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ABSTRACT

**A SIMPLE HYBRID MODEL FOR ESTIMATING
REAL ESTATE PRICE INDEXES**

by

John M. Quigley

The accurate measurement of housing and real estate prices is of real theoretical importance and is crucial to understanding the operation of the housing market. Two basic techniques -- hedonic and repeat sales methods -- have been developed to measure and analyze the structure of housing prices.

This paper presents an explicit model for combining samples of single sales and multiple sales for the analysis of housing prices and the computation of more efficient price indices. The procedure is based upon an explicit error structure, incorporating a random walk in housing prices. It is also based upon robust generalized least squares estimation to improve the efficiency of estimation.

The technique is illustrated using a unique sample of condominium sales during a twelve year period in downtown Los Angeles.

I. Introduction

The accurate measurement of housing and real estate price trends is of real theoretical importance and is crucial to understanding the operation of the housing market. For example, recent conclusions about the efficiency of the housing market (Case and Shiller, 1989) depend upon price indexes to measure the returns to arbitrage. Models of consumer behavior, and in particular models which investigate the determinants of speculative price bubbles in real estate (Abraham and Hendershott, 1994), depend upon the accurate measurement of those prices.

The accurate measurement of housing prices is also of enormous practical importance. Applications range from the estimation of regional variation in the cost of living to the computation of transfer payments to the indigent. More recently, as primary housing markets have become more integrated with secondary markets, the computation of housing prices has become of great practical importance to investors who confront choices among portfolios composed of housing securities and other investment assets (Shiller, 1993).

Two basic techniques have been developed to measure and analyze the structure of housing prices. For more than twenty years, hedonic models (Kain and Quigley, 1970) have been used to analyze market prices; repeat sales models have been utilized for an even longer period of time (Baily, Muth, and Nourse, 1963).

Hedonic models relate the selling prices (or monthly rents) of dwellings to measures of their physical and locational

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characteristics and to some representation of time. Hedonic
models are routinely estimated from repeated cross sectional
samples of dwellings, for example sale prices and housing
characteristics reported by multiple listing services or
government agencies (see, for example, Pollakowski, 1987).
However, neither the functional form of the relationship nor the
set of variables is known with certainty; this limits the
generality of the procedure when applied across markets or time
periods.

Repeat sales models avoid these difficulties by measuring
the price of the same house at several points in time. This
obviates the need to measure the characteristics of houses (but
only as long as these characteristics have remained constant
between sales). It also limits the samples available for
analysis. More important than the smaller size of repeat sales
samples is the possibility that they may not be representative of
local housing markets, at least not in the short or medium run
(Gatzlaff and Haurin, 1993).

Repeat sales models typically specify a random walk in
housing prices (Case and Shiller, 1987; Abraham and Schauman,
1991; Quigley and Van Order, forthcoming).

This paper presents an explicit procedure for combining
samples of single sales and multiple sales in the analysis of
housing prices and in the computation of price indices. This is
not the first proposal for combining information across samples
within a single market. Indeed, the so-called hybrid model (Case
and Quigley, 1991) has been used extensively in recent research

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(Case, Pollakowski, and Wachter, 1991). However, in contrast to previous work, the procedure introduced in this paper is based upon an explicit error structure.[1]

Section II below presents the basic model. Section III presents an empirical analysis comparing the estimation of house price indexes. This empirical analysis is based upon an unusual and quite special sample of condominium dwellings in the downtown Los Angeles area. The empirical analysis reported below is based upon essentially all sales of condominium apartments in the downtown Los Angeles area during a twelve-year period. The sample is unusually well suited to the comparative analysis. The dwellings in the sample are all drawn from a few high-rise buildings located within a quarter mile of each other. Thus their locational and public service attributes are quite similar. The sample also includes a large number of repeat sales, facilitating a comparison of alternative estimators of price indices.

