The Choice of Methodology for Computing Housing Price Indexes: Comparisons of Temporal Aggregation and Sample Definition

Article *in* The Journal of Real Estate Finance and Economics · February 1999

DOI: 10.1023/A:1007846404582 · Source: RePEc

Christian L. Redfearn
University of Southern California

Journal of Real Estate Finance and Economics, 19:2, 91–112 (1999)

The Choice of Methodology for Computing Housing Price Indexes: Comparisons of Temporal Aggregation and Sample Definition

PETER ENGLUND
Stockholm School of Economics
Sweden

JOHN M. QUIGLEY
University of California
Berkeley

CHRISTIAN L. REDFEARN
University of California
Berkeley

Abstract

Housing transactions are executed and recorded daily, but are routinely pooled into longer time periods for the measurement and analysis of housing price trends. We utilize an unusually rich data set, covering essentially all arm's length housing sales in Sweden for a dozen years, in an attempt to understand the effect of temporal aggregation upon estimates of housing prices and their volatilities. This rich data set also provides a unique opportunity to compare the results using the conventional weighted repeat sales model (WRS) to those based on a research strategy which incorporates all available information on house sales. The results indicate the clear importance of temporal disaggregation in the estimation of housing prices and volatilities—regardless of the model employed.

The appropriately disaggregated model is then used as a benchmark to compare estimates of the course of housing prices produced by the two models during the twelve year period 1981–1993. These results indicate that much of the difference between estimates of price movements can be attributed to the data limitations which are inherent in the repeat sales approach. The results, thus, suggest caution in the interpretation of government-produced price indices or those produced by private firms based on the repeated sales model.

Key Words: temporal aggregation, repeat sales, hybrid price model

1. Introduction

The single largest investment most households ever make is in owner-occupied housing. Most home-owning households purchase insurance to protect this asset against unexpected loss from natural disaster, but few households can shield their housing investments from real estate cycles and price declines. Booms and busts in residential real estate markets are well documented, but hedging mechanisms that would allow middle-income households to diversify their real estate holdings or to insure the values of their homes have yet to be established. There are many economic and legal issues in designing programs to diversify housing price risk, but none is more basic than the accurate measurement of price levels and volatilities.

A substantial literature exists on the measurement of prices for non-standard assets such as housing. There are two major problems to be overcome in constructing a price index for housing: the relative infrequency of dwelling unit sales; and the heterogeneity in characteristics across housing units. Simple price indexes based on mean or median housing prices (for example, the index produced by the National Association of Realtors) do not consider the characteristics of houses sold. They are thus unable to distinguish between movements in prices and changes in the composition of homes sold from one period to the next. Crude regression models (e.g., the U.S. Bureau of the Census C-27 Index) are just that: crude. More sophisticated repeat sales models (for example, Bailey, Muth, and Nourse, 1963 and Case and Shiller, 1987) are based on strong assumptions about the constancy of the housing quality of any given dwelling.

Beyond the issue of model selection is the appropriate measurement of time itself in analyzing trends and volatilities in prices. This paper addresses the implications of aggregating observations on housing prices across time, that is combining housing sales observed in continuous time into discrete time periods for statistical analysis.

The data we analyze cover essentially all arm's length (i.e., anonymous) housing sales in Sweden from 1981 to 1993. The exceptional nature of these data supports a detailed analysis of temporal aggregation and other properties of price indexes. All previous work comparing volatility estimates has been based on the most parsimonious model imaginable, a so-called weighted repeat sales model (WRS). In contrast, our analysis is based upon a detailed model of housing price determination using information on a wide variety of hedonic characteristics, as well as the WRS model.

The data also provide a unique opportunity to compare the properties of repeat sales estimators with more sophisticated methods. Following the framework offered by Calhoun, Chinloy, and Megbolugbe (CCM, 1995) for the analysis of U.S. data, a comparable repeat sales price index is estimated for the three largest metropolitan regions in Sweden. We also estimate a more elaborate hybrid price index using the same data.

Tests for temporal aggregation bias are performed using both indexes. For each index, our results parallel those of CCM based on U.S. data on house sales in five census regions. Our results suggest strongly that housing price indexes should be estimated using the finest disaggregation of time available.

The research design, based on two indexes estimated from the same underlying data, also provides an opportunity to examine differences between the now-standard repeat sales estimator and a more elaborate hybrid technique. Our comparison suggests that much of the difference in estimates of price trends can be attributed to the maintained hypothesis of constant house quality and the data limitations inherent in the repeat sales approach to the measurement of housing prices.

Section 2 briefly reviews the methodology underlying the two indexes: the weighted repeat sales index (Case and Shiller, 1987) and the ''hybrid'' index of Englund, Quigley, and Redfearn (1998). Section 3 describes the data and discusses the different samples utilized in constructing each index. Section 4 discusses the results of the tests for temporal aggregation bias and provides further comparisons of the hybrid and repeat sales indexes. Section 5 provides a brief conclusion.

2. Methodologies for Estimating Housing Price Trends

The most widely used technique for estimating housing price trends is the repeat sales method introduced by Bailey, Muth, and Nourse (1963). As extended by Case and Shiller (1987), the weighted repeat sales model (WRS) is widely used in academic research. It also forms the basis for regional housing price trends published by the federal government (OFHEO, 1997) and defines the methodology which underlies all proprietary indices used commercially in the U.S.[1] An alternative estimator, combining single sales and repeat sales, is proposed by Englund, Quigley, and Redfearn (EQR, 1998). It is an extension of work on hybrid indexes developed in Quigley (1995) and Hill, Knight, and Sirmans (1997). This estimator utilizes information on all sales, as well as all available information on housing attributes, to estimate trends in housing prices. The two models are described in detail in the appendix; the relevant properties of both are summarized below.

The genius of the repeat sales method is that, under appropriate assumptions, it completely controls for housing quality while requiring little data in comparison to hedonic or hybrid methods. Under the maintained hypotheses of the model, differences in observed selling prices of houses can be attributed solely to changes in aggregate housing prices. In practice, few data sets allow verification of these maintained hypotheses; for example, that those units sold twice are unchanged between sales (and there is no previous analysis of the topic). Typically, dwelling modifications involve improvements and corresponding increases in value, increases that are improperly attributed to price changes whenever units which have been modified are included in the analysis.

Even if the characteristics of houses were carefully matched to insure that they were unchanged between sales, two aspects of the weighted repeat sales method would remain problematic. The first is the inability of the WRS method to account for depreciation and normal maintenance. In the presence of depreciation, the repeat sales index is necessarily biased downward if the rate of depreciation exceeds normal maintenance. The second problem concerns interpretation and sample selectivity. The WRS index is constructed from a non-random sample of the stock of houses and the population of house sales, namely those houses that have sold more frequently during a given interval. Thus, the repeat sales index may be a poor measure of prices for the entire stock of housing and even for those which have been sold during any time interval.

The hybrid method takes advantage of the information that is present in repeat sales, but without ignoring information on single sales. The hybrid method is data intensive, but where the data are available, it represents an obvious improvement over the repeat sales method. Computed price indexes are based on far more information, and the information used is more representative of the housing stock. Within the hybrid model, repeat sales of houses permit the investigation of depreciation and vintage effects,[2] as well as the temporal course of house prices.

