1} + \beta_{22}\%\Delta S_{t-2} + \beta_3\Delta V_t + \beta_4\Delta V_t \times d_t + \beta_5\%\Delta r_t + \varepsilon_t. \quad (29)$$

In this specification, $\%\Delta R_t$ is the real rental growth rate and $\%\Delta R_{t-1}$ its first lag, used here because the vacancy rate is not available in the Chinese

Table 5 ■ Rental determinants with quarterly Hong Kong panel data.

Dependent Variable: $\%\Delta R_t$				
Variables	Model (1)	Model (2)	Model (3)	Model (4)
$Vacancy_{t-1}$	–0.375*			–0.014
	(0.221)			(0.137)
$\%\Delta S_{t-1}$		0.424***	0.416***	0.416***
		(0.043)	(0.040)	(0.041)
ΔV_t		–1.139*	–1.098*	–1.098*
		(0.635)	(0.610)	(0.611)
$\Delta V_t \times d_t$		1.493**	1.460**	1.460**
		(0.766)	(0.742)	(0.743)
$\%\Delta r_t$			0.045*	0.046
			(0.027)	(0.028)
Constant	1.784	–0.412	–0.301*	–0.233
	(1.084)	(0.202)	(0.179)	(0.713)
Obs	590	585	585	585
Adjusted R^2	0.0001	0.46	0.47	0.47
$\beta_3 + \beta_4$		0.354	0.362	0.362
F-test for $\beta_3 + \beta_4 = 0$		5.20**	5.50**	5.46**

Note: This table presents the results of estimating the following panel data fixed-effects regression for five categories of Hong Kong housing units: Categories 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: $\%\Delta R_t = \beta_0 + \beta_1 Vacancy_{t-1} + \beta_2 \%\Delta S_{t-1} + \beta_3 \Delta V_t + \beta_4 \Delta V_t \times d_t + \beta_5 \%\Delta r_t + \varepsilon_t$, 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, V_t is the squared real demeaned housing price growth, ΔV_t is the first difference of V_t, d_t is a price trend dummy equal to 1 for $\%\Delta S_t > 0$ and $\%\Delta r_t$ is the real interest rate growth. The numbers in the parentheses are two-way cluster-robust standard errors. The symbols *,**,***denote statistical significance at 10%, 5% and 1% level, respectively.

data. We include together the first and second lags of the real housing price growth, $\%\Delta S_{t-1}$ and $\%\Delta S_{t-2}$, because housing prices in the mainland cities exhibit a high degree of persistence. As before, V_t is the variance of the real housing price growth proxied by the squared demeaned growth rate and ΔV_t its first difference, d_t is a housing price trend dummy equal to one if $\%\Delta S_t > 0$ and $\%\Delta r_t$ is the percentage change of the real risk-free interest rate.

As shown in Table 6, the results for large cities in mainland China are consistent with the results for Hong Kong. In Model 1, the lagged rental growth is not significant in explaining the rental growth and the adjusted R-squared is virtually zero. In Model 2, the lagged housing price growth and

Table 6 ■ Rental determinants with monthly Chinese panel data.

Dependent Variable: $\%\Delta R_t$				
Variables	Model (1)	Model (2)	Model (3)	Model (4)
$\%\Delta R_{t-1}$	–0.095			–0.058
	(0.064)			(0.088)
$\%\Delta S_{t-1}$		–0.003	–0.013	0.007
		(0.038)	(0.042)	(0.063)
$\%\Delta S_{t-2}$		0.131**	0.110*	0.103*
		(0.060)	(0.058)	(0.057)
ΔV_t		–0.878	–0.851	–1.012
		(1.001)	(1.070)	(0.962)
$\Delta V_t \times d_t$		3.922**	3.673*	3.794**
		(1.934)	(1.872)	(1.730)
$\%\Delta r_t$			0.041	0.041
			(0.030)	(0.030)
Constant	0.005***	0.003***	0.004***	0.004***
	(0.0009)	(0.001)	(0.001)	(0.001)
Obs	350	345	345	345
Adjusted R^2	0.0002	0.052	0.070	0.070
$\beta_3 + \beta_4$				
		3.044	2.822	2.782
F-test for $\beta_3 + \beta_4 = 0$		10.75***	9.35***	9.07***