II. The Model

The sale value or monthly rent of a housing unit represents an amalgam, PQ, of an index representing the price, P, of housing

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[1]After this paper was drafted, we became aware of other recent work [Hill, Knight, and Sirmans, 1994] which combines single sales and multiple sales using an explicit error structure, but relying upon maximum likelihood techniques. In contrast, the procedure discussed below relies upon robust generalized least squares models to achieve asymptotic efficiency. The procedure introduced below also follows most of the recent literature in specifying a random walk in housing prices.

and another representing the level of services, Q, emitted by that unit. To represent this, suppose

(1) $V_{it} = Q_{it} + P_t + \omega_{it}$,

where V_{it} is the logarithm of the observed selling price of house i at time t, Q_{it} is the log of the quality of house i sold at time t, and P_t is the log of the constant quality housing price index at time t. ω_{it} is a random error.

According to equation (1), each house emits a quality of service Q_{it} which is priced at P_t at a particular point in time. Q_{it} is unobserved, but

(2) $Q_{it} = \beta \, X_{it} + \xi_i + \eta_{it}$.

According to equation (2), housing quality is a function of a vector of observable characteristics of dwellings at time t, X_{it}, and a dwelling-unit-specific factor, ξ_i. The term ξ_i represents the unmeasured characteristics of house i, and η_{it} is a random error. Combining (1) and (2) yields

(3) $V_{it} = \beta \, X_{it} + P_t + \delta_{it}$,

where δ_{it} is the composite error term,

(4) $\quad \delta_{it} = \xi_i + \eta_{it} + \omega_{it} = \xi_i + \varepsilon_{it}$.

Assume

(5) $\quad E(\xi_i) \quad = 0 \qquad\qquad E(\varepsilon_{it}) \quad = 0$

$\quad E(\xi_i)^2 \quad = \sigma_\xi^2 \qquad\qquad E(\varepsilon_{it})^2 \quad = \sigma_\varepsilon^2$

$\quad E(\xi_i\xi_j) \quad = 0 \qquad\qquad E(\varepsilon_{it}\varepsilon_{j\tau}) \quad = 0$

$\quad E(\xi_i\varepsilon_{jt}) = 0$

Suppose, based on empirical evidence,[2] that housing prices follow a random walk such that

(6) $\quad E(\varepsilon_{it} - \varepsilon_{i\tau})^2 / \sigma_\varepsilon^2 = A(t - \tau) + B(t - \tau)^2$.

According to equation (6), if A is positive, the variance in housing price for an individual dwelling increases with the elapsed time between its first sale, τ, and a subsequent sale at time t. If B is negative, then the variance increases at a decreasing rate.

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[2]Case and Shiller (1987, 1989) specified the error structure in equation (6) with B = 0, finding A > 0 and statistically significant for four metropolitan areas. Abraham and Shauman (1991) and Quigley and Van Order (forthcoming) specified the error structure in equation (6) and found that A > 0, B < 0 for 27 of 30 metropolitan areas and all 5 census regions.

If all dwellings in a given sample are repeat sales, all the parameters of the model can be estimated in an asymptotically efficient manner.

Multiple sales provide two important sources of information in estimating the model. First, they permit the systematic components of housing quality to be distinguished from the idiosyncratic components that vary among individual dwelling units. Second, they permit the variance-covariance matrix of disturbances to be estimated, thus improving the efficiency of estimation of the price index P_t as well as the parameters β.

A sample of single sales permits equation (3) to be estimated, but it does not permit the measured characteristics of houses to be distinguished from the unmeasured, individual specific, characteristics of those dwelling units. Presumably, many characteristics of individual houses that are difficult to measure quantitatively, particularly in a large sample, are important in affecting house values. Samples of individual sales do not permit these idiosyncratic elements to be analyzed. In addition, single sales do not permit the variance in values to be analyzed as a function of the elapsed time between sales.

Obviously, ceteris paribus, price indices estimated from equally sized samples of multiple sales are more efficient than those arising from samples of single sales.

Unfortunately, a random sample of transactions during any time interval is likely to yield a subsample of repeat transactions which is much smaller than the subsample of single

sales. For example, Abraham and Schauman (1991) found, using Freddie Mac data, that only two and a half percent of transactions in 30 metropolitan areas were repeat sales over a 19 year time interval. Case and Shiller (1987) found that only 4.1 percent of transactions were repeat sales in four large metropolitan areas over a 16 year interval. Clapp, Giancotto, and Tirtiroglu (1991) found that 25 percent of Connecticut transactions were repeat sales, while recent work by Bradford Case, Pollakowski, and Wachter (1991) found that in a seven year period only about 14 percent of 12,681 transactions in Fairfax County, Virginia were repeat sales without changes in housing attributes.