In the next section, we describe the data used in the analysis. In section 4, we compare the implications of these techniques for the representation of time in price indexes. We consider the implications of the aggregation of sales reported daily into months, quarters, half years, or years for the estimation of housing prices, the returns to housing investment, and price volatilities.

3. Data on Swedish Housing Prices

The data used in this analysis consist of essentially every arm's length sale in the three major metropolitan regions in Sweden (Stockholm, Gothenburg, and Malmö) during the period from January 1, 1981 through August 31, 1993. Contract data reporting the transaction price for each sale have been merged with tax assessment records containing detailed information about the characteristics of each house. Repeat sales are identified, as is the location of each unit down to the smallest geographical unit, the parish (something akin to a census tract). The data set is exceptional in its detailed description of each dwelling at the date of sale and its identification of repeat sales. Together, these characteristics of the data make possible the comparison between the hybrid and repeat sales methods discussed above. Moreover, they permit a comparison of results using different subsamples. In particular, we compare the results obtained by the WRS method using all repeat sales models with those obtained using dwellings whose constant quality over time can be verified.

Both of the models employed in this paper rely on the use of information embodied in repeat sales. However sales of units that sell more than once during the sample period are a small fraction of all housing sales in any market run. Table 1 describes the distribution of observations on sales and dwellings by number of sales.[3] Almost three quarters of all units sold during the sample period were sold only once. Table 2 provides a summary of the variables used to control for quality and their average values for the dwellings located in each of the three regions. The variables describe the size and quality of each dwelling, as well as numerous amenities.

Table 1. Number of dwellings and sales, 1981:I–1993:III.

Number of Sales	Region			Total Number of Dwellings	Total Number of Sales
	Stockholm	Gothenburg	Malmö		
1	47,100	67,014	54,806	168,920	168,920
2	10,083	14,429	12,858	37,370	74,740
3	1,829	2,798	2,759	7,386	22,158
4	273	404	397	1,074	4,296
5	40	48	67	155	775
6	3	3	2	8	48
7	2	1	1	4	28
8	0	0	0	0	0
Total	59,330	84,697	70,890	214,917	270,965

Table 2. Average characteristics of house sales by region, 1981:I–1993:III (standard deviations in parentheses).

	Region		
	Stockholm	Gothenburg	Malmö
Number of transactions	74077	106147	90741
Number of dwellings	59330	84697	70890
Sale price	772.655	496.385	438.664
(Crowns, SEK)	(462.05)	(346.02)	(283.62)
Size			
Interior size	122.004	118.256	119.678
(square meters)	(35.98)	(37.78)	(39.88)
Parcel size	827.392	1092.914	1084.492
(square meters)	(814.00)	(1109.95)	(1080.94)
One car garage	0.705	0.621	0.581
(1 = yes)	(0.46)	(0.49)	(0.49)
Two car garage	0.047	0.059	0.044
(1 = yes)	(0.21)	(0.24)	(0.20)
Amenity			
Tile bath	0.118	0.110	0.143
(1 = yes)	(0.32)	(0.31)	(0.35)
Sewer connection	0.988	0.977	0.974
(1 = yes)	(0.11)	(0.15)	(0.16)
Sauna	0.217	0.177	0.122
(1 = yes)	(0.41)	(0.38)	(0.33)
Stone/brick	0.234	0.288	0.548
(1 = yes)	(0.42)	(0.45)	(0.50)
Single detached	0.664	0.784	0.865
(1 = yes)	(0.47)	(0.41)	(0.34)
Finished basement	0.162	0.171	0.134
(1 = yes)	(0.37)	(0.38)	(0.34)
Fireplace	0.368	0.339	0.259
(1 = yes)	(0.48)	(0.47)	(0.44)
Laundry room	0.842	0.811	0.784
(1 = yes)	(0.36)	(0.39)	(0.41)
Waterfront location	0.007	0.004	0.004
(1 = yes)	(0.08)	(0.06)	(0.07)
Quality			
Age at time of sale	26.572	30.578	39.674
(Years)	(20.48)	(23.46)	(28.42)
Vintage	59.915	55.995	47.057
(19xx)	(20.35)	(23.33)	(28.33)
Insulation			
Walls only	0.832	0.791	0.802
(1 = yes)	(0.37)	(0.41)	(0.40)
Walls and windows	0.163	0.195	0.179
(1 = yes)	(0.37)	(0.40)	(0.38)

Table 2. (*continued*)

	Region		
	Stockholm	Gothenburg	Malmö
Kitchen			
Good	0.198	0.247	0.279
(1 = yes)	(0.40)	(0.43)	(0.45)
Excellent	0.789	0.725	0.687
(1 = yes)	(0.41)	(0.45)	(0.46)
Heating system			
Electric radiator	0.400	0.359	0.323
(1 = yes)	(0.49)	(0.48)	(0.47)
Electric furnace	0.111	0.106	0.090
(1 = yes)	(0.31)	(0.31)	(0.29)
Solar/other	0.344	0.424	0.478
(1 = yes)	(0.48)	(0.49)	(0.50)
Exterior steam	0.083	0.037	0.067
(1 = yes)	(0.28)	(0.19)	(0.25)
Other central heat	0.050	0.051	0.021
(1 = yes)	(0.22)	(0.22)	(0.14)
Wood burning stove	0.009	0.018	0.009
(1 = yes)	(0.09)	(0.13)	(0.09)
Roof			
Cement/steel	0.663	0.766	0.657
(1 = yes)	(0.47)	(0.42)	(0.47)
Slate/copper	0.009	0.013	0.015
(1 = yes)	(0.10)	(0.11)	(0.12)
Other			
Distance	4.744	5.863	5.318
(Kilometers)	(6.09)	(5.81)	(5.30)
Urban area	0.903	0.745	0.757
(1 = yes)	(0.30)	(0.44)	(0.43)
Capital subsidy	2.979	2.845	2.361
(000s, SEK)	(12.16)	(11.64)	(10.85)
Conditional subsidy	25.863	24.013	24.769
(000s, SEK)	(26.30)	(25.21)	(26.08)

These variables describe the physical structure and amount of land on which the dwelling sits, but there remain external influences on housing prices. The importance of location to housing prices is well established. While necessarily incomplete, we have computed several variables to measure more desirable locations. These include dummy variables for each of the 111 labor market areas defined by Sweden's Central Bureau of Statistics, and the approximate distance of each dwelling to the center of the local labor market in which it is located. This variable measures the linear distance from the center of the parish in which a dwelling is located to the center of the nearest labor market area. Also included is an estimate of the present value of capital subsidies on newer dwellings.[4]

These regions include the three largest cities in Sweden. The primacy of Stockholm is apparent in the prices of dwellings. The average price of about 770,000 SEK in Stockholm is about sixty percent higher than the average prices in Gothenburg and Malmö. Differences in the representative units exist across the three regions, with Stockholm having younger, and in general, higher quality dwellings. The younger housing stock in Stockholm is also reflected in more dwellings with access to a garage, a sauna, a fireplace, an excellent kitchen, and a laundry room. The parcel size, the dummy for single detached home, and the urban/rural dummy, together indicate the greater urbanization of the Stockholm region.

