*JSPS Grants-in-Aid for Creative Scientific Research*

*Understanding Inflation Dynamics of the Japanese Economy*

*Working Paper Series No.48*

# House Prices in Tokyo: A Comparison of Repeat-Sales and Hedonic Measures

Chihiro Shimizu
Kiyohiko G. Nishimura
and
Tsutomu Wanatabe

November 10, 2009

Research Center for Price Dynamics
Institute of Economic Research, Hitotsubashi University
Naka 2-1, Kunitachi-city, Tokyo 186-8603, JAPAN
Tel/Fax: +81-42-580-9138
E-mail: sousei-sec@ier.hit-u.ac.jp
http://www.ier.hit-u.ac.jp/~ifd/

# House Prices in Tokyo: A Comparison of Repeat-Sales and Hedonic Measures

Chihiro Shimizu* Kiyohiko G. Nishimura† Tsutomu Watanabe‡

First Draft: May 21, 2009
This version: November 8, 2009

**Abstract**

Do the indexes of house prices behave differently depending on the estimation methods? If so, to what extent? To address these questions, we use a unique dataset that we have compiled from individual listings in a widely circulated real estate advertisement magazine. The dataset contains more than 400 thousand listings of housing prices in 1986 to 2008, including the period of housing bubble and its burst. We find that there exists a substantial discrepancy in terms of turning points between hedonic and repeat sales indexes, even though the hedonic index is adjusted for structural change and the repeat sales index is adjusted in a way Case and Shiller suggested. Specifically, the repeat sales measure tends to exhibit a delayed turn compared with the hedonic measure; for example, the hedonic measure of condominium prices hit bottom at the beginning of 2002, while the corresponding repeat-sales measure exhibits reversal only in the spring of 2004. Such a discrepancy cannot be fully removed even if we adjust the repeat sales index for depreciation (age effects).

*JEL Classification Number*: C43; C81; R21; R31
*Keywords*: hedonic price index; repeat sales price index; aggregation bias; housing depreciation

*Correspondence: Chihiro Shimizu, International School of Economics and Business Administration, Reitaku University, Kashiwa, Chiba 277-8686, Japan. E-mail: cshimizu@reitaku-u.ac.jp. We would like to thank Erwin Diewert, David Fenwick, Peter von der Lippe, and participants at the 11th Ottawa Group Meeting held in Neuchâtel, Switzerland for helpful comments on a preliminary draft. We also appreciate detailed comments from an anonymous referee. Nishimura's contribution was made mostly before he joined the Policy Board. This research is a part of the project entitled: Understanding Inflation Dynamics of the Japanese Economy, funded by JSPS Grant-in-Aid for Creative Scientific Research (18GS0101).

†Deputy Governor, Bank of Japan.

‡Research Center for Price Dynamics, Hitotsubashi University.

# 1 Introduction

Fluctuations in real estate prices have substantial impacts on economic activities. In Japan, a sharp rise in real estate prices during the latter half of the 1980s and its decline in the early 1990s has led to a decade-long stagnation of the Japanese economy. More recently, a rapid rise in housing prices and its reversal in the United States have triggered a global financial crisis. In such circumstances, the development of appropriate indexes that allow one to capture changes in real estate prices with precision is extremely important not only for policy makers but also for market participants who are looking for the time when housing prices hit bottom.

Research has been conducted intensively on methods of compiling housing price indexes appropriately. The location, history and facilities of each house are different from each other in varying degrees, so there are no two houses that are identical in terms of quality. Even if the location and facilities are the same, the age of the building may differ, in which case the degree of deterioration varies accordingly and the houses are not identical. In other words, houses have particularity with few equivalents.

There are two approaches to construct a housing price index that take into account issues resulting from the aforementioned particularity with few equivalents: the hedonic method and the repeat sales method. In this paper, we compare these two methods for estimating the price indexes of the housing market in Tokyo.

On one hand, previous research has identified two major problems for the repeat sales method: (i) there is sample selection bias because houses that are traded in the market quite often have different characteristics than the typical house (Clapp and Giaccotto 1992); (ii) the assumption of no over time changes in property characteristics is unrealistic (Case and Shiller 1987, 1989; Clapp and Giaccotto 1992, 1998, 1999; Goodman and Thibodeau 1998; Case et al. 1991). On the other hand, the hedonic method is said to suffer from the following problems: (iii) there is an omitted variable bias (Case and Quigley 1991; Clapp 2003, Ekeland et al. 2004); (iv) the assumption of no structural change (i.e., no over time changes in parameters) during the sample period is unrealistic (Case et al. 1991; Clapp et al. 1991; Clapp and Giaccotto 1992, 1998; Shimizu and Nishimura 2006, 2007, Shimizu et al. 2007).

From the theoretical viewpoints, it is almost impossible to measure the true quality-adjusted change in the price of a house because one does not observe the same unit over time without any depreciation or renovation, and thus it is quite difficult to say which of the two measures performs better. However, it is often said that, at least from the practical perspective, the repeat sales method is much easier and less costly to be implemented (e.g., Bourassa et al. 2006). However, as far as the Japanese housing market is concerned, there are some reasons to worry more about the problems associated with the repeated sales method. First, the Japanese housing market is less liquid compared with those in other countries including the U.S., so that a house is less likely to be traded multiple times.[1] Second, the quality of a house changes over time more rapidly in Japan because of the short lifespan of a house and less developed renovation markets (i.e., renovation plays little role in restoring the quality of a house). This implies that a standard repeat sales index will *ceteris paribus* underestimate house price changes in Japan. Taking these two features of the Japanese housing market into consideration, Shimizu et al. (2007) advocates adopting the hedonic method in Japan, and proposes an estimation procedure to allow for over time structural changes and seasonal sample selection bias.

The rest of this paper is organized as follows. Section 2 presents an overview of the two methods. Section 3 describes properties of housing in the dataset. The dataset we use in this paper is compiled from individual listings in a widely circulated real estate advertisement magazine. The dataset contains more than 0.46 million listings of housing prices, from 1986 to 2008, including the period of housing bubble and its burst. Section 4 presents estimation results. We find that repeat sales measures are biased due to the lack of appropriate treatment of depreciation, and that hedonic measures are biased because of over time changes in parameters. More importantly, we find that there exists a substantial discrepancy in terms of turning points between structural-change-adjusted hedonic and Case-Shiller-adjusted repeat sales price indexes. Specifically, the repeat sales measure tends to exhibit a delayed turn compared with the hedonic measure; for example, the hedonic measure of condominium prices hit bottom at the beginning of 2002, while the corresponding repeat-sales measure exhibits reversal only in the spring of 2004. Such a discrepancy cannot be fully removed even if we consider age-effect adjustment to repeat sales indexes. Section 5 concludes the paper.

[1] This is partly because of the presence of legal restrictions regarding reselling within a short period of time, such as "the national land use plan."

## 2 Five Measures of House Prices

### 2.1 Standard hedonic index

Let us begin with a hedonic price index. Suppose that we have the price and property-characteristics data of houses, pooled for all periods $t = 1, 2, \cdots, T$, and that the number of data samples in period $t$ is $n_t$. Then, a standard hedonic price index is produced from the following house-price estimation model:

$$\ln P_{it} = \beta_t^{'} x_{it} + \epsilon_{it} \tag{1}$$

where $P_{it}$ is the price of house $i$ in period $t$, $\beta_t$ is a vector of parameters associated with residential property characteristics, $x_{it}$ is a vector of property characteristic for house $i$ in period $t$, and $\epsilon_{it}$ is an error term, which consists of time dummies and iid disturbance ($\epsilon_{it} \equiv \alpha + \delta_t + v_{it}$ and $v_{it} \sim N(0, \sigma_v^2)$). The standard hedonic price index is then constructed from the time dummies. The coefficient $\beta_t$ is often assumed to be constant over time; in that case, the model is referred to as "restricted hedonic model".