More important than the small sample sizes for analysis of repeat sales is the possibility--indeed the presumption--that repeat sales are not a random sample of all housing sales, at least not during the short or medium run. It has repeatedly been found that dwellings which are subject to repeat sales differ in many characteristics from those which are sold only once during a given time interval. In particular, lower priced and homogeneous "starter" homes are more frequently traded than higher priced luxury accommodations. One study reports a fifteen percent lower average price for repeat sales than for single sales of residential properties (Clapp, Giancotto, and Tirtiroglu, 1991). Another recent study presents an explicit model of the sample selection process which generates observations on sales in local

housing markets (Gatzlaff and Haurin, 1993).   The authors
conclude that repeat sales indexes are likely to be quite biased.

To combine samples of single and multiple sales in a single
analysis, combine equations (3) and (4)

(7) $V_{it} = \beta X_{it} + P_t + \xi_i + \varepsilon_{it}$,

and estimate the parameters using the subsample of repeat sales.
That is, regress the log sale price on the log of housing
characteristics, a set of dummy variables for time period (or
perhaps some other parameterization of time), and a set of dummy
variables for individual dwellings.   Similarly, estimate (3)
using the same sample. This yields $\hat{\sigma}_\varepsilon^2$, $\hat{\sigma}_\delta^2$, unbiased estimates
of σ_ε^2 and σ_δ^2, and a set of residuals $\hat{\varepsilon}_{it}$. After some slight
manipulation[3], this also yields $\hat{\sigma}_\xi^2$, an unbiased estimate of σ_ξ^2.

For all multiple sales, estimate equation (6) with dependent
variable $[\hat{\varepsilon}_{it} - \hat{\varepsilon}_\tau]^2$. This yields regression coefficients $\hat{A}$ and
$\hat{B}$, estimates of A and B.   Together, these parameters identify
completely the variance-covariance matrix of disturbances in
equation (7).

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[3] $\hat{\sigma}_\xi^2 = (\hat{\sigma}_\delta \cdot f - \hat{\sigma}_\varepsilon^2)/H$ where H is the number of individual
dwellings and f corrects for degrees of freedom, i.e. $f = (N-H)/N$
where N is the degrees of freedom in the computation of $\hat{\sigma}_\delta^2$.

$$(8) \quad E(\xi_i + \varepsilon_{it}, \; \xi_j + \varepsilon_{j\tau}) = \begin{cases} 0 & \text{for } i \neq j, \\ \hat{\sigma}_\xi^2 + \hat{\sigma}_\varepsilon^2 [1 + \hat{A}(t-\tau) + \hat{B}(t-\tau)^2] & \text{for } i = j. \end{cases}$$

Now, using the entire sample of single sales and repeat sales, estimate equation (7) by generalized least squares, where the weights are derived from equation (8).

The advantage of this approach is that it utilizes all sales observations, not just repeat sales, in a common framework. The procedure utilizes the unique information on repeat sales to account for the contribution of unmeasured housing attributes to the total variance and to account for the error covariances. It utilizes the additional information on single sales to increase the efficiency of estimation of the parameters β and P_t.

III. Empirical Analysis

The empirical analysis is based upon a sample of 843 condominium sales recorded during the twelve year period, from January 1980 through December 1991, in downtown Los Angeles. The sample represents essentially every condominium sale within the downtown area during this time period. Condominiums were located in four different high rise properties which realtors and real estate agents consider "comparable" for the purpose of appraisal. There are no other "comparables" within several miles of downtown. We gathered information on the original selling prices of each of the condominiums in one of the high rise properties completed in 1980 together with all subsequent sales of these

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dwelling units. We also obtained information on all condominium sales in each of the other three properties beginning in 1980. Property characteristics were obtained by matching addresses to condominium floor plans. Resale information was obtained from multiple listing services, from court records, and from real estate lenders.

Because the sample consists of properties in only four high rise buildings located within about a quarter mile of each other, the neighborhood and public service amenities associated with these properties are identical. The condominiums vary in their size and their location within each of the buildings. We recorded the date of each sale and the selling price of the property. Selling prices are reported in real terms, using the quarterly Consumer Price Index (See **Economic Report of the President**, 1992). In none of the condominiums, were the physical characteristics of the sale properties changed during the sample period.