4. Time Aggregation

Table 3 summarizes the statistical comparison of price indexes computed at four levels of aggregation—monthly, quarterly, semi-annually, and annually. The same comparison is made for each model, the WRS and the EQR. The results are reported separately for each of the three regions.

Table 3. Tests of disaggregation of price trends over time F-ratios comparing more restricted models (columns) compared to less restricted models (rows).

		WRS Model			EQR Model		
Region	Time Period	Quarters	Half Years	Years	Quarters	Half Years	Years
Stockholm							
	Months	1.630	1.979	4.347	1.739	1.459	2.340
	Quarters		5.217	12.726		1.735	4.648
	Half years			13.463			5.121
Gothenburg							
	Months	2.156	2.635	4.606	1.830	1.524	2.056
	Quarters		7.009	12.375		1.758	3.293
	Half years			11.247			3.120
Malmö							
	Months	1.517	1.716	3.466	2.582	2.056	2.859
	Quarters		4.130	9.622		1.921	4.480
	Half years			10.043			4.699

Note: The critical values of the F statistic, F(U-R, ∞), where U is the number of parameters estimated in the unrestricted model and R is the number of parameters in the restricted model, are:

	Upper One Percent		
Time Period	Quarters	Half Years	Years
Months	1.43	1.37	1.36
Quarters		1.68	1.84
Half years			2.17

The table reports F-tests of the restrictions inherent in representing time in the computation of price indexes by aggregate measures. For example, the entry in the first row and column provides a test of the hypothesis that, for the WRS model applied to data from the Stockholm region, the coefficients on monthly prices within quarters are identical. According to the entry ($F = 1.630$), the hypothesis can be rejected at the one percent level of confidence (where the critical value is 1.43).

The table presents a complete set of tests, comparing more restricted models (columns) with less restricted models (rows) for all four aggregations of time initially measured in days.[5] The tests consistently allow rejection at the one percent level of the more aggregated models against the less aggregated alternatives. These results hold across all three regions both for a simple and parsimonious model, the WRS, and for a more complete model, the EQR. The F-ratios are mostly larger for the WRS model than for the EQR model, in particular when comparing the cruder levels of aggregation. The results for the WRS model are quite consistent with those reported by CCM (1995, tables 1 through 5) for five census regions in the U.S. The results reported in columns 4, 5, and 6 provide further confirmation, using a different model. The conclusion is clear: in the estimation of housing price indexes, time should generally be represented using the lowest level of aggregation possible. Arbitrary aggregations into broader representations of time are generally unwarranted.

Table 4 indicates some of the implications of the aggregation of time in these three bodies of data. Again we present estimates based on both the WRS and the EQR models for different representations of time. The average values of the price indexes for the entire period (panel A) vary little with the representation of time, although there is a slight trend upward as the level of aggregation increases. Furthermore, the estimated evolution of nominal prices, including their acceleration beginning in 1986, their peak in 1991, and their rapid decline thereafter, is consistent regardless of the degree of temporal aggregation. This evolution is illustrated below. The mean values of the price indexes for Stockholm and Malmö are slightly higher for the WRS models than for the EQR models, whereas the two models yield similar indexes for Gothenburg.

Panel B compares the estimated mean returns to investment in owner occupied housing, for a one-year holding period. There is some tendency for returns estimates to be smaller for larger aggregations of time. Further, the WRS models generally yield higher estimated rates of return than the EQR models.

Panel C reports the estimated volatilities in annual returns implied by the various models. The volatilities are computed from annual returns estimated using each model. The estimated variance in annual returns is generally somewhat lower when estimated from levels of time aggregation that are greater than monthly. The volatility is substantially greater in Stockholm than in either Gothenburg or Malmö.

5. Comparing Methodologies

Figures 1, 2, and 3 compare the estimates of the course of housing prices for the three regions. The figures report the estimated price indexes as well as the 95% confidence

Table 4. Estimates of house prices, returns, and volatilities.

		WRS Models	EQR Models
a. Mean Value of Price Index (1981:Feb = 100)			
Stockholm:	Monthly	152.191	148.241
	Quarterly	155.910	152.501
	Semi-Annual	159.232	153.816
	Annual	160.100	155.285
Gothenburg:	Monthly	141.051	141.766
	Quarterly	142.942	145.045
	Semi-annual	146.256	145.284
	Annual	147.703	145.731
Malmö:	Monthly	140.091	139.678
	Quarterly	146.374	136.570
	Semi-annual	146.749	138.990
	Annual	149.508	140.837
b. Mean Return (times 100) (Annualized percent change)			
Stockholm:	Monthly	6.455	6.186
	Quarterly	6.304	6.010
	Semi-annual	6.081	5.806
	Annual	5.973	5.759
Gothenburg:	Monthly	6.083	5.807
	Quarterly	5.841	5.682
	Semi-annual	5.731	5.625
	Annual	5.641	5.429
Malmö:	Monthly	6.845	5.847
	Quarterly	6.697	5.649
	Semi-annual	6.418	5.463
	Annual	6.420	5.453
c. Volatility (times 10000) (Variance in annualized percent change)			
Stockholm:	Monthly	138.703	150.891
	Quarterly	138.084	147.200
	Semi-annual	138.175	146.140
	Annual	141.849	144.066
Gothenburg:	Monthly	79.575	78.994
	Quarterly	79.575	72.821
	Semi-annual	76.566	70.851
	Annual	77.757	70.507
Malmö:	Monthly	91.170	87.378
	Quarterly	88.000	83.108
	Semi-annual	88.038	82.372
	Annual	86.123	79.672

intervals. All prices are estimated using the most appropriate representation of time, in months. Results are presented for both methodologies, the WRS and the EQR methods.

Inspection of the figures reveals a striking regularity. While in each region the two indexes track each other closely, the confidence intervals are substantially narrower for the