### 2.2 Standard repeat sales index

The standard repeat-sales method starts with the assumption that the residential property characteristics do not change over time and that the parameters associated with the characteristics do not change either. The underlying price determination model is not different from equation (1). However, the repeat sales method focuses on houses that appear multiple times in the data set, or houses transacted repeatedly. Suppose that house $i$ is transacted twice, in period $s$ and period $t$. Then the change in the house price is given by

$$\Delta_{t,s} \ln P_i = (\beta_t^{'} x_{it} - \beta_s^{'} x_{is}) + (\delta_t - \delta_s) + (v_{it} - v_{is}) = (\delta_t - \delta_s) + (v_{it} - v_{is}) \tag{2}$$

indicating that the price change is solely determined by the difference between the two transaction times, irrespective of residential property characteristics. From equation (2) we have:

$$\Delta_{t,s} \ln P_i = D_i^{'} \delta + \nu_{its} \tag{3}$$

where $\nu_{its} \equiv v_{it} - v_{is}$ and $D_i$ is a time dummy variable vector, which takes a value of 1 at the second transaction, -1 at the first transaction, and 0 in the other periods. By estimating (3), we get a repeat sales index as $I^{RS} \equiv \{\exp(0), \exp(\hat{\delta}_2), \cdots, \exp(\hat{\delta}_T)\}$.

## 2.3 Case-Shiller adjustment to repeat sales index

There are two problems in the standard repeat sales method just described. One is heteroscedasticity: error terms are likely to become larger when two transaction dates are further apart. The second is the age effect: a house is not qualitatively the same as time goes by. Such heteroscedasticity in the error term is taken into consideration in the GLS method proposed by Case and Shiller (1987, 1989). Specifically, we start by assuming that:

$$E(\nu_{it} - \nu_{is})^2 = \xi_1(t - s) \tag{4}$$

and then proceed as follows: (i) we estimate equation (3); (ii) we regress the square of the estimated disturbance term on a constant term, $\xi_0$, and the transaction period, $t - s$; (iii) we estimate (3) with GLS, with a weight variable of $[\hat{\xi}_0 + \hat{\xi}_1(t - s)]^{1/2}$. In this way, we get a Case-Shiller-adjusted repeat sales index as $I^{WRS} \equiv \{\exp(0), \exp(\tilde{\delta}_2), \cdots, \exp(\tilde{\delta}_T)\}$.

## 2.4 Age-adjustment to repeat sales index

Let us now turn to the adjustment of the age effect. Most researchers including Bailey et al. (1963) and Case and Shiller (1987, 1989) estimate price indexes under the assumption that housing characteristics do not change over time.[2] However, houses actually deteriorate as time goes by. This means that the utility flow of a house diminishes with time. Thus, it is likely that the quality of a house at the time of selling is lower when the house was bought long time ago than when it was purchased only a few periods ago. The house quality also changes with maintenance expenditure and large-scale renovations. Furthermore, the house quality also changes if there are major changes in the surrounding environment, the convenience of public transport, etc. In research related to estimating housing price indexes, these problems are known as aggregation bias. Notably, with respect to the repeat-sales method, Diewert (2007) pointed out a "depreciation problem" based on the number of years since construction and a "renovation problem" based on renovations and so forth. In Japan, since the renovation market is not well developed, the renovation problem is considered to have

[2]It should be noted that an adjustment to cope with the age effect is conducted in constructing the official S&P/Case-Shiller home price index. Standard & Poor's (2008) states that "Sales pairs are also weighted based on the time interval between the first and second sales. If a sales pair interval is longer, then it is more likely that a house may have experienced physical changes. Sales pairs with longer intervals are, therefore, given less weight than sales pairs with shorter intervals." (page 7)

only minor impact; however, since the number of years for which houses in the market is remarkably short, the depreciation problem is potentially significant.

To take account of the age effect, we assume that the housing attributes vector $x$ can be decomposed into two parts: the attributes that changes over time (like the age of a house), which are referred to as "capital goods" and denoted by $k$, and the attributes that are time invariant, which are denoted by $z$. If the capital goods depreciate exponentially, then the change in the log of capital goods from period $s$ to period $t$ is given by $\ln k_t - \ln k_s = c(t-s)$, where $c$ represents the rate of depreciation . In this case, the repeat sales regression model is $\Delta_{t,s} \ln P_i = \theta(t-s) + (\delta_t - \delta_s) + \nu_{its}$, where the first term on the right hand side represents the contribution of the change in the time-variant attributes. The presence of this term implies that, if one estimates the repeat sales index without considering the age effect, the estimated time effect would have a downward bias.

One may want to estimate $\theta$ and $\delta$ simultaneously, but one cannot do that because of the presence of multicollinearity. A number of methods have been proposed to overcome this problem. In this paper we basically follow the method proposed by McMillen (2003), but instead of assuming that capital goods depreciate exponentially, we assume that they depreciate as follows:

$$\ln k_t - \ln k_s = c[(\tau + t - s)^\lambda - \tau^\lambda] \tag{5}$$

where $\tau$ represents the age of a house in period $s$, and $\lambda$ is a positive parameter. Note that equation (5) reduces to $\ln k_t - \ln k_s = c(t-s)$ if $\lambda$ is equal to unity, and $\ln k_t - \ln k_s$ depends only on the interval between $t$ and $s$. Otherwise, however, $\ln k_t - \ln k_s$ depends on the age $\tau$ as well as on the interval between $t$ and $s$. Given this specification about the way capital goods depreciate, the change in the house price between $t$ and $s$ can be expressed as:

$$\Delta_{t,s} \ln P_i = \theta[(\tau_i + t - s)^\lambda - \tau_i^\lambda] - (\delta_t - \delta_s) + \nu_{its} \tag{6}$$

The first and second terms on the right hand side are not linearly correlated unless $\lambda$ is equal to unity, so that we can discriminate between these two terms. We run nonlinear least square regressions to estimate $\theta$, $\lambda$, and the parameters associated with the time dummies.

## 2.5 Structural-change adjustment to hedonic index

Finally, we modify the standard hedonic model, given by equation (1), so that we allow for over time changes in the parameters associated with attributes of a house.

Structural changes in the Japanese housing market have two important features. First, they usually occur only gradually, with a few exception triggered by changes in regulations by the central and local governments. Such gradual changes are quite different from "regime changes" discussed by econometricians such as Bai and Perron (1998), in which structural parameters exhibit a discontinuous shift at multiple times. Second, changes in parameters reflect structural changes not only at the low frequency but also at the high frequency. Specifically, as found by Shimizu et al. (2007), changes in parameters at the high frequency are associated with seasonal changes in activities at the housing market. For example, the number of transactions is high at the end of a fiscal year, namely, between January and March, when people move from one place to another because of seasonal reasons such as job transfer, while the number is low during the summer.