Note: This table presents the results of estimating the following panel data fix-effects regression for five large cities in mainland China: Shanghai, Beijing, Shenzhen, Guangzhou and Tianjin: $\%\Delta R_t = \beta_0 + \beta_1\%\Delta R_{t-1} + \beta_{21}\%\Delta S_{t-1} + \beta_{22}\%\Delta S_{t-2} + \beta_3\Delta V_t + \beta_4\Delta V_t \times d_t + \beta_5\%\Delta r_t + \varepsilon_t$, where $\%\Delta R_t$ is real rental growth and $\%\Delta R_{t-1}$ its first lag, $\%\Delta S_{t-1}$ and $\%\Delta S_{t-2}$ are the first and second lags of the real housing price growth, V_t is the real demeaned housing price growth squared and ΔV_t its first difference, d_t is a price trend dummy equal to 1 when $\%\Delta S_t > 0$ and $\%\Delta r_t$ is the real interest rate growth. The numbers in the parentheses are two-way cluster-robust standard errors. The symbols *,**,***denote statistical significance at 10%, 5% and 1% level, respectively.

its variance shocks can explain a significantly higher portion, or 5.2%, of the rental growth variations. Moreover, there is evidence for the monotonic price effect as the coefficient for the second lag of the housing price growth is significantly positive. The regime-dependent variance effect is partially confirmed: the F-test shows that housing price variance shocks have a positive impact on the rental growth when housing prices are rising ($\beta_4 + \beta_3 > 0$), while the negative impact ($\beta_3 < 0$) on the rental growth with decreasing housing prices is not significant.[17] In Models 3 and 4, the monotonic price

[17]Possibly, this is because the Chinese housing market did not experience any extended period of decline from 2008 to 2013, as shown in Figure 2.

Table 7 ■ Robustness check with monthly Hong Kong aggregate data and alternative variance measure.

Dependent Variable: $\%\Delta R_t$				
Variables	Model (1)	Model (2)	Model (3)	Model (4)
$Vacancy_{t-1}$	0.0004			0.0004
	(0.002)			(0.001)
$\%\Delta S_{t-1}$		0.272^{***}	0.263^{***}	0.265^{***}
		(0.052)	(0.045)	(0.045)
ΔV_t		–3.999	–4.116	–4.068
		(3.197)	(3.229)	(3.268)
$\Delta V_t \times d_t$		13.617^{**}	14.273^{**}	14.278^{**}
		(6.376)	(6.766)	(6.780)
$\%\Delta r_t$			0.021	0.021
			(0.024)	(0.024)
Constant	–0.001	–0.0003	–0.000	–0.002
	(0.007)	(0.001)	(0.001)	(0.005)
Obs	239	240	240	238
Adjusted R^2	–0.004	0.302	0.305	0.303
$\beta_3 + \beta_4$		9.618	10.157	10.210
F-test for $\beta_3 + \beta_4 = 0$		3.996^{**}	4.00^{**}	4.02^{**}

Note: This table presents the results of estimating the following model using monthly Hong Kong aggregate data from January 1993 to March 2013: $\%\Delta R_t = \beta_0 + \beta_1 Vacancy_{t-1} + \beta_2 \%\Delta S_{t-1} + \beta_3 \Delta V_t + \beta_4 \Delta V_t \times d_t + \beta_5 \%\Delta r_t + \varepsilon_t$, 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, V_t is the estimated conditional variance of the real housing price growth from the EGARCH(2,2,2) model, ΔV_t is the AR(2) residual of V_t, d_t is a price trend dummy equal to 1 for $\%\Delta S_t > 0$ and $\%\Delta r_t$ is the real interest rate growth. The numbers in the parentheses are Newey-West robust standard errors. The symbols *,**,***denote statistical significance at 10%, 5% and 1% level, respectively.

effect and the positive variance effect remain significant, suggesting a strong effect of housing price dynamics on rent. Arguably, real options effects of the housing price dynamics on rent also exist in the data from large cities in mainland China.

Robustness of the Variance Effect

First, we use an alternative variance measure based on the EGARCH model and find similar results. As shown in Table 7, the results using monthly Hong Kong aggregate data and estimated conditional variances from the EGARCH model are consistent with those in Table 4. Across models, the monotonic price effect remains highly significant and robust, and the F-tests confirm the regime-dependent variance effect. As shown in Table 8, there is also strong

Table 8 ■ Robustness check with monthly Chinese panel data and alternative variance measure.