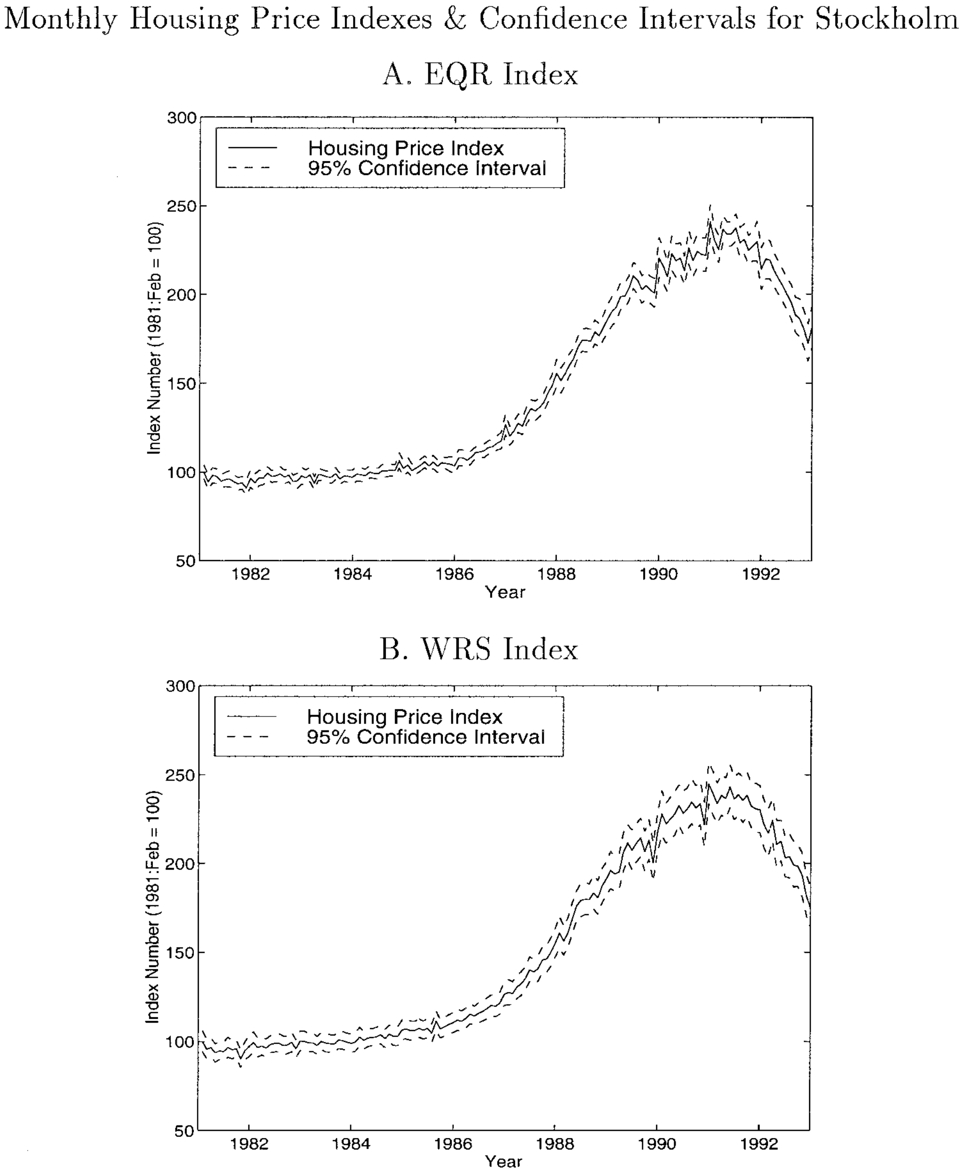


Figure 1.

EQR models than for the WRS models. This is expected, as the EQR model incorporates much more information in the estimation of the price index than does the WRS model. The EQR model employs single sales as well as multiple sales, and it utilizes extensive information about the qualitative and quantitative attributes of dwellings.

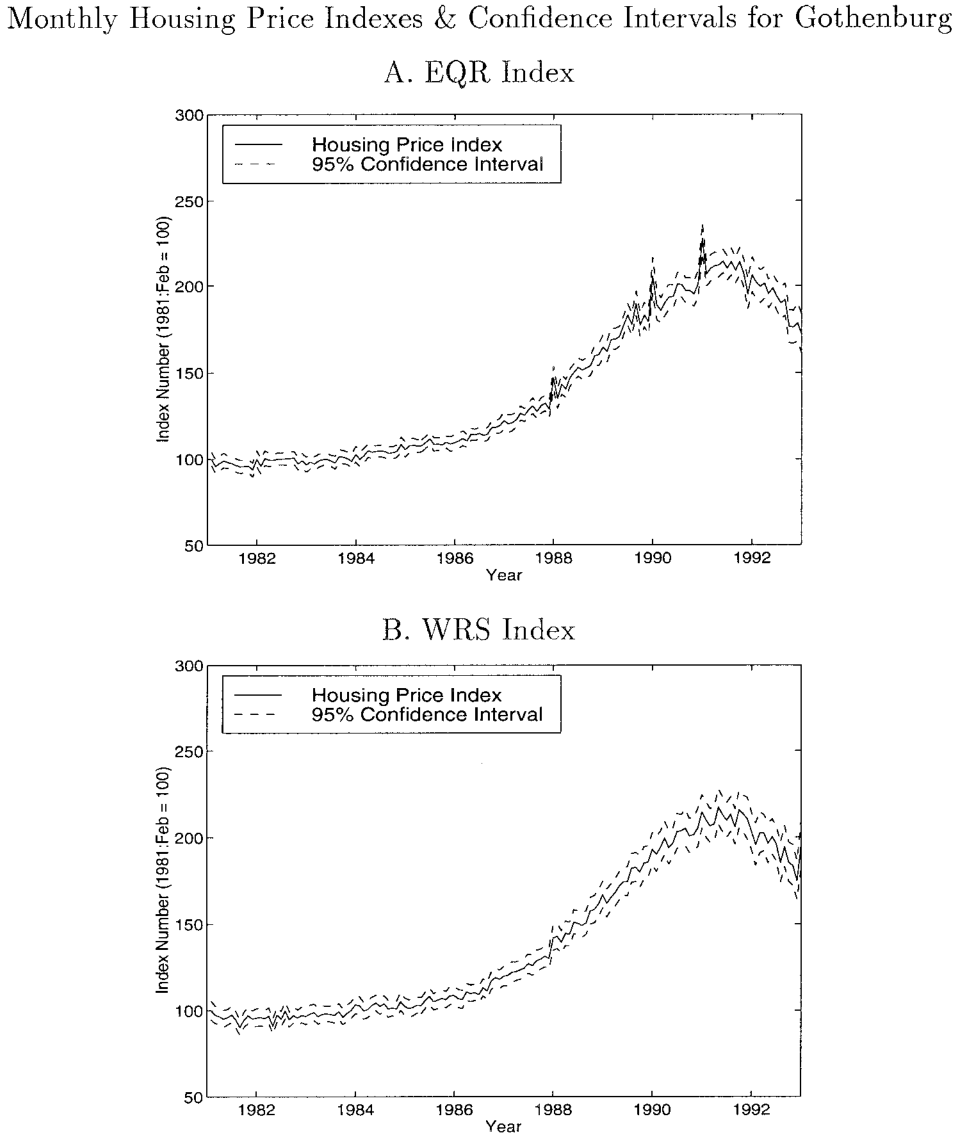
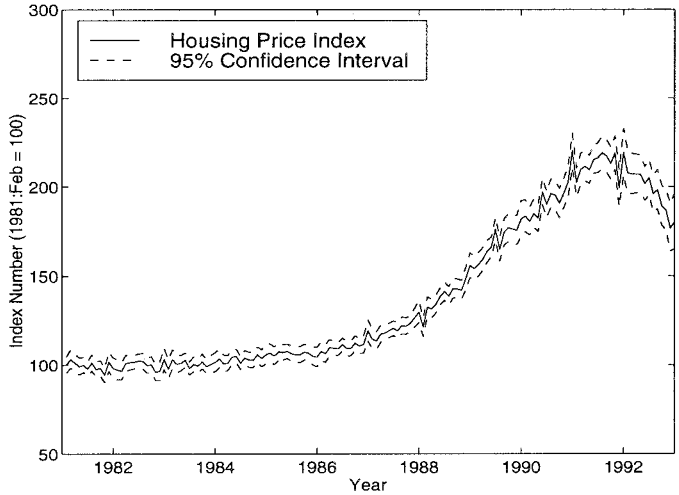


Figure 2.