One way to allow for gradual shifts in parameters is to employ an adjacent-periods regression, in which equation (1) is estimated using only two periods that are adjacent to each other, thereby minimizing the disadvantage of pooled regressions. For example, Triplett (2004) argue that the adjacent-period estimator is "a more benign constraint on the hedonic coefficients" based on the presumption that coefficients usually change less between two adjacent periods than over more extended intervals. However, as far as seasonal changes in parameters are concerned, this presumption may not be necessarily satisfied, so that adjacent-period regression may not work very well. To cope with this problem, Shimizu et al. (2007) propose a regression method using multiple "neighborhood periods", typically 12 or 24 months, rather than two adjacent periods. Specifically, they estimate parameters on the basis of a process of successive changes by taking a certain length as the estimation window, by shifting this period in a way of rolling regressions, in essence similar to moving averages. This method could be able to handle seasonal changes in parameters better than adjacent-periods regressions, although it might suffer more in terms of the disadvantage due to pooling.

Specifically, we start by replacing equation (1) by

$$\ln P_{it} = \beta' x_{it} + \epsilon_{it} \qquad \text{for} \quad t = 1, \ldots, \psi \tag{7}$$

where $\psi$ represents the window width. Then we repeatedly estimate this for the period $[2, \psi + 1], [3, \psi + 2], \cdots, [T - \psi + 1, T]$. This model is referred to as the overlapping-period hedonic housing model (OPHM). Note that this reduces to adjacent-periods regression for $\psi = 2$. Each of the regressions with the window of $\psi$ provides estimates of the parameters associated with the time dummies.

# 3 Data

## 3.1 Outline

We collect housing prices from a weekly magazine, *Shukan Jutaku Joho* (Residential Information Weekly) published by Recruit Co., Ltd., one of the largest vendors of residential lettings information in Japan. The Recruit dataset covers the 23 special wards of Tokyo for the period 1986 to 2008, including the bubble period in the late 1980s and its collapse in the early 90s. It contains 157,627 listings for condominiums and 315,791 listings for single family houses, and 473,418 listings in total.[3] *Shukan Jutaku Joho* provides time-series of housing prices from the week when it is first posted until the week it is removed because of successful transaction.[4] We only use the price in the final week because this can be safely regarded as sufficiently close to the contract price.[5]

## 3.2 Variables

Table 1 shows a list of the attributes of a house. This includes ground area ($GA$), floor space ($FS$), and front road width ($RW$) as key attributes of a house. The age of a house is defined as the number of months between the date of the construction of the house and the transaction. We define south-facing dummy, $SD$, to indicate whether the house's windows are south-facing or not (note that Japanese are particularly fond of sunshine). Private-road dummy, $PD$, indicates whether a house has an adjacent private road or not. Land-only dummy, $LD$, indicates whether a transaction is only for land without a building or not. The convenience of public transportation from each house location is represented by travel time to the central business district (CBD),[6] which is

[3]Shimizu et al. (2004) report that the Recruit data cover more than 95 percent of the entire transactions in the 23 special wards of Tokyo. On the other hand, its coverage for suburban areas is very limited. We use only information for the units located in the special wards of Tokyo.

[4]There are two reasons for the listing of a unit being removed from the magazine: a successful deal or a withdrawal (i.e. the seller gives up looking for a buyer and thus withdraws the listing). We were allowed access information regarding which the two reasons applied for individual cases and discarded those where the seller withdrew the listing.

[5]Recruit Co., Ltd. provided us with information on contract prices for about 24 percent of the entire listings. Using this information, we were able to confirm that prices in the final week were almost always identical with the contract prices (i.e., they differed at a probability of less than 0.1 percent).

[6]Travel time to the CBD is measured as follows. The metropolitan area of Tokyo is composed of 23 wards centering on the Tokyo Station area and containing a dense railway network. Within this area, we choose seven railway/subway stations as the central stations, which include Tokyo, Shinagawa, Shibuya, Shinjuku, Ikebukuro, Ueno, and Otemachi. Then, we define travel time to the CBD by the minutes needed to commute to the nearest of the seven stations in the daytime.

denoted by $TT$) and time to the nearest station,[7] which is denoted by $TS$. We use a ward dummy, $WD$, to indicate differences in the quality of public services available in each district, and a railway line dummy, $RD$, to indicate along which railway/subway line a house is located.

### 3.3 Hedonic sample versus repeat sales sample

Table 2 compares the sample used in hedonic regressions and the sample used in repeat sales regressions. Since repeat sales regressions use only observations from houses that are traded multiple times, the repeat sales sample is a subset of the hedonic sample. The ratio of the repeat sales sample to the hedonic sample is 42.7 percent for condominiums, and 6.1 percent for single family houses, indicating that single family houses are less likely to appear multiple times in the market.

The average price for condominiums is 38 million yen in the hedonic sample, while it is 44 million yen in the repeat sales sample. On the other hand, the average price for single family houses is 79 million yen in the hedonic sample and 76 million yen in the repeat sales sample. Turning to the attributes of a house, houses in the repeat sales sample tend to be larger in terms of the floor space, and more conveniently located in terms of time to a nearest station and travel time to the central business district, although these differences are not statistically significant. An important and statistically significant difference between the two samples is the average age of houses for single family houses; namely, the repeat sales sample consists of houses that are constructed relatively recently. Somewhat interestingly, single family houses in the repeat sales sample are larger in the floor space, more conveniently located, more recently constructed, but they are less expensive.

## 4 Estimation Results

### 4.1 Age effects

Table 3 presents regression results for a standard hedonic model described in equation (1). The model fits well both for condominiums and single family houses: the adjusted R-square is 0.876 for condominiums and 0.861 for single-family houses. The coefficient

[7] The time to the nearest station, $TS$, is defined as walking time to a nearest station if a house is located within the walking distance from a station, and the sum of walking time to a bus stop and onboard time from the bus stop to a nearest station if a house is located in a bus transportation area. within the walking distance from a station. We use a bus dummy, $BD$, to indicate whether a house is located in a walking distance area from a station or in a bus transportation area.

of our interest is the one on the age of a house. It is -0.186 for condominiums, implying that they depreciate by 18.6 percent per year. On the other hand, the corresponding coefficient for single family houses is -.011, implying that single family houses depreciate only by 1.1 percent per year.

These results suggest that the standard repeat sales measures, which do not care about depreciation, contain larger downward biases for condominiums, as compared with single family houses. To see this, we estimate age-adjusted repeat sales measures following the method described in section 2.4. Specifically, we estimate equation (6) by maximum likelihood method to obtain $\theta$ and $\lambda$. Table 4 presents regression results. We see at the top panel that the estimates of $\theta$ are negative as predicted (i.e. older houses are less expensive) and significantly different from zero both for condominiums and single family houses. More importantly, the estimate of $\lambda$ is 0.8944 for condominiums and 1.1041 for single family houses, indicating that both are close to but significantly different from unity, therefore the age terms and the time dummies are successfully identified. The estimated coefficients of $\theta$ and $\lambda$ imply that condominiums depreciate by 9.0 percent during a year starting from the age of zero (i.e. newly constructed condominiums), and by 6.4 percent during a year starting from the age of ten years old. Note that the estimated rate of depreciation is no longer independent of the age of a house, unlike the case in the hedonic regressions shown in Table 3. The corresponding figures for single family houses are 2.9 percent per year at the age of zero and 4.0 percent per year at the age of ten years old, showing again that single family houses depreciates less than condominiums. Turning to the bottom panel of Table 4, we look at regression performance of three types of repeat-sales measures: the standard repeat-sales index; the heteroscedasticity-adjusted repeat-sales index (i.e., the Case-Shiller index), and the age-adjusted repeat-sales index. We see that the age-adjusted repeat-sales measures performs better than the other two measures, both for condominiums and single family houses, although we fail to find a significant improvement in regression performance.