Dependent Variable: $\%\Delta R_t$				
Variables	Model (1)	Model (2)	Model (3)	Model (4)
$\%\Delta R_{t-1}$	–0.095			–0.047
	(0.064)			(0.077)
$\%\Delta S_{t-1}$		–0.029	–0.039	–0.023
		(0.051)	(0.052)	(0.064)
$\%\Delta S_{t-2}$		0.133**	0.111*	0.106*
		(0.066)	(0.062)	(0.062)
ΔV_t		–2.273	–2.474	–2.519
		(2.415)	(2.478)	(2.482)
$\Delta V_t \times d_t$		12.438**	11.650**	11.422*
		(6.433)	(5.916)	(6.274)
$\%\Delta r_t$			0.012	0.012
			(0.007)	(0.0307)
Constant	0.005***	0.004***	0.004***	0.004***
	(0.0009)	(0.001)	(0.001)	(0.001)
Obs	350	340	340	340
Adjusted R^2	0.0002	0.040	0.059	0.058
$\beta_3 + \beta_4$		3.044	2.845	2.807
		10.165	9.176	8.903
F-test for $\beta_3 + \beta_4 = 0$		8.05***	6.58**	6.01**

Note: This table presents the results of estimating the following panel data fix-effects regression for five large cities in mainland China: Shanghai, Beijing, Shenzhen, Guangzhou and Tianjin: $\%\Delta R_t = \beta_0 + \beta_1\%\Delta R_{t-1} + \beta_{21}\%\Delta S_{t-1} + \beta_{22}\%\Delta S_{t-2} + \beta_3\Delta V_t + \beta_4\Delta V_t \times d_t + \beta_5\%\Delta r_t + \varepsilon_t$, where $\%\Delta R_t$ is real rental growth and $\%\Delta R_{t-1}$ its first lag, $\%\Delta S_{t-1}$ and $\%\Delta S_{t-2}$ are the first and second lags of the real housing price growth, V_t is the estimated conditional variance of the real housing price growth from the EGARCH(2,2,2) model, ΔV_t is the AR(1) residual of V_t, d_t is a price trend dummy equal to 1 when $\%\Delta S_t > 0$ and $\%\Delta r_t$ is the real interest rate growth. The numbers in the parentheses are two-way cluster-robust standard errors. The symbols *,**,***denote statistical significance at 10%, 5% and 1% level, respectively.

and robust evidence of the monotonic price effect and positive variance effect for large cities in mainland China.

Next, we extend the specification estimated in Table 4 using monthly Hong Kong aggregate data to include the variance of the Hang Seng Index (HSI) and its interaction with the housing price trend dummy. Our theoretical model predicts a regime-dependent variance effect based on the housing price variance, not stock market variance, even if the two are correlated. The first two columns of Table 9 shows that this is indeed the case, where the HSI

Table 9 ■ Rental determinants with Hang Seng Index Variance.

Variables	Full Sample	Full Sample	Subsample (2003–2013)	Subsample (1993–2003)
$Vacancy_{t-1}$		0.001	0.002	–0.001
		(0.001)	(0.003)	(0.001)
$\%\Delta S_{t-1}$	0.308***	0.309***	0.255***	0.255***
	(0.031)	(0.031)	(0.055)	(0.035)
ΔV_t	–1.590***	–1.634***	–10.16***	–0.423
	(0.570)	(0.573)	(1.637)	(0.554)
$\Delta V_t \times d_t$	5.022***	5.167***	15.35***	2.730**
	(0.987)	(1.001)	(1.993)	(1.221)
ΔV_t^{hs}	0.162	0.166	0.219	0.093
	(0.124)	(0.124)	(0.194)	(0.143)
$\Delta V_t^{hs} \times d_t$	–0.075	–0.087	–0.416	0.177
	(0.214)	(0.215)	(0.342)	(0.241)
$\%\Delta r_t$	0.002	0.001	–0.024	0.051**
	(0.016)	(0.015)	(0.019)	(0.023)
Constant	–0.001	–0.004	–0.003	0.001
	(0.001)	(0.004)	(0.013)	(0.004)
Obs	241	239	109	130
Adjusted R^2	0.35	0.36	0.49	0.34
$\beta_3 + \beta_4$	3.432	3.533	5.191	2.307
F-test for $\beta_3 + \beta_4 = 0$	12.95***	13.35***	29.85***	2.55*