The likelihood that an observed sale is a repeat sale increases with the length of the sample period—the samples used in the WRS and EQR methods should approach one another as the time horizon is extended. During the thirteen year sample period, roughly forty percent of observed sales are drawn from dwellings that sell at least two times.

Monthly Housing Price Indexes & Confidence Intervals for Malmö

A. EQR Index



B. WRS Index

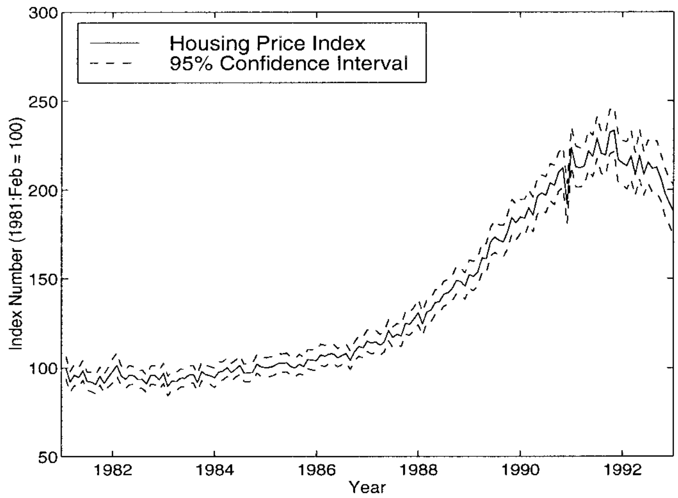


Figure 3.

Table 5 shows how the repeat sales requirement greatly restricts the set of information on which repeat sales indexes are based in short sample periods. The table also illustrates the impact that this restriction has on the resulting confidence intervals, as well as average price levels and average percent returns.

Table 5. Differences between the EQR and WRS indexes as a function of sample period. (Indexes are normalized—1981: January = 100).

		EQR Method			WRS Method		
	Percent Repeat Sales	Mean Width of Confidence Interval	Mean Price Level	Mean Repeat Return	Mean Width of Confidence Interval	Mean Price Level	Mean Percent Return
Stockholm:							
1981–1982	4.6	7.441	96.328	− 0.377	25.452	100.616	0.050
1983	8.0	6.927	96.770	− 0.044	14.202	101.900	0.218
1984	11.9	7.236	97.478	0.077	12.777	100.911	0.213
1985	16.0	7.229	98.760	0.063	12.768	101.751	0.205
1986	19.6	6.808	100.803	0.283	11.236	103.511	0.313
1987–1988	3.4	10.732	118.123	1.296	28.921	118.464	1.434
1989	5.7	13.237	141.822	0.976	22.983	142.681	1.362
1991–1992	3.0	7.666	88.861	− 1.690	35.844	91.999	− 0.976
1993:Aug	4.5	7.901	84.550	− 1.104	26.642	86.428	− 0.616
Gothenburg:							
1981–1982	7.4	7.384	98.704	− 0.073	20.307	92.723	− 0.129
1983	13.2	7.130	99.022	− 0.011	15.388	96.769	0.160
1984	18.5	7.288	100.227	0.167	13.040	100.650	0.343
1985	21.6	7.329	101.965	0.178	12.346	101.594	0.253
1986	25.0	7.171	103.874	0.175	11.193	102.268	0.274
1987–1988	4.6	8.489	112.590	1.042	18.971	118.324	1.445
1989	7.5	9.672	122.825	0.845	17.390	124.269	1.365
1990	12.4	10.554	132.420	0.949	18.135	135.583	1.299
1991–1992	2.9	7.931	88.640	− 1.083	22.239	93.651	− 0.534
1993:Aug	4.4	8.561	86.061	− 0.463	21.612	92.316	− 0.029
Malmö:							
1981–1982	6.6	8.759	99.370	− 0.098	24.925	92.471	0.219
1983	10.3	8.499	99.779	0.027	19.731	93.984	0.050
1984	13.7	8.124	100.629	0.126	16.585	98.502	0.269
1985	17.5	8.076	101.756	0.161	13.452	98.538	0.170
1986	21.6	8.488	102.965	0.168	12.239	99.861	0.212
1987–1988	5.6	8.827	106.987	0.912	20.509	108.231	0.862
1989	9.0	10.059	117.441	0.929	23.587	123.074	1.526
1990	14.6	11.079	127.704	0.993	18.502	135.710	1.288
1991–1992	4.3	9.767	93.275	− 1.135	32.615	111.254	0.383
1993:Aug	6.1	10.711	90.445	− 0.664	27.895	104.376	0.076

The table examines sample periods of various lengths for each of the three metropolitan areas during segments of the price cycle that roughly correspond to stable, climbing, and falling nominal house prices. Indexes are constructed using both the EQR and the WRS methods for each of the sample periods. The relationship between length of sample period and percentage of observed sales which are repeat sales is as expected. It is clear that in short sample periods indexes based on repeat sales utilize a very small fraction of the available market information on housing sales. In Stockholm, the percentage of observed sales that are drawn from dwellings that sell more than once rises from 4.6% to 19.6% as the sample period increases from 24 to 72 months. The impact on the 95% confidence interval for the WRS index is striking, as the average width narrows from 25 to 11 units.

This noise in the price series has substantial impact on estimated average price levels and estimated average returns. Both can vary widely between the two methods in short intervals. However, there is a slight tendency for the differences to diminish as the sample period is lengthened, and, as shown in table 4, the differences are small over the full sample period. In Stockholm the difference between estimates of the average monthly return during the initial 24-month period is close to half a percentage point. At the end of the period of stable prices this difference is only 0.03 percentage points.

The advantage of the EQR method over the WRS method is obvious in these short sample periods. In each case the confidence interval for the indexes based on the EQR method is substantially narrower. In the shortest intervals the intervals differ by a factor of three. As expected, the difference declines as the sample period is lengthened and as the percentage of sales which are repeat sales increases.

The small sample sizes that are used in a repeat sales index point to another potential problem with their use. The repeat sales may not be a random sample of the housing stock. (This, in turn, may bias estimates of price indices. See Englund, Quigley, and Redfearn, 1999). For example, ''starter'' homes are commonly thought to sell more frequently than more expensive homes. As discussed above, over the course of the full sample period approximately 40% of observed sales are drawn from units that sell more than once. This percentage drops to under ten percent in shorter intervals. The data allow a comparison of the populations used in the estimation of each index.

In general, the Swedish data support the notion that smaller, more modest homes sell more frequently. However, as with the percentage of all sales that are second sales, the average characteristics of dwellings must grow more similar as the sample period is extended.[6] In all three metropolitan areas, the average multiple sale unit in the short sample periods is smaller, both in terms of interior and exterior size; it is less likely to be detached, have a fireplace, or be on the waterfront. To the extent that price movements are not identical across different populations of dwellings, a price index based on repeat sales may be biased, in our case, tracking prices for smaller, more modest homes rather than the price level for the entire housing stock.