Finally, we compare the three repeat-sales measures estimated for condominiums in Figure 1. The standard repeat-sales index and the heteroscedasticity-adjusted repeat-sales index starts in the first quarter of 1986, while the age adjusted repeat-sales index starts in the fourth quarter of 1989. To make comparison easier, the three indexes are normalized so that they are all equal to unity in the fourth quarter of 1989. The first thing we can see from this figure is that there is almost no difference between the standard repeat-sales index and the heteroscedasticity-adjusted repeat-sales index.

This suggests that heteroscedasticity due to heterogeneous transaction intervals may not be so important as far as the Japanese housing market is concerned. Second, the age-adjusted repeat-sales index behaves differently from the other two indexes. Specifically, it exhibits a less rapid decline in the 1990s, i.e. the period of bubble bursting. This difference reflects the relative importance of the age effect, implying that the other two repeat-sales indexes, which pay no attention to the age effect, tend to overestimate the magnitude of bubble bursting.

### 4.2 Structural-change adjustment to the standard hedonic measure

To eliminate a measurement error due to the shifts in the parameters in the standard hedonic model, given by equation (1), we estimate equation (7), which allows gradual shifts in the parameters. Specifically, we set the width of rolling regression by $\psi = 12$ (i.e., 12-months rolling regression) and estimate (7). The result is presented in Table 5, which compares key parameters between the standard hedonic model and the rolling hedonic model. For condominiums, we see that the average value of each parameter estimated by the rolling hedonic regression is close to the estimate obtained by the standard hedonic regression. For example, the parameter associated with the age of a house is -0.186 by the standard hedonic regression, while the average value of the corresponding parameters estimated by the rolling regression is -0.182. More importantly, we find that the estimated parameters fluctuate much during the sample period. For example, the parameter associated with the age of a house fluctuates between -0.108 and -0.237, indicating that non-negligible structural changes occur during the sample period. We see the same regularities for single family houses.

### 4.3 How much can the difference be reconciled?

As we stated in section 1, the standard hedonic measure may be biased either because of omitted variables or because of shifts in structural parameters. We have solved the latter problem, at least partially, by allowing the parameters of a hedonic regression to change over time. On the other hand, the standard repeat sales measure faces the problem of non-random sampling and the problem of changes in the attributes of a house, such as its aging. We have removed a part of the latter problem by making an age adjustment to repeat-sales measures. We now proceed to ask how much the difference between the hedonic and repeat-sales measures has been reconciled through these adjustments. To do so, we will investigate whether the five indexes we have estimated are close to each other by looking at contemporaneous and dynamic relationship between them.

### 4.3.1 Contemporaneous correlation between the five indexes

As a first step, we compare the five indexes for condominiums in terms of the quarterly growth rates. The results are presented in Figure 2. The horizontal axis in the upper left panel represents the growth rate of the standard repeat-sales index, while the vertical axis represents the growth rate of the Case-Shiller type repeat-sales index. One can clearly see that almost all dots in this panel are exactly on the 45 degree line, implying that these two indexes are closely correlated with each other. In fact, the coefficient of correlation is 0.990 at the quarterly frequency, and 0.953 at the monthly frequency. If we regress the quarterly growth rate of the Case-Shiller repeat-sales index, denoted by $y$, on that of the standard repeat-sales index, denoted by $x$, we get $y = 0.9439x - 0.0002$, indicating that the coefficient on $x$ and the constant term are very close to unity and zero, respectively. Similarly, the lower left panel compares the growth rate of the standard repeat-sales index and the age-adjusted repeat-sales index. Again, almost all dots are on the 45 degree line, indicating a high correlation between the two indexes (the coefficient of correlation is 0.989 at the quarterly frequency and 0.953 at the monthly frequency). The two panels suggest that these two adjustments to the standard repeat-sales index are of little quantitative importance, as far as the Japanese housing data is concerned.

Turning to the upper right panel, which compares the standard hedonic index and the standard repeat-sales index, dots are again scattered along the 45 degree line but not exactly on it, indicating a lower correlation than before (0.957 at the quarterly frequency and 0.584 at the monthly frequency). Finally, the lower right panel compares the standard repeat-sales index and the rolling hedonic index, showing that the two indexes are correlated even more weakly (0.910 at the quarterly frequency and 0.513 at the monthly frequency). These two panels suggest that the role of rolling regression in eliminating the discrepancy between the hedonic and the repeat-sales indexes may not be so large.

To examine contemporaneous relationship in a different way, we regress the quarterly growth rate of one of the five indexes, say index A, on the quarterly growth rate of the other index, say index B, to obtain a simple linear relationship $y = a + bx$. Then we conduct a F-test against the null hypothesis that $a = 0$ and $b = 1$. The results of this exercise are presented in Table 6, in which the number in each cell represents the p-value associated with the null hypothesis that $a = 0$ and $b = 1$ in a regression in which the index on the corresponding row is a dependent variable while the index on the corresponding column is an independent variable. For example, the number at the lower left corner of the upper panel, 0.0234, indicates the p-value associated with the null hypothesis in a regression in which the growth rate of the rolling hedonic index is a dependent variable and the growth rate of the standard repeat-sales index is an independent variable. The upper panel, which presents the results for condominiums, shows that the null hypothesis cannot be rejected in almost all cases.[8] Somewhat interestingly, the null hypothesis cannot be rejected even when the standard repeat-sales index is regressed on the standard hedonic index or when the standard hedonic index is regressed on the standard repeat-sales index, implying that hedonic and repeat-sales measures are close to each other even before any adjustment is made to each of the two measures.[9]

#### 4.3.2 Dynamic relationship between the five indexes

The presence of a close contemporaneous correlation in terms of quarterly growth rates between the five indexes does not immediately imply that the five indexes perfectly move together. It is still possible that there exist some lead-lag relationships between the five indexes; for example, an index may tend to precede the other four indexes. To investigate such dynamic relationships between the five indexes, we conduct pairwise Granger causality tests. The results for condominiums and single family houses are presented, respectively, in the upper and lower panels of Table 7. The number in each cell represents the p-value associated with the null hypothesis that the index on the row does not Granger-cause the index on the column. For example, the number in the cell of the third row and the second column, 0.2018, represents the p-value associated with the null hypothesis that the Case-Shiller type repeat-sales index does not cause the standard repeat-sales index. The panel for condominiums shows that one can easily reject the null that the standard hedonic index does not cause the other four indexes. On the other hand, one cannot reject the null that each of the other four indexes does not cause the standard hedonic index. These two results indicate that fluctuations in

[8]There are two cases in which the p-value exceeds 10 percent: when the standard hedonic index is regressed on the age-adjusted repeat-sales index (p-value=0.2151); when the rolling hedonic index is regressed on the standard hedonic index (p-value=0.1013).