Note: This table presents the results of estimating the following model using monthly Hong Kong aggregate data from January 1993 to March 2013: $\%\Delta R_t = \beta 0 + \beta_1 Vacancy_{t-1} + \beta_2 \%\Delta S_{t-1} + \beta_3 \Delta V_t + \beta_4 \Delta V_t \times d_t + \beta_5 \Delta V_t^{hs} + \beta_6 \Delta V_t^{hs} \times d_t + \beta_7 \%\Delta r_t + \varepsilon_t$, where $\%\Delta R_t$ is real rental growth, $Vacancy_{t-1}$ is the lagged vacancy rate, $\%\Delta S_{t-1}$ is the real housing price growth and its lag, V_t is the squared real demeaned housing price growth, ΔV_t is the first difference of V_t, d_t is a price trend dummy equal to 1 for $\%\Delta S_t > 0$, V_t^{hs} is the squared real demeaned Hang Seng Index growth, ΔV_t^{hs} is the first difference of V_t^{hs} and $\%\Delta r_t$ is the real interest rate growth. The numbers in the parentheses are Newey-West robust standard errors. The symbols *, **, ***denote statistical significance at 10%, 5% and 1% level, respectively.

variance and its interaction with the housing price trend dummy do not play any significant role in explaining rental growth. In the last two columns of Table 9, we repeat the estimation for the first half (1993–2003) and the second half (2003–2013) of the sample period, since 2003 was the end of the HK housing crisis after the Asian financial crisis and SARS crisis. The housing price variance effect is much stronger during the second half of the sample period, consistent with the prominent role of the housing market in the global financial crisis.

Table 10 ■ Rental determinants with Chinese data including CSI 300 Variance.

Dependent Variable: $\%\Delta R_t$

Variables	Model (1)	Model (2)	Model (3)	Model (4)
$\%\Delta R_{t-1}$	–0.078			0.026
	(0.052)			(0.053)
$\%\Delta S_{t-1}$		0.121***	0.118***	0.112**
		(0.040)	(0.042)	(0.043)
$\%\Delta S_{t-2}$		0.134***	0.132***	0.132***
		(0.038)	(0.038)	(0.038)
ΔV_t		–0.271	–0.199	–0.199
		(1.030)	(1.058)	(1.060)
$\Delta V_t \times d_t$		2.414**	3.350**	2.319**
		(1.076)	(1.098)	(1.101)
ΔV_t^{CSI}		–0.083	–0.081	–0.082
		(0.052)	(0.053)	(0.053)
$\Delta V_t^{CSI} \times d_t$		0.103*	0.099*	0.099*
		(0.055)	(0.056)	(0.057)
$\%\Delta r_t$			0.004	0.004
			(0.015)	(0.015)
Constant	0.002***	0.001	0.001	0.001
	(0.0007)	(0.001)	(0.001)	(0.001)
Obs	350	345	345	345
Adjusted R^2	0.008	0.154	0.155	0.156
$\beta_3 + \beta_4$		3.044	2.845	2.807
		2.143	2.151	2.120
F-test for $\beta_3 + \beta_4 = 0$		3.20**	3.08**	2.97*

Note: This table presents the results of estimating the following panel data fix-effects regression for five large cities in mainland China: Shanghai, Beijing, Shenzhen, Guangzhou and Tianjin: $\%\Delta R_t = \beta_0 + \beta_1\%\Delta R_{t-1} + \beta_{21}\%\Delta S_{t-1} + \beta_{22}\%\Delta S_{t-2} + \beta_3\Delta V_t + \beta_4\Delta V_t \times d_t + \beta_5\Delta V_t^{CSI} + \beta_6\Delta V_t^{CSI} \times d_t + \beta_7\%\Delta r_t + \varepsilon_t$, where $\%\Delta R_t$ is real rental growth and $\%\Delta R_{t-1}$ its first lag, $\%\Delta S_{t-1}$ and $\%\Delta S_{t-2}$ are the first and second lags of the real housing price growth, V_t is the real demeaned housing price growth squared and ΔV_t its first difference, V_t^{CSI} is the squared real demeaned CSI 300 Index growth, d_t is a price trend dummy equal to 1 when $\%\Delta S_t > 0$ and $\%\Delta r_t$ is the real interest rate growth. The numbers in the parentheses are two-way cluster-robust standard errors. The symbols *,**,***denote statistical significance at 10%, 5% and 1% level, respectively.