That the percentage of observations drawn from dwellings which sell at least twice is so small is particularly troubling in light of the implicit assumption about constant quality between paired sales. As noted in the appendix, by basing the index upon the time interval between sales of the ''same'' house (and only the time interval between sales), the computation of the WRS index assumes that each house is *really* identical at each sale. The WRS indexes constructed above are based on pairs of sales from the same dwelling without regard to its underlying attributes. In order to employ the WRS method correctly, those units that are altered between sales should be identified and removed prior to estimation of a WRS index, further reducing already small sample sizes. However, the

Table 6. Number and distribution of second sales.

	Stockholm			Gothenburg			Malmö		
A. Sales									
Total number of sales	74077			106147			90741		
Number of dwellings sold more than one time	12230			17683			16084		
Number of paired sales	14747			21450			19842		
B. Paired Sales*									
Years Between Sales	Paired Sales	Identical Second Sales	Percent	Paired Sales	Identical Second Sales	Percent	Paired Sales	Identical Second Sales	Percent
0	928	779	83.9	2024	1479	73.1	1646	1293	78.6
1	2679	2177	81.3	4999	3777	75.6	4306	3288	76.4
2	2540	1900	74.8	4151	2881	69.4	3872	2790	72.1
3	2439	1547	63.4	3592	2173	60.5	3383	2009	59.4
4	1885	1027	54.5	2410	1281	53.2	2330	1311	56.3
5	1409	617	43.8	1647	782	47.5	1680	832	49.5
6	1070	381	35.6	1094	466	42.6	1135	474	41.8
7	833	231	27.7	707	251	35.5	692	232	33.5
8	478	85	17.8	408	100	24.5	429	82	19.1
9	274	27	9.9	259	46	17.8	220	29	13.2
10	146	19	13.0	113	14	12.4	116	15	12.9
11	55	5	9.1	39	7	18.0	33	5	15.2
12	11	1	9.1	7	4	57.1	0	0	0.0
Total	14747	8796	59.6	21450	13261	61.8	19842	12360	62.3

Note: *Number of paired sales, and the number of identical paired sales by interval between sales (using only those observations for which no measured attributes have missing values)

WRS method is often employed precisely because data on attributes are not available, thus rendering verification of the constant quality assumption impossible. The rich sample of Swedish housing data permits this implicit assumption to be tested.

Table 6 identifies the number and distribution of second sales over the course of the full sample period. It also distinguishes between the total number of second sales and those second sales that have remained unaltered across 26 measured characteristics. Panel B reports that approximately forty percent of the second sales in the observed pairs have been altered between sales.[7] Of course, even if the measured characteristics of houses sold at two points in time are the same, the dwellings are still not identical. The mere passage of time means that the house may have depreciated.

As demonstrated in table 7, the changes in recorded housing quality between the first and second sale of each pair are generally consistent with improvements in housing quality

Table 7. Changes in the attributes of the second sale of paired sales.
Percentage of units exhibiting changes in the level of an attribute.

	Stockholm			Gothenburg			Malmö		
Attribute	Decrease	Same	Increase	Decrease	Same	Increase	Decrease	Same	Increase
Plot size	4.8	90.3	4.9	5.9	87.6	6.5	3.5	91.1	5.4
Living space	1.2	97.9	0.9	3.7	92.6	3.6	1.8	96.5	1.8
One-car garage	2.6	94.0	3.4	2.8	93.0	4.2	2.9	93.6	3.5
Two-car garage	1.0	98.6	0.4	0.9	98.0	1.1	0.7	98.4	0.9
Tiled bath	1.5	92.1	6.4	2.3	93.4	4.3	3.0	92.0	4.9
Sewer connection	0.1	99.6	0.3	0.2	98.9	0.9	0.1	99.1	0.8
Sauna	1.8	94.4	3.8	1.7	95.4	2.9	1.0	97.1	1.9
Wall construction	1.9	96.5	1.6	2.2	95.8	2.1	2.9	94.7	2.4
Furnished basement	2.6	95.3	2.2	2.1	95.4	2.5	1.1	97.2	1.7
Fireplace	0.9	96.4	2.7	2.0	94.1	4.0	1.0	95.0	4.0
Laundry room	4.7	92.0	3.3	4.8	91.4	3.8	4.7	91.1	4.1
Waterfront property	0.1	99.9	0.0	0.1	99.9	0.1	0.1	99.9	0.0
Quality 1[a]	3.8	94.3	1.8	4.2	93.1	2.7	3.5	94.1	2.4
Quality 2[b]	2.0	94.1	3.9	3.1	92.4	4.5	2.7	93.2	4.1
Good kitchen	5.7	89.7	4.6	5.8	88.8	5.4	6.4	87.7	5.9
Excellent kitchen	5.3	89.7	5.0	6.2	88.6	5.1	7.3	87.2	5.5
Heat	0.0	99.9	0.0	0.1	99.8	0.1	0.0	99.8	0.2
Good roof	0.2	99.3	0.5	0.2	99.1	0.7	0.2	98.9	0.9
Excellent Roof	0.9	96.2	2.9	1.6	95.7	2.7	2.2	94.3	3.5

Notes: Quality 1 is defined as ''winter quality''. Quality 2 is ''isolation quality''.

over time. The availability of a garage, the quality of bathrooms and materials, and the likelihood of a sauna and fireplace all increase. Several measures are not easily interpreted as they have been affected by a rising standard (see note 8), but even for some of these variables the average quality has improved between sales of dwellings. If these improvements are ignored in the computation of the price index, the WRS will overestimate housing price appreciation.

In addition, however, during the interval between sales, dwellings depreciate. Some or all of this may be offset by expenditures on maintenance, but empirical evidence suggests that the offset is incomplete (see Kain and Quigley, 1970, Palmquist, 1980, and Hill et al., 1997, for examples using data obtained during three decades).

If unmeasured quality improvements of x percent are undertaken with probability π each year, while unmeasured depreciation net of normal maintenance is δ percent, it is easy to show that the price index ϕ_t computed from the WRS model will be a biased estimate of the true price level, I_t.

$$E(\phi_t) = I_t(1 + \pi x - \delta)^t. \tag{1}$$

Figure 4 illustrates the dramatic difference between WRS indexes when the maintained hypothesis of constant quality is enforced in one sample and explicitly violated in another.