[9]Turning to the lower panel of Table 6, which presents the results for single family houses, we see that there are more cases in which the null hypothesis is rejected. For example, the p-value is very high at 0.7605 when the standard hedonic index is regressed on the standard repeat-sales index, so that we can no longer say that hedonic and repeat-sales measures are close to each other even without any adjustment. However, we still can reject the null if we make an age-adjustment to repeat-sales measures, and allow for structural shifts in parameters to hedonic measure.

the standard hedonic index tend to precede those in the other four indexes. The same property is observed for single family houses.

To illustrate such lead-lag relationships between the five indexes, we compare them in terms of the timing in which each index hit bottom after the bursting of the housing bubble in the early 1990s. The result for condominiums is presented in Figure 3. We see that all of the three repeat-sales indexes hit bottom simultaneously on the first quarter of 2004. In contrast, the two hedonic indexes hit bottom on the first quarter of 2002, indicating that a turn in the hedonic indexes preceded the one in the repeat-sales indexes by two years.

An important issue we need to address is where such lead-lag relationships between the hedonic and repeat-sales indexes come from. There are at least two possibilities. First, the presence of the lead-lag relationships may be related to the omitted variable problem in hedonic regressions. It is possible that the variables omitted in hedonic regressions move only with some lags relative to the other variables, leading to a delayed response of the estimated hedonic indexes to various shocks. The second possibility is related to sample selection bias in the estimated repeat-sales indexes. As we have seen in Table 2, the fraction of the sample employed in producing the repeat-sales indexes is very limited, and more importantly, it might be biased in the sense that the employed sample consists of houses whose prices exhibit a delayed response to various shocks.

How can we discriminate between these two possibilities? One way to identify a factor behind the relationships is to apply hedonic regression to the repeat-sales sample (i.e. the sample consisting of houses that are traded multiple times). The new hedonic index produced in this way differs from the standard one in terms of the employed sample, while they are identical in terms of the list of explanatory variables in hedonic regression, so that they commonly suffer from the problem of omitted variables. Therefore, any remaining difference between the new and standard hedonic indexes can be regarded as stemming from the difference in employed samples. If we still observe a lead-lag relationship between the new and standard hedonic indexes, it implies that the relationship comes from the sample selection bias in repeat-sales indexes.

Figure 4 presents the result of this exercise. We apply hedonic regression to four different samples: the sample of houses that were traded once or more (i.e. the entire sample); the sample of houses that were traded more than once (i.e. the original repeat-sales sample); the sample of houses that were traded more than twice; the sample of houses that were traded more than three times. We see that the index estimated using the sample of houses that were traded more than once exhibits a delayed turn compared with the one estimated from the sample of houses that were traded more than once, suggesting that the lead-lag relationships between the hedonic and repeat-sales indexes in Figure 3 mainly come from sample selection bias in repeat-sales indexes. It is consistent with this finding that the indexes estimated using either the sample of houses traded more than twice or the sample of houses traded more than three times exhibit even longer delay at their turning points.

## 5 Conclusion

Do the indexes of house prices behave differently depending on the estimation methods? If so, to what extent? To address these questions, we have estimated five house price indexes, consisting of two kinds of hedonic indexes and three kinds of repeat-sales indexes, using a unique dataset that we have compiled from individual listings in a widely circulated real estate advertisement magazine.

We have found no significant difference between the five indexes in terms of *contemporaneous* correlation. In fact, we have found that the five indexes are almost identical in terms of quarterly growth rates. However, we have found significant difference between the five indexes in terms of *dynamic* relationship. Specifically, we have found that there exists a substantial discrepancy in terms of turning points between hedonic and repeat sales indexes, even though the hedonic index is adjusted for structural change and the repeat sales index is adjusted in a way Case and Shiller suggested. The repeat sales measure tends to exhibit a delayed turn compared with the hedonic measure; for example, the hedonic measure of condominium prices hit bottom at the beginning of 2002, while the corresponding repeat-sales measure exhibits reversal only in the spring of 2004. Such a discrepancy cannot be fully removed even if we adjust the repeat sales index for depreciation (age effects). We provide empirical evidence suggesting that such difference between the hedonic and repeat-sales indexes mainly come from non-randomness in repeat-sales sample.

## References

[1] Bai, J., and P. Perron (1998), "Estimating and testing linear models with multiple structural changes," Econometrica **66**, 47-78.

[2] Bailey, M.J., R.F. Muth, and H.O. Nourse (1963), "A Regression Model for Real Estate Price Index Construction," Journal of the American Statistical Association **58**, 933-942.

[3] Bourassa, S.T, Martin Hoesli and Jian Sun (2006), "A Simple adternative house price index method," Journal of Housing Economics **15**, 80-97.

[4] Case, B., H.O. Pollakowski, and S.M. Wachter (1991), "On Choosing among House Price Index Methodologies," AREUEA Journal **19**, 286-307.

[5] Case, B., and J.M. Quigley (1991), "The Dynamics of Real Estate Prices," Review of Economics and Statistics **22**, 50-58.

[6] Case, K.E., and R.J. Shiller (1987), "Prices of Single Family Homes since 1970: New Indexes for Four Cities," New England Economic Review Sept./Oct., 45-56.

[7] Case, K.E., and R.J. Shiller (1989), "The Efficiency of the Market for Single Family Homes," The American Economic Review **79**, 125-137.

[8] Clapp, J.M., and C. Giaccotto (1992), "Estimating Price Trends for Residential Property: A Comparison of Repeat Sales and Assessed Value Methods," Journal of Real Estate Finance and Economics **5**, 357-374.

[9] Clapp, J.M., and C. Giaccotto (1998), "Price indexes Based on the Hedonic Repeat-Sales Method: Application to the Housing Market," Journal of Real Estate Finance and Economics **16**, 5-26.

[10] Diewert, W. E. (2007), "The Paris OECD-IMF Workshop on Real Estate Price Indexes: Conclusions and Future Directions," The University of British Columbia, Department of Economics, Discussion Paper 07-01.

[11] Ekeland, I., J.J. Heckman, and L. Nesheim (2004), "Identification and Estimation of Hedonic Models," Journal of Political Economy **112**, 60-109.

[12] Goodman, A.C. and T.G.Thibodeau (1998), "Dwelling Age Heteroskedasticity in Repeat Sales House Price Equations," Real Estate Economics **26**, 151-171.

[13] McMillen, D.P. (2003), "The Return of Centralization to Chicago: Using Repeat Sales to Identify Changes in House Price Distance Gradients," Regional Science and Urban Economics **33**, 287-304.

[14] Shimizu, C., K. G. Nishimura, and Y. Asami (2004), "Search and Vacancy Costs in the Tokyo Housing Market: An Attempt to Measure Social Costs of Imperfect Information," Review of Urban and Regional Development Studies **16**, 210-230.

[15] Shimizu, C., and K.G. Nishimura (2006), "Biases in Appraisal Land Price Information: The Case of Japan," Journal of Property Investment and Finance **26**, 150-175.

[16] Shimizu, C., and K.G. Nishimura (2007), "Pricing Structure in Tokyo Metropolitan Land Markets and Its Structural Changes: Pre-Bubble, Bubble, and Post-Bubble Periods," Journal of Real Estate Finance and Economics **35**, 475-496.