Lastly, we extend the specification estimated in Table 6 using monthly Chinese panel data to include the variance of the CSI 300 index and its interaction with the housing price trend dummy. The resulting Table 10 shows that the interaction term does add significant explanatory power to the regression R-squared. For example, Model 4 in Table 6 has an R-squared of 7.0%, while the R-squared of the augmented Model 4 in Table 10 increases to 15.6%.

Nevertheless, the findings with respect to the monotonic price effect and positive housing price variance effect are qualitatively unchanged.

Conclusion

This article explores a possibility that the housing price, like other asset prices, is externally-determined and can drive rental rate changes, which is in sharp contrast to the traditional view that rent is fundamental to the determination of the housing price. We demonstrate in theory that housing price uncertainty can have a significant impact on the property investments of individual households, leading to fluctuations in the rental market of a large city. 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.

As a first step with simple and strong assumptions, the theoretical model shows that the housing price dynamics could affect rent through two effects. The first effect is a monotonic price effect: rent increases with the housing price. The second effect is a regime-dependent variance effect: rent increases with the housing price variance when the housing market is rising and decreases with the housing price variance when the housing market is falling. We find that the property and rental market data from Hong Kong and mainland China's cities are largely consistent with these results.

The policy implications of the article are important given the large weight on rent in the CPI–property bubbles may spill over to rent inflation and pricking the bubble may cause rent deflation. Furthermore, rent is not just driven by fundamentals; the housing price shock and its variance also play important roles in rental adjustments. Therefore, the price-to-rent ratio could misstate the size of housing bubbles due to the option component of rent.

For future research, we can extend our model in various dimensions. For example, a more plausible formulation is to allow rent R and/or private valuation K to be related to the market price of housing. We can also allow renegotiation between renters and landlords when contract maturity is up. Moreover, we can consider the household financing decision and incorporate the effect of mortgage payment on the incentive to sell.

Another direction of future research is to consider buy-to-rent investors, who purchase large portfolios of houses and manage them as rental property (Mills, Molloy and Zarutskie 2017), and to value the redevelopment option of urban land across the spectrum of the housing life cycle (Munneke and Womack

2017). Finally, it is interesting to find city-level data of large cities like New York, Tokyo and London and see whether there are similar results.

An earlier version of this article was awarded the 2016 Global Chinese Real Estate Congress Best Article Award. The authors gratefully acknowledge many helpful comments on earlier versions from Sumit Agarwal, Warren Bailey, David Bjerk, Albert Lee Chun, Ricardo Fernholz, Dong He, Eric Helland, Eric Hughson, Charles Leung, André Meier, Guillaume Plantin, Wenlan Qian, Joshua Rosett, Ko Wang, Thomas Willett, Vincent Yao, participants at the Hong Kong Institute for Monetary Research (HKIMR) and the Chinese University of Hong Kong Joint Conference, the 2014 FMA Asian Conference in Tokyo, the 2016 Annual Meeting of Global Chinese Real Estate Congress and particularly an anonymous referee. They would also like to thank Wenqi Liu, Michael Dai and Ruomei Zhang for excellent research assistance. Zhou acknowledges the financial support of Fundamental Research Funds for the Central Universities (Project 2072016012).

References

Andersen, S., J.Y. Campbell, K.M. Nielsen and T. Ramadorai. 2015. *Inattention and Inertia in Household Finance: Evidence from the Danish Mortgage Market*. Working Paper, Harvard University.

Arnott, R. 1995. Time for Revisionism on Rent Control. *Journal of Economic Perspectives* 9(1): 99–120.

Ayuso, J. and F. Restoy. 2006. House Prices and Rents: An Equilibrium Asset Pricing Approach. *Journal of Empirical Finance* 13: 371–388.

Bailey, W., W. Huang and Z. Yang. 2011. Bank Loans with Chinese Characteristics: Some Evidence on Inside Debt in a State-Controlled Banking System. *Journal of Financial and Quantitative Analysis* 46: 1795–1830.

Bajari, P., P. Chan, D. Krueger and D. Miller. 2013. A Dynamic Model of Housing Demand: Estimation and Policy Implications. *International Economic Review* 54: 409–442.

Bernanke, B.S. 1983. Irreversibility, Uncertainty, and Cyclical Investment. *Quarterly Journal of Economics* 98: 85–106.

Bloom, N. 2009. The Impact of Uncertainty Shocks. *Econometrica* 77(3): 623–685.