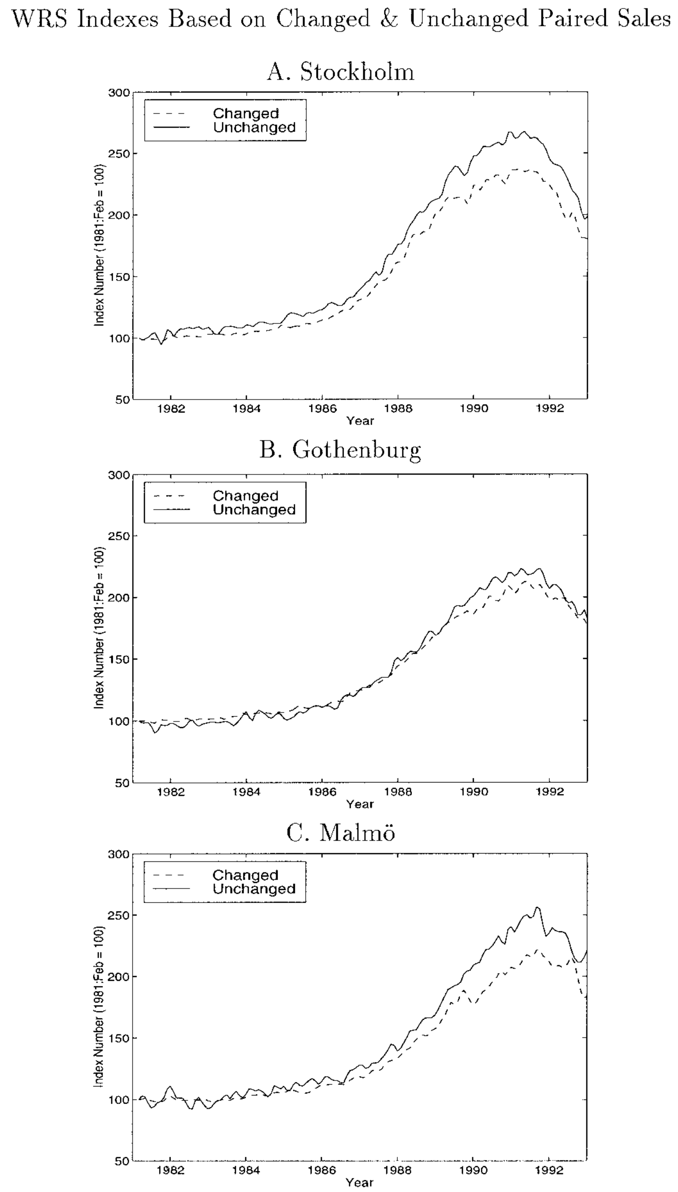


Figure 4.

For each of the three metropolitan areas, the pool of repeat sales has been divided into two subsamples. The first sample is confined to dwellings whose measurable characteristics are unchanged between sales as demanded by the underlying theory. The second sample consists of those pairs in which a change in attributes has been measured between sales. The differences between the two indexes are clearly visible. Note that, despite the clear difference in the evolution of prices, it is the union of these two data sets that serves as the basis for repeat sales indexes that cannot differentiate between altered and unaltered properties. In each of the three metropolitan areas the index that is based on altered properties is substantially higher than the correctly estimated repeat sales index. This difference is consistent with improvements in quality over time. Without measuring and controlling for housing quality directly, the WRS methodology leads to much higher estimates of housing prices during the second half of the sample period.

The indexes reported in figure 4 are based upon a sample which has ''filtered out'' dwellings changed by explicit renovation decisions during the interval between sales. Of necessity, however, the sample includes dwellings that have depreciated during the interval. Thus, from equation (1), an index computed from this sample is lower than the true price index.

The dilemma in computing the WRS index is clear: either ''filter'' the data (to insure that $\pi x = 0$ for the houses used to compute the index) and thereby underestimate the price index; or do not ''filter'' the data and have no evidence at all about whether too much or too little maintenance and improvement $(\pi x \gtrless \delta)$ has been performed.

Thus, a major advantage of the EQR methodology is the explicit measurement of quality variation and differences in dwelling age over time.

6. Conclusion

In this paper, we have considered the aggregation of housing sales reported in continuous time to discrete periods for the computation of indexes of house prices, investment returns, and the volatility of returns. We have also considered the properties of repeat sales estimators and hybrid estimators of the price indexes.

The analysis indicates quite clearly that house price estimates ought to be undertaken using the finest disaggregation of time available. On statistical grounds, price indices based on monthly aggregations dominate those based on quarterly data. Quarterly data, in turn, dominates semi-annual data for the computation of price indices.[8] In this conclusion, we reinforce that made by Calhoun, Chinloy, and Megbolugbe using U.S. data. Volatilities in returns are substantially higher when estimated using monthly time intervals. However, our results also suggest that for a consistently defined holding period, returns and volatilities do not differ very much, at least for this data set.

This analysis also suggests, however, that extreme caution should be exercised in interpreting the WRS indices of housing prices as they are typically computed for academic and business applications. The implicit assumption of constant quality is difficult to verify, but is essential to the method. In the housing markets analyzed here, dwelling improvements are undertaken frequently and are widespread. These changes in physical structure violate the maintained hypothesis of the WRS method. Furthermore, the results indicate that correctly implementing the WRS method greatly restricts the set of observations that are utilized, perhaps narrowing the sample to observations drawn from non-representative dwellings. In these conclusions, we reinforce those made by Meese and Wallace (1997), using U.S. data which was more limited in geographical scope, sample size, and in the measurement of housing prices. While further research is needed to clarify the relationship between repeat sales indexes and price movements in the remainder of the housing stock, it appears that the widespread use of the WRS indexes in the U.S. provides an inadequate picture of housing price movements.

Appendix: Models of Housing Price Trends

1. The Weighted Repeat Sales Method

Assume, following Case and Shiller (1989), that the log price of the ith house at time t, P_{it}, is given by

$$P_{it} = I_t + H_{it} + N_{it} \tag{A1}$$

where I_t is the logarithm of the price level at t, H_{it} is a Gaussian random walk, such that

$$\begin{aligned} &E(H_{it} - H_{i\tau}) = 0 \\ &E(H_{it} - H_{i\tau})^2 = (t-\tau)\sigma_H{}^2 \end{aligned} \tag{A2}$$

and N_{it} is white noise, such that

$$\begin{aligned} &E(N_{it}) = 0 \\ &E(N_{it})^2 = \sigma_N{}^2 \end{aligned} \tag{A3}$$

Let $V_{it} = P_{it} + Q_{it}$ be the log sale price of house i at time t, where Q_{it} is a quality indicator. For houses sold at time τ and time t (i.e., repeat sales) during the interval (1,S), the index is computed in three steps. In the first step, equation (A4) is estimated and the residuals, μ_{it}, saved for use in the second step.

$$V_{it} - V_{i\tau} = \sum_s \phi_s D_{is} + \mu_{it}, \ s = (1, 2, \ldots, S), \tag{A4}$$

where $D_{is} = 1$ if $s = t$, $D_{is} = -1$ if $s = \tau$, and $D_{is} = 0$ otherwise. ϕ_s is the estimate of I_s, the log of the price level at time s.

In the second stage, the squared residuals from (A4), $(\mu_{it} - \mu_{i\tau})^2$, are regressed upon a constant and the elapsed time between sales, $(t - \tau)$, yielding estimates of the variances $\sigma_H{}^2$ and $\sigma_N{}^2$. In the third stage, equation (A4) is re-estimated by generalized least squares with diagonal elements $\sqrt{\hat{\sigma}_N^2 + (t-\tau)\hat{\sigma}_H^2}$.

Note the assumption about dwelling quality implicit in this formulation. The left hand side of (A4) can be interpreted unambiguously as a log price change if $Q_{i\tau} = Q_{it}$. The estimates of the price index are therefore functions of dwelling quality unless quality remains constant across time. Clearly $Q_{i\tau} = Q_{it}$ is a maintained hypothesis in adopting this procedure.