[17] Shimizu, C., H. Takatsuji, H. Ono, and K.G. Nishimura (2007), "Change in House Price Structure with Time and Housing Price Index," RIPESS (Reitaku Institute of Political Economics and Social Studies) Working Paper, No.25. Available at http://ripess.reitaku-u.ac.jp/report/doc/ 2009020715164991_0.pdf

[18] Standard & Poor's (2008), S&P/Case-Shiller Home Price indexes: Index Methodology, March 2008. Available at http://www2.standardandpoors.com/spf/pdf/ index/ SP_CS_Home_Price_indexes_Methodology_Web.pdf

[19] Triplett, Jack (2004), Handbook on Hedonic Indexes and Quality Adjustments in Price Indexes, OECD Science, Technology and Industry Working Papers 2004/9.

## Table 1: List of variables

| Symbol | Variable | Contents | Unit |
|---|---|---|---|
| *GA* | Ground area / square meters | Ground area | $m^2$ |
| *FS* | Floor space / square meters | Floor space | $m^2$ |
| *RW* | Front road width | Front road width | 10cm |
| *Age* | Number of years since construction | Period between the date when the data are deleted from the magazine and the date of construction of the building | months |
| *TS* | Time to nearest station | Time to nearest station (by foot or bus) | minutes |
| *TT* | Travel time to central business district | Minimum day-time train travel time to nearest of 7 terminal stations in 2000 | minutes |
| *BD* | Bus dummy | The time includes bus travel time 1, | (0,1) |
| | | does not include bus travel time 0. | |
| *FD* | First floor dummy | The property is on the ground floor 1, | (0,1) |
| | | on another floor 0. | |
| *SD* | South-facing dummy | Windows facing south 1, | (0,1) |
| | | Facing other directions 0. | |
| *LDk* (*k*=0,…,*K*) | Location (ward) dummy | *k*- th administrative district 1, | (0,1) |
| | | other district 0. | |
| *TDm* (*m*=0,…,*M*) | Time dummy (monthly) | *m*- th month 1, | (0,1) |
| | | other month 0. | |

# Table 2: Hedonic vs. repeat-sales samples

| Variables | Condominium | | Single family house | |
|---|---|---|---|---|
| | Hedonic sample | Repeat-sales sample | Hedonic sample | Repeat-sales sample |
| Average price (10,000 yen) | 3,862.26<br>(3,190.83) | 4,463.43<br>(4284.10) | 7,950.65<br>(8275.04) | 7,635.24<br>(7055.96) |
| *FS* : Floor space (m²) | 58.31<br>(21.47) | 59.54<br>(24.09) | 102.53<br>(43.47) | 105.82<br>(45.60) |
| *GA* : Ground Area (m²) | -<br>- | -<br>- | 108.20<br>(71.19) | 101.41<br>(63.17) |
| *Age* :Age of Building(months) | 166.82<br>(101.17) | 180.20<br>(101.35) | 162.19<br>(102.66) | 63.79<br>(99.39) |
| *TS* : Time to the nearest station: (minutes) | 7.96<br>(4.43) | 7.77<br>(4.28) | 9.85<br>(4.54) | 9.60<br>(4.37) |
| *TT* : Travel Time to Central Business District (minutes) | 12.58<br>(7.09) | 10.73<br>(6.88) | 13.23<br>(6.34) | 11.89<br>(6.18) |
| | n=157,627 | n=67,436 | n=315,791 | n=19,428 |

**Table 3: Standard hedonic regressions**

| Variables | Condominium | | Single family house | |
|---|---|---|---|---|
| | coefficient | t-value | coefficient | t-value |
| Constant | 4.623 | 413.320 | 5.083 | 365.180 |
| *FS* : Floor space ($m^2$) | 1.031 | 870.240 | 0.068 | 282.610 |
| *GA* : Ground Area ($m^2$) | - | - | 0.819 | 931.250 |
| *Age* :Age of Building(months) | -0.145 | -223.970 | -0.039 | -157.230 |
| *TS* : Time to the nearest station: (minutes) | -0.047 | -61.410 | -0.126 | -139.630 |
| *Bus:Bus Dummy* | -0.152 | -7.060 | -0.056 | -54.160 |
| $Bus \times TS$ | 0.008 | 0.980 | -0.056 | -54.160 |
| *TT* : Travel Time to Central Business District (minutes) | -0.072 | -90.970 | -0.080 | -87.550 |
| *Top:Top of Building* | 0.022 | 5.390 | - | - |
| *BeforeConstruction Standard* | -0.090 | -80.770 | - | - |
| *Steel Dummy* | 0.010 | 10.650 | - | - |
| *Balcony Area* | 0.022 | 32.950 | - | - |
| *Road Width* | - | - | 0.207 | 154.500 |
| *Private Road* | - | - | -0.003 | -9.840 |
| *Land only Dummy* | - | - | 0.039 | 6.440 |
| *Old house* | - | - | -0.086 | -36.020 |
| *New Construction* | - | - | -0.121 | -69.330 |
| | n=157,627 | | n=315,791 | |
| Adjusted R-square= | 0.876 | | 0.861 | |

Note: Dependent variable is the log of price.

## Table 4: Age-adjusted repeat-sales measures

| | θ | λ |
|---|---|---|
| Condominium | | |
| coef. | -0.0098 | 0.8944 |
| s.e. | 0.0004 | 0.0113 |
| p-value | [.000] | [.000] |
| Single family house | | |
| coef. | -0.0019 | 1.1041 |
| s.e. | 0.0002 | 0.0269 |
| p-value | [.000] | [.000] |

| | standard error of reg. | adjusted R-square | S.B.I.C |
|---|---|---|---|
| Condominium | | | |
| Standard repeat-sales | 0.175 | 0.751 | -20311.0 |
| Case-Shiller repeat-sales | 0.191 | 0.760 | -12925.4 |
| Age-adjusted repeat-sales | 0.190 | 0.761 | -13246.6 |
| Single family house | | | |
| Standard repeat-sales | 0.211 | 0.478 | -2087.0 |
| Case-Shiller repeat-sales | 0.218 | 0.511 | -1136.1 |
| Age-adjusted repeat-sales | 0.218 | 0.513 | -1176.4 |

**Table 5: Standard vs. rolling hedonic regressions**

| | Constant | $FS$ : Floor space | $Age$ :Age of Building | $TS$ : Time to the nearest station: | $TT$ : Travel Time to Central Business District |
|---|---|---|---|---|---|
| Condominium | | | | | |
| Standard hedonic regression | 4.470 | 0.029 | -0.186 | -0.069 | -0.068 |
| 12-months rolling regression | | | | | |
| Average | 4.852 | 0.047 | -0.182 | -0.072 | -0.072 |
| Standard deviation | 0.629 | 0.078 | 0.029 | 0.010 | 0.031 |
| Min | 4.193 | -0.124 | -0.237 | -0.098 | -0.130 |
| Max | 6.171 | 0.133 | -0.108 | -0.050 | -0.022 |
| Single family house | | | | | |
| Standard hedonic regression | 4.615 | 0.002 | -0.011 | -0.013 | -0.009 |
| 12-months rolling regression | | | | | |
| Average | 4.912 | 0.002 | -0.012 | -0.013 | -0.009 |
| Standard deviation | 0.261 | 0.001 | 0.001 | 0.002 | 0.002 |
| Min | 4.596 | 0.001 | -0.015 | -0.019 | -0.012 |
| Max | 5.425 | 0.003 | -0.009 | -0.009 | -0.004 |