Bloom, N., S. Bond and J. Van Reenen. 2007. Uncertainty and Investment Dynamics. *Review of Economic Studies* 74: 391–415.

Brennan, M. 1990. Latent Assets. *Journal of Finance* 45(3): 709–730.

———. and E.S. Schwartz. 1985. Evaluating Natural Resource Investments. *Journal of Business* 85: 135–157.

Bunch, D. and H.E. Johnson. 2000. The American Put Option and Its Critical Stock Price. *Journal of Finance* 55: 2333–2356.

Chambers, M., C. Garriga and D. Schlagenhauf. 2009. Accounting for Changes in the Homeownership Rate. *International Economic Review* 50: 677–726.

Childs, P.D., S.H. Ott and A.J. Triantis. 1998. Capital Budgeting for Interrelated Projects: A Real Options Approach. *Journal of Financial and Quantitative Analysis* 33: 305–334.

Dales, P. 2011. *Rental Market Set to Shine*. U.S. Housing Market Focus, Capital Economics.

Dixit, A. and R.S. Pindyck. 1994. *Investment Under Uncertainty*. Princeton, NJ: Princeton University Press.

Eubank, A.A. and C.F. Sirmans. 1979. The Price Adjustment Mechanism for Rental Housing in the United States. *Quarterly Journal of Economics* 93: 163–183.

Grenadier, S.R. 1995. Valuing Lease Contracts: A Real-options Approach. *Journal of Financial Economics* 38: 297–331.

Han, L. 2010. The Effects of Price Uncertainty on Housing Demand: Empirical Evidence from the U.S. Markets. *Review of Financial Studies* 23: 3889–3928.

———. 2013. Understanding the Puzzling Risk-Return Relationship for Housing. *Review of Financial Studies* 26: 877–928.

Hendershott, P.H. 1996. Rental Adjustment and Valuation in Overbuilt Markets: Evidence from Sydney. *Journal of Urban Economics* 39: 51–67.

———., C.M. Lizieri and G.A. Matysiak. 1999. The Workings of the London Office Market. *Real Estate Economics* 27: 365–387.

Henry, C. 1974. Investment Decisions under Uncertainty: The Irreversibility Effect. *American Economic Review* 64: 1006–1012.

Hilber, C.A. and W. Vermeulen. 2016. The impact of supply constraints on house prices in England. *Economic Journal* 126: 358–405.

Himmelberg, C., C. Mayer and T. Sinai. 2005. Assessing High House Prices: Bubbles, Fundamentals and Misperceptions. *Journal of Economic Perspectives* 19: 67–92.

Kim, I.J. 1990. The Analytic Valuation of American Options. *Review of Financial Studies* 3: 547–572.

Lai, R.N. and R. Van Order. 2017. U.S. House Prices over the Last 30 Years: Bubbles, Regime Shifts and Market (In)Efficiency. *Real Estate Economics* 45: 259–300.

Leahy, J. and T. Whited. 1996. The Effects of Uncertainty on Investment: Some Stylized Facts. *Journal of Money, Credit, and Banking* 28: 64–83.

Lee, N.J., T.N. Seslen and W.C. Wheaton. 2015. Do House Price Levels Anticipate Subsequent Price Changes within Metropolitan Areas? *Real Estate Economics* 43: 782–805.

Majd, S. and R.S. Pindyck. 1987. Time to Build, Option Value, and Investment Decisions. *Journal of Financial Economics* 18: 7–27.

Mills, J., R. Molloy and R. Zarutskie. 2017. Large-Scale Buy-to Rent Investors in the Single-Family Housing Market:The Emergence of a New Asset Class. *Real Estate Economics*, forthcoming.

Munneke, H.J. and K.S. Womack. 2017. Valuing the Redevelopment Option Component of Urban Land Values. *Real Estate Economics*, forthcoming.

Petersen, M.A. 2009. Estimating Standard Errors in Finance Panel Data Sets: Comparing Approaches. *Review of Financial Studies* 22: 435–480.

Poterba, J. 1991. House Price Dynamics: The Role of Tax Policy and Demography. *Brookings Papers on Economic Activity* 2: 143–203.

Qian, W. 2013. Why Do Sellers Hold Out in the Housing Market? An Option-based Explanation. *Real Estate Economics* 41: 384–417.

Richard, S.F. and R. Roll. 1989. Prepayments on Fixed-rate Mortgage-backed Securities. *Journal of Portfolio Management* 15: 73–82.