The 843 sales represent transactions on 584 different properties. 380 of these properties, or about 45 percent, were sold one time. Another 158 were sold twice, 37 were sold three times, 9 were sold four times.

Table 1 provides a summary of the characteristics of observations on the first sales and those on multiple sales. Note that observations on repeat sales tend to be of smaller units, located on higher floors in these condominiums. They are also substantially less valuable than those sold only once during the twelve-year period. The table also indicates the

Table 1
Average Characteristics
of Single Sales and Multiple Sales:
Downtown Los Angeles Condominiums
(standard deviations in parentheses)

A.   By Order of Sale

	First Sale	Second Sale	Third Sale	Fourth Sale	All Sales
Size (1000 sq ft)	1.091 (0.33)	1.023 (0.33)	0.955 (0.32)	0.877 (0.36)	1.065 (0.33)
Location (Story)	9.962 (7.25)	11.525 (7.79)	13.696 (8.17)	14.444 (9.18)	10.592 (7.52)
Elapsed Time* (quarters)	29.430 (5.18)	19.157 (11.31)	12.652 (9.39)	7.333 (7.87)	25.793 (9.36)
Price (10000 1980 dollars)	20.353 (6.30)	16.170 (5.80)	14.535 (5.30)	11.982 (3.96)	18.934 (6.49)
Number of Sales	584	204	46	9	843

B.   By Number of Sales

	Units Sold				
	One Time	Two Times	Three Times	Four Times	All Units
Size (1000 sq ft)	1.127 (0.33)	1.043 (0.33)	0.974 (0.33)	0.877 (0.34)	1.065 (0.33)
Location (Story)	9.124 (6.81)	10.89 (7.58)	13.514 (7.96)	14.444 (8.78)	10.592 (7.52)
Elapsed Time* (quarters)	30.533 (5.65)	23.796 (9.57)	18.637 (9.65)	15.347 (9.59)	25.793 (9.36)
Price (10000 1980 dollars)	20.596 (5.96)	18.102 (6.55)	17.719 (6.70)	14.066 (5.47)	18.934 (6.48)
Number of Units	380	158	37	9	584

Note: *Elapsed time from previous sale or from January 1, 1980.

characteristics of dwelling units sold one time during the period as well as those sold two, three, and four times during the twelve-year interval. During a twelve-year period, dwelling units involved in multiple sales constitute about 65 percent of all units in the sample, but their economic characteristics differ in important ways from those units involved in single sales.

The statistical analysis relates the selling prices of these apartments to the sizes, x_1, and location, x_2, of these properties and to the timing of sales. The deterministic part of the model is:

$$(9) \quad \log V_{it} = \beta_0 + \beta_1 \log x_{i1} + \beta_2 \log x_{i2} + \sum_{t=1}^{45} P_t \, d_{it} \quad .$$

In this formulation, time, d_{it}, is measured in quarter years from July 1, 1980 (1980:III). The dummy variable, d_{it}, has a value of one if dwelling unit i is sold in quarter t and zero otherwise. The coefficients of the set of dummy variables, P_t, represent the price index for downtown condominiums.

For comparison, we also report the results using a simple exponential price trend:

$$(10) \quad \log V_{it} = \beta_0 + \beta_1 \log x_{i1} + \beta_2 \log x_{i2} + P_0 t \quad ,$$

where t is measured in quarters.

Panel A in Table 2 reports the coefficients of ordinary least squares (OLS) regression estimates of equations (9) and (10) based on the entire sample of 843 observations on condominium sales. Regression I explains about 73 percent of the variance in log selling prices during the twelve-year period. The variables measuring size and location are highly significant as is the set of 45 coefficients (not presented) which represent time. For comparison, regression II reports the results using a single exponential price trend.

Regressions III and IV report the results of the same model estimated on the subsample of 463 repeat sales. The precision of the parameter estimates is reduced, presumably reflecting the smaller sample size.