Table 6: Contemporaneous relationship between the five measures

**Condominium**

| | Standard repeat-sales | Case-Shiller repeat-sales | Age-adjusted repeat-sales | Standard hedonic | Rolling hedonic |
|---|---|---|---|---|---|
| Standard RS | | 0.0015 | 0.0001 | 0.0001 | 0.0001 |
| Case-Shiller RS | 0.0001 | | 0.0001 | 0.0001 | 0.0001 |
| Age-adjusted RS | 0.0001 | 0.0001 | | 0.0262 | 0.0068 |
| Standard hedonic | 0.0106 | 0.0029 | 0.2151 | | 0.0057 |
| Rolling hedonic | 0.0234 | 0.0412 | 0.0001 | 0.1013 | |

**Single family house**

| | Standard repeat-sales | Case-Shiller repeat-sales | Age-adjusted repeat-sales | Standard hedonic | Rolling hedonic |
|---|---|---|---|---|---|
| Standard RS | | 0.8740 | 0.0104 | 0.0001 | 0.1595 |
| Case-Shiller RS | 0.6461 | | 0.0001 | 0.0010 | 0.1522 |
| Age-adjusted RS | 0.0369 | 0.0001 | | 0.0088 | 0.2864 |
| Standard hedonic | 0.7605 | 0.8689 | 0.0005 | | 0.7229 |
| Rolling hedonic | 0.0002 | 0.0001 | 0.0001 | 0.001 | |

Note: We regress the quarterly growth rate of index A, $y$, on the quarterly growth rate of index B, $x$, to obtain a simple linear relationship $y = a + bx$. The number in each cell represents the p-value associated with the null hypothesis that $a = 0$ and $b = 1$ in a regression in which the index on the row is a dependent variable and the index on the column is an independent variable.

Table 7: Pairwise Granger-causality tests

**Condominium**

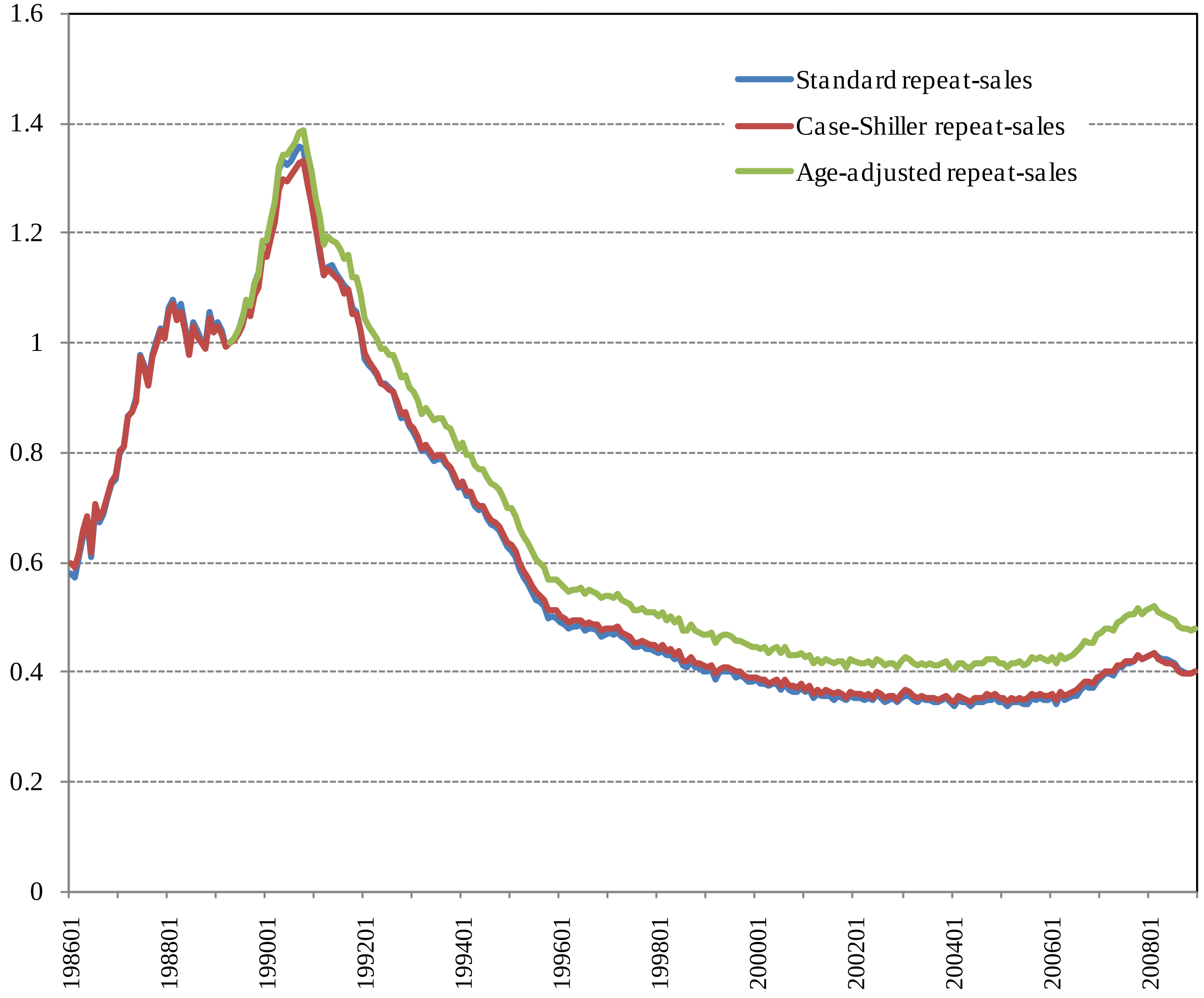
| | Standard repeat-sales | Case-Shiller repeat-sales | Age-adjusted repeat-sales | Standard hedonic | Rolling hedonic |
|---|---|---|---|---|---|
| Standard RS | | 0.0120 | 0.0019 | 0.0037 | 0.0000 |
| Case-Shiller RS | 0.2018 | | n.a. | 0.0411 | 0.0000 |
| Age-adjusted RS | 0.0568 | n.a. | | 0.1067 | 0.0000 |
| Standard hedonic | 0.0005 | 0.0001 | 0.0000 | | 0.0000 |
| Rolling hedonic | 0.0067 | 0.0095 | 0.0025 | 0.2209 | |

**Single family house**

| | Standard repeat-sales | Case-Shiller repeat-sales | Age-adjusted repeat-sales | Standard hedonic | Rolling hedonic |
|---|---|---|---|---|---|
| Standard RS | | 0.2726 | 0.4345 | 0.2119 | 0.0040 |
| Case-Shiller RS | 0.2397 | | n.a. | 0.1714 | 0.0098 |
| Age-adjusted RS | 0.3275 | n.a. | | 0.1622 | 0.0078 |
| Standard hedonic | 0.0028 | 0.0025 | 0.0023 | | 0.0018 |
| Rolling hedonic | 0.0705 | 0.0642 | 0.0709 | 0.1642 | |

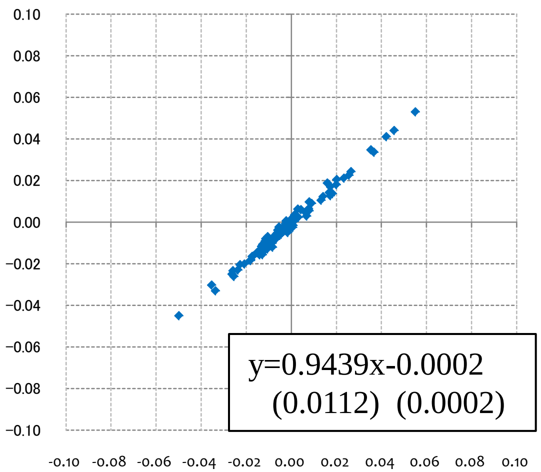
Note: The number in each cell represents the p-value associated with the null hypothesis that the variable on the row does not Granger-cause the variable on the column.