2. *The Hybrid Method*

Following Englund, Quigley, and Redfearn (1998), assume

$$V_{it} = \beta X_{it} + P_{it} + \xi_i + \varepsilon_{it} = \beta X_{it} + P_{it} + \gamma_{it} \tag{A5}$$

where X_{it} represents the logarithm of observable characteristics of dwelling i, and P_{it} and V_{it} are defined above. ξ_i represents an error due to the unmeasured, individual-specific characteristics of dwelling i and is distributed with zero mean and variance $\sigma_{\xi}{}^2$. ε_{it} is an error term. Components of X_{it} include the vintage (y_i, year built) and the accumulated depreciation ($t - y_i$, age) of the dwelling. In a cross section, y_i, $(t - y_i)$, and P_t cannot be separately identified, but from a subsample of repeat sales at various ages and years, the parameters can be recovered.

To implement the model, estimate (A5) using the subsample of paired repeat sales at time t and time τ. Then use the residuals from the regression to estimate jointly

$$\gamma_{it} - \gamma_{i\tau} = \beta_d[t - \tau] + \varepsilon_{it} - \varepsilon_{i\tau} \tag{A6}$$

and

$$\varepsilon_{it} = \rho^{(t-\tau)}\varepsilon_{i,t-\tau} + V_{it}, \tag{A7}$$

where ε_{jt} and $\varepsilon_{j\tau}$ are defined as above, and ρ is the serial correlation coefficient. V_{it} is the residual, and is distributed with zero mean and variance $\sigma_v{}^2$. Equation (A6) provides an estimate of depreciation, β_d.[9]

Together, these parameters yield an estimate of the variance-covariance matrix of the errors in equation (A5). From equation (A7) we obtain an estimate of $\sigma_v{}^2$. An estimate of $\sigma_{\xi}{}^2$ is constructed from the residuals in the first-step estimation of (A5), knowing ρ and $\sigma_v{}^2$. Together these parameters describe completely the variance-covariance matrix of the errors for equation (A7).

$$E(\gamma_{it}, \gamma_{j\tau}) = \begin{cases} 0 & \text{for } i \neq j \\ \sigma_{\xi}{}^2 + \sigma_v{}^2\{\rho^{(t-\tau)}/(1-\rho^2)\} + \beta_d{}^2 A_t A_\tau & \text{for } i = j, \end{cases} \tag{A8}$$

where A_j is the age of the house in year j.

The final step is the re-estimation of (A5) by generalized least squares including all observations in the sample, not merely repeat sales, and relying on equation (A8).

This hybrid method is more data intensive than the repeat sales method. It relies upon qualitative and quantitative information about each housing unit at the time of sale to control for housing quality in an explicit manner. The method also capitalizes on the unique information provided by repeat sales of individual units. This permits us to separate the effects of time on housing prices from depreciation and vintage effects and to improve the efficiency of parameter estimates by explicit attention to the components of the error structure.

Acknowledgments

Support for this research has been provided by the Fisher Center for Real Estate and Urban Economics, University of California, Berkeley and by the Swedish Council for Building Research. The paper has benefited from unusually constructive, detailed comments from two anonymous reviewers.

Notes

1. This includes, for example, the price series marketed by Case-Shiller-Weiss, Inc., MRAC, and TRW, Inc.
2. ''Depreciation'' is the decline in quality over some time interval after accounting for normal maintenance, while ''vintage'' refers to the elements of quality and style embedded in the dwelling at the time of construction.
3. To insure that the observations included in the data were indeed arm's length market transactions, only the first sale of paired sales that occurred within a six-month period were retained. This filter was imposed to remove ''distressed sales'' and non-market transactions from the data set. Sales within the six-month period were observed to have a large negative serial correlation. This is consistent with a distressed sale shortly after an initial purchase or a pair of sales in which one serves as a familial transfer either preceded or followed by an arm's length sale.
4. Beginning in 1975 the government provided interest-subsidized loans to owners of newly constructed housing. The value of the subsidy depended on the construction costs and the vintage of the unit, and decayed with time. While the average estimated present value of the subsidy (''capital subsidy'' in Table 2) is small, less than 3000 SEK or \$400 US, the average for transactions involving subsidized dwellings (''conditional subsidy'' in Table 2) is an order of magnitude larger. During the 1980s the average subsidy on newly constructed homes was as high as twenty percent of the initial price of the dwelling.
5. For each metropolitan region and for each model, the table presents tests of six joint null hypotheses, $H_0^{r,c}$ where r is the row and c is the column. Without loss of generality, re-index the set of coefficients ϕ described in Appendix A as $\phi_{y.m}$ where y is the year (1981 through 1993) and m is the month (1 through 12). For convenience, we suppress the first subscript. The six joint null hypotheses tested in the table are of the form:

$$H_0^{1,1} : \phi_1 = \phi_2 = \phi_3 = \phi^{q1}; \phi_4 = \phi_5 = \phi_6 = \phi^{q2}; \phi_7 = \phi_8 = \phi_9 = \phi^{q3}; \phi_{10} = \phi_{11} = \phi_{12} = \phi^{q4}.$$
$$H_0^{1,2} : \phi_1 = \phi_2 = \phi_3 = \phi_4 = \phi_5 = \phi_6 = \phi^{h1}; \phi_7 = \phi_8 = \phi_9 = \phi_{10} = \phi_{11} = \phi_{12} = \phi^{h2}.$$
$$H_0^{1,3} : \phi_1 = \phi_2 = \phi_3 = \phi_4 = \phi_5 = \phi_6 = \phi_7 = \phi_8 = \phi_9 = \phi_{10} = \phi_{11} = \phi_{12} = \phi^{a1}.$$
$$H_0^{2,2} : \phi^{q1} = \phi^{q2} = \phi^{h1}; \phi^{q3} = \phi^{q4} = \phi^{h2}.$$
$$H_0^{2,3} : \phi^{q1} = \phi^{q2} = \phi^{q3} = \phi^{q4} = \phi^{a1}.$$
$$H_0^{3,3} : \phi^{h1} = \phi^{h2} = \phi^{a1}.$$

6. Despite a time series of more than a dozen years, however, this convergence is slow in these data.
7. The only other study which compares paired sales with changes in attributes with paired sales of dwellings with unchanged attributes, by Meese and Wallace (1997), uses data from Oakland and Fremont, California over an 18 year period. For Oakland, Meese and Wallace found that 59% of paired sales had changes in the measured attributes, while for Fremont, they reported that 47% of the dwellings had changed attributes.
8. As pointed out by a careful reviewer of this paper, these statements require some qualifications. Our results clearly reject the aggregation of temporal data from months to quarters to half-years to years in the computation of housing price indexes. They do not provide evidence on the implications of aggregation for the mean squared errors associated with the estimates. In both these respects, our results follow Calhoun, et al. (1995). The more- and less-restrictive sets of estimates could be combined efficiently using a Bayes estimator, but this is beyond the scope of the present paper. See Knight et al., (1992) for a description and a relevant example.
9. Data on repeat sales allows the identification of vintage, age, and depreciation effects. Subtracting the estimate of the effect of depreciation obtained in equation (A8) from the coefficient on the age estimated in (A7) yields an estimate of the vintage effect. That is, $\beta_v = \beta_y - \beta_d$.

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