Rosen, K.T. and L.B. Smith. 1983. The Price Adjustment Process for Rental Housing and the Natural Vacancy Rate. *American Economic Review* 73: 779–786.

Saiz, A. 2003. Room in the Kitchen for the Melting Pot: Immigration and Rental Prices. *Review of Economics and Statistics* 85: 502–521.

Shiller, R. 2008. Understanding Recent Trends in House Prices and Homeownership. In *Housing, Housing Finance, and Monetary Policy*, Jackson Hole Conference Series, Federal Reserve Bank of Kansas City, 85–123.

Smith, L.B. 1974. A Note on the Rent Adjustment Mechanism for Rental Housing. *American Economic Review* 64: 478–481.

Sommer, K., P. Sullivan and R. Verbrugge. 2013. The Equilibrium Effect of Fundamentals on House Prices and Rents. *Journal of Monetary Economics* 60: 853–870.

Titman, S. 1985. Urban Land Prices under Uncertainty. *American Economic Review* 75: 505–514.

Triantis, A.J. and J.E. Hodder. 1990. Valuing Flexibility as a Complex Option. *Journal of Finance* 45: 549–566.

Wang, H., C. Zhang and W. Dai. *Rental Adjustment and Housing Prices: Evidence from Hong Kong's Residential Property Market*. Working Paper, Hong Kong Monetary Authority (2012).

Wheaton, W. 1990. Vacancy, Search, and Prices in a Housing Market Matching Model. *Journal of Political Economy* 98: 1270–1292.

Yao, H. and F. Pretorius. 2014. Demand Uncertainty, Development Timing and Leasehold Land Valuation: Empirical Testing of Real Options in Residential Real Estate Development, *Real Estate Economics* 42: 829–868.

IRTG 1792 Discussion Paper Series 2018

For a complete list of Discussion Papers published, please visit irtg1792.hu-berlin.de.

001 "Data Driven Value-at-Risk Forecasting using a SVR-GARCH-KDE Hybrid" by Marius Lux, Wolfgang Karl Härdle and Stefan Lessmann, January 2018.
002 "Nonparametric Variable Selection and Its Application to Additive Models" by Zheng-Hui Feng, Lu Lin, Ruo-Qing Zhu asnd Li-Xing Zhu, January 2018.
003 "Systemic Risk in Global Volatility Spillover Networks: Evidence from Option-implied Volatility Indices " by Zihui Yang and Yinggang Zhou, January 2018.
004 "Pricing Cryptocurrency options: the case of CRIX and Bitcoin" by Cathy YH Chen, Wolfgang Karl Härdle, Ai Jun Hou and Weining Wang, January 2018.
005 "Testing for bubbles in cryptocurrencies with time-varying volatility" by Christian M. Hafner, January 2018.
006 "A Note on Cryptocurrencies and Currency Competition" by Anna Almosova, January 2018.
007 "Knowing me, knowing you: inventor mobility and the formation of technology-oriented alliances" by Stefan Wagner and Martin C. Goossen, February 2018.
008 "A Monetary Model of Blockchain" by Anna Almosova, February 2018.
009 "Deregulated day-ahead electricity markets in Southeast Europe: Price forecasting and comparative structural analysis" by Antanina Hryshchuk, Stefan Lessmann, February 2018.
010 "How Sensitive are Tail-related Risk Measures in a Contamination Neighbourhood?" by Wolfgang Karl Härdle, Chengxiu Ling, February 2018.
011 "How to Measure a Performance of a Collaborative Research Centre" by Alona Zharova, Janine Tellinger-Rice, Wolfgang Karl Härdle, February 2018.
012 "Targeting customers for profit: An ensemble learning framework to support marketing decision making" by Stefan Lessmann, Kristof Coussement, Koen W. De Bock, Johannes Haupt, February 2018.
013 "Improving Crime Count Forecasts Using Twitter and Taxi Data" by Lara Vomfell, Wolfgang Karl Härdle, Stefan Lessmann, February 2018.
014 "Price Discovery on Bitcoin Markets" by Paolo Pagnottoni, Dirk G. Baur, Thomas Dimpfl, March 2018.
015 "Bitcoin is not the New Gold - A Comparison of Volatility, Correlation, and Portfolio Performance" by Tony Klein, Hien Pham Thu, Thomas Walther, March 2018.
016 "Time-varying Limit Order Book Networks" by Wolfgang Karl Härdle, Shi Chen, Chong Liang, Melanie Schienle, April 2018.
017 "Regularization Approach for NetworkModeling of German EnergyMarket" by Shi Chen, Wolfgang Karl Härdle, Brenda López Cabrera, May 2018.
018 "Adaptive Nonparametric Clustering" by Kirill Efimov, Larisa Adamyan, Vladimir Spokoiny, May 2018.
019 "Lasso, knockoff and Gaussian covariates: a comparison" by Laurie Davies, May 2018.