# Figure 1: Repeat-sales measures

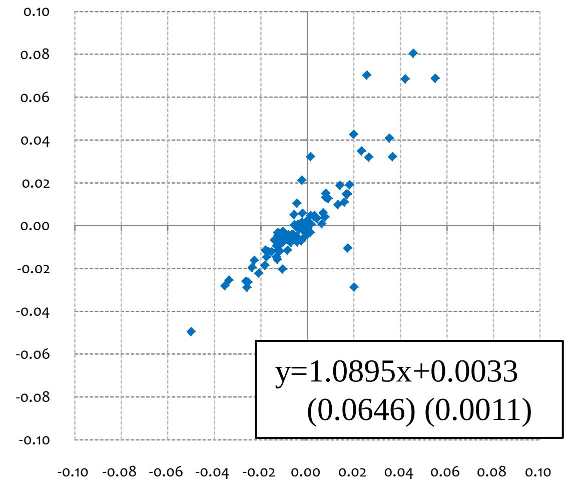


# Figure 2: Comparison of the five indexes in terms of the quarterly growth rate

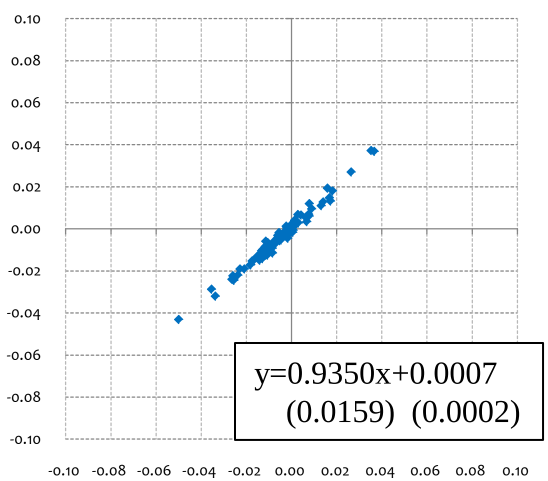
**Case-Shiller vs. Standard repeat sales**



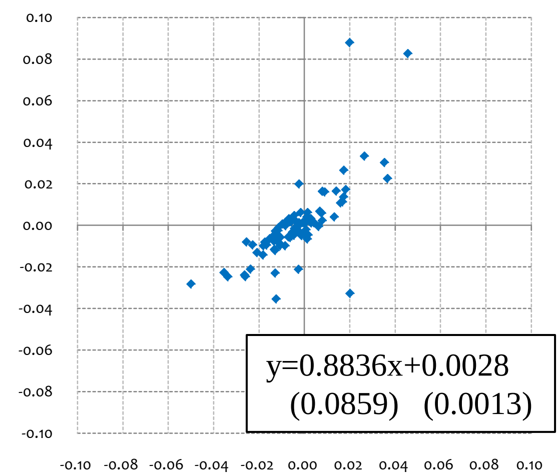

**Traditional hedonic vs. Standard repeat sales**



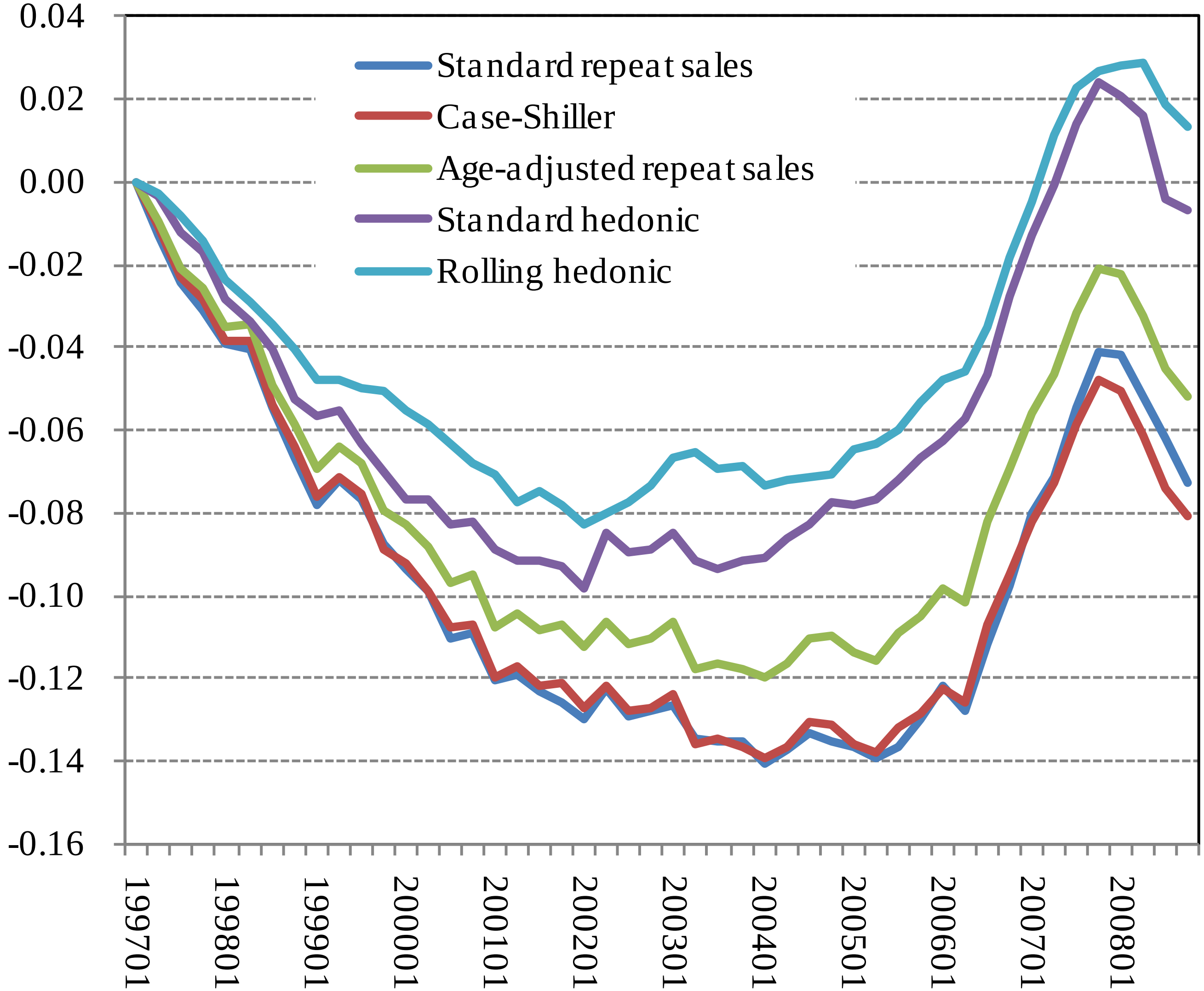

**Age-adjusted repeat sales vs. Standard repeat sales**




**Rolling hedonic vs. Standard repeat sales**



# Figure 3: When did condominium prices hit bottom?



# Figure 4: Hedonic indexes estimated using repeat-sales samples