Regressions V and VI report the results of the OLS regressions on repeat sales incorporating the error structure of equation (4). Regression V includes variables representing size and location, 45 variables representing time, and a separate dummy variable for each of the dwelling units. This latter set of variables is highly significant and increases the explained variance in the model from 73 percent to 91 percent. Regression VI provides analogous estimates based on a simple exponential price trend. In both cases, when the dwelling-unit-specific dummy variables are included, the size and location variables are statistically insignificant.

Table 3 uses the regression results reported in regression V to estimate the parameters of the random walk process. In this analysis, the dependent variable is computed from the residuals

Table 2
Ordinary Least Squares Regression Coefficients
(t ratios in parentheses)

	Intercept	Size	Location	Time	Dwelling Unit Dummies	R^2	$\hat{\sigma}_\delta^2$	$\hat{\sigma}_\xi^2$	$\hat{\sigma}_\varepsilon^2$
A. All sales (843 observations)									
I.	5.319 (27.44)	0.913 (41.72)	0.071 (7.29)	*	No	0.730	0.037	--	--
II.	5.754 (36.13)	0.922 (41.48)	0.061 (6.57)	-0.009 (16.37)	No	0.685	0.041	--	--
B. Repeat sales (463 observations)									
III.	5.440 (21.14)	0.902 (28.88)	0.051 (3.62)	*	No	0.742	0.041	--	--
IV.	5.818 (25.71)	0.913 (29.16)	0.052 (3.85)	-0.009 (12.78)	No	0.680	0.046	--	--
V.	5.136 (0.90)	0.172 (0.11)	2.179 (0.83)	*	Yes	0.907	--	3.231	0.029
VI.	6.027 (1.13)	0.655 (0.45)	0.761 (0.33)	-0.010 (15.53)	Yes	0.879	--	0.393	0.031

Note: Dependent variable is the logarithm of selling price in 1980 dollars.

* Regression includes 45 variables measuring elapsed time in quarters from January 1, 1980.

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Table 3
Estimates of Random Walk Parameters *
(t ratios in parentheses)

VII. $(\hat{\varepsilon}_{it} - \hat{\varepsilon}_{i\tau})^2/\hat{\sigma}_\varepsilon^2 = 0.0018[t - \tau]$ $R^2 = 0.052$
                               (7.94)

VIII. $(\hat{\varepsilon}_{it} - \hat{\varepsilon}_{i\tau})^2/\hat{\sigma}_\varepsilon^2 = 0.0050[t - \tau] - 0.0001[t - \tau]^2$ $R^2 = 0.032$
                               (5.79)   (3.83)

Note: * Regressions are based on 323 observations on differences in residuals for dwellings sold more than once.

in the regression. Regression VII reports the results of a linearly increasing random walk term; regression VIII estimates a quadratic. The results indicate quite strongly that the variance in housing price increases between sales, but at a decreasing rate.

Table 4 presents the generalized least squares (GLS) regression results, incorporating the individual specific error variance and the random walk in housing prices. We use the coefficients of the quadratic specification of the random walk, Regression VIII, together with the error variances reported in Table 2 to compute the elements of the variance-covariance matrix, specified in equation (8), for the GLS regressions.

The parameters presented in Table 4 differ from those in Table 2, panel A, only in their efficiency of estimation. Those in Table 4 utilize the additional information made available to the analyst when there are multiple observations on at least some of the dwellings in the sample.

Figure 1 illustrates the advantage of this GLS procedure when compared to the OLS estimates using the entire sample of 843 observations on condominium sales. The figure presents the 95 percent confidence interval for the housing price index computed from the coefficients, P_t, of the dummy variables in regressions I and IX. The index is normalized so that the initial price level, for 1980:III is one. The solid line represents the confidence interval associated with the OLS estimate (regression I); the broken line represents the confidence interval

Table 4
Generalized Least Squares Regression Coefficients
843 Observations
(t ratios in parentheses)

	Intercept	Size	Location	Time	$\hat{\sigma}_\delta^2$
IX.	5.251	0.933	0.044	*	0.055
	(34.40)	(48.14)	(5.06)		
X.	5.802	0.919	0.045	−0.009	0.073
	(38.05)	(43.74)	(4.99)	(17.98)	

Note: * Regression includes 45 variables measuring time in quarters from January 1, 1980.

Figure 1
Comparison of 95 percent confidence intervals:
Prices of Los Angeles Condominiums