IRTG 1792, Spandauer Straße 1, D-10178 Berlin
http://irtg1792.hu-berlin.de

This research was supported by the Deutsche Forschungsgemeinschaft through the IRTG 1792.

IRTG 1792 Discussion Paper Series 2018

For a complete list of Discussion Papers published, please visit irtg1792.hu-berlin.de.

020 "A Regime Shift Model with Nonparametric Switching Mechanism" by Haiqiang Chen, Yingxing Li, Ming Lin and Yanli Zhu, May 2018.
021 "LASSO-Driven Inference in Time and Space" by Victor Chernozhukov, Wolfgang K. Härdle, Chen Huang, Weining Wang, June 2018.
022 " Learning from Errors: The case of monetary and fiscal policy regimes" by Andreas Tryphonides, June 2018.
023 "Textual Sentiment, Option Characteristics, and Stock Return Predictability" by Cathy Yi-Hsuan Chen, Matthias R. Fengler, Wolfgang Karl Härdle, Yanchu Liu, June 2018.
024 "Bootstrap Confidence Sets For Spectral Projectors Of Sample Covariance" by A. Naumov, V. Spokoiny, V. Ulyanov, June 2018.
025 "Construction of Non-asymptotic Confidence Sets in 2 -Wasserstein Space" by Johannes Ebert, Vladimir Spokoiny, Alexandra Suvorikova, June 2018.
026 "Large ball probabilities, Gaussian comparison and anti-concentration" by Friedrich Götze, Alexey Naumov, Vladimir Spokoiny, Vladimir Ulyanov, June 2018.
027 "Bayesian inference for spectral projectors of covariance matrix" by Igor Silin, Vladimir Spokoiny, June 2018.
028 "Toolbox: Gaussian comparison on Eucledian balls" by Andzhey Koziuk, Vladimir Spokoiny, June 2018.
029 "Pointwise adaptation via stagewise aggregation of local estimates for multiclass classification" by Nikita Puchkin, Vladimir Spokoiny, June 2018.
030 "Gaussian Process Forecast with multidimensional distributional entries" by Francois Bachoc, Alexandra Suvorikova, Jean-Michel Loubes, Vladimir Spokoiny, June 2018.
031 "Instrumental variables regression" by Andzhey Koziuk, Vladimir Spokoiny, June 2018.
032 "Understanding Latent Group Structure of Cryptocurrencies Market: A Dynamic Network Perspective" by Li Guo, Yubo Tao and Wolfgang Karl Härdle, July 2018.
033 "Optimal contracts under competition when uncertainty from adverse selection and moral hazard are present" by Natalie Packham, August 2018.
034 "A factor-model approach for correlation scenarios and correlation stress-testing" by Natalie Packham and Fabian Woebbeking, August 2018.
035 "Correlation Under Stress In Normal Variance Mixture Models" by Michael Kalkbrener and Natalie Packham, August 2018.
036 "Model risk of contingent claims" by Nils Detering and Natalie Packham, August 2018.
037 "Default probabilities and default correlations under stress" by Natalie Packham, Michael Kalkbrener and Ludger Overbeck, August 2018.
038 "Tail-Risk Protection Trading Strategies" by Natalie Packham, Jochen Papenbrock, Peter Schwendner and Fabian Woebbeking, August 2018.

IRTG 1792, Spandauer Straße 1, D-10178 Berlin
http://irtg1792.hu-berlin.de

This research was supported by the Deutsche Forschungsgemeinschaft through the IRTG 1792.

IRTG 1792 Discussion Paper Series 2018

For a complete list of Discussion Papers published, please visit irtg1792.hu-berlin.de.

IRTG 1792, Spandauer Straße 1, D-10178 Berlin
http://irtg1792.hu-berlin.de

This research was supported by the Deutsche Forschungsgemeinschaft through the IRTG 1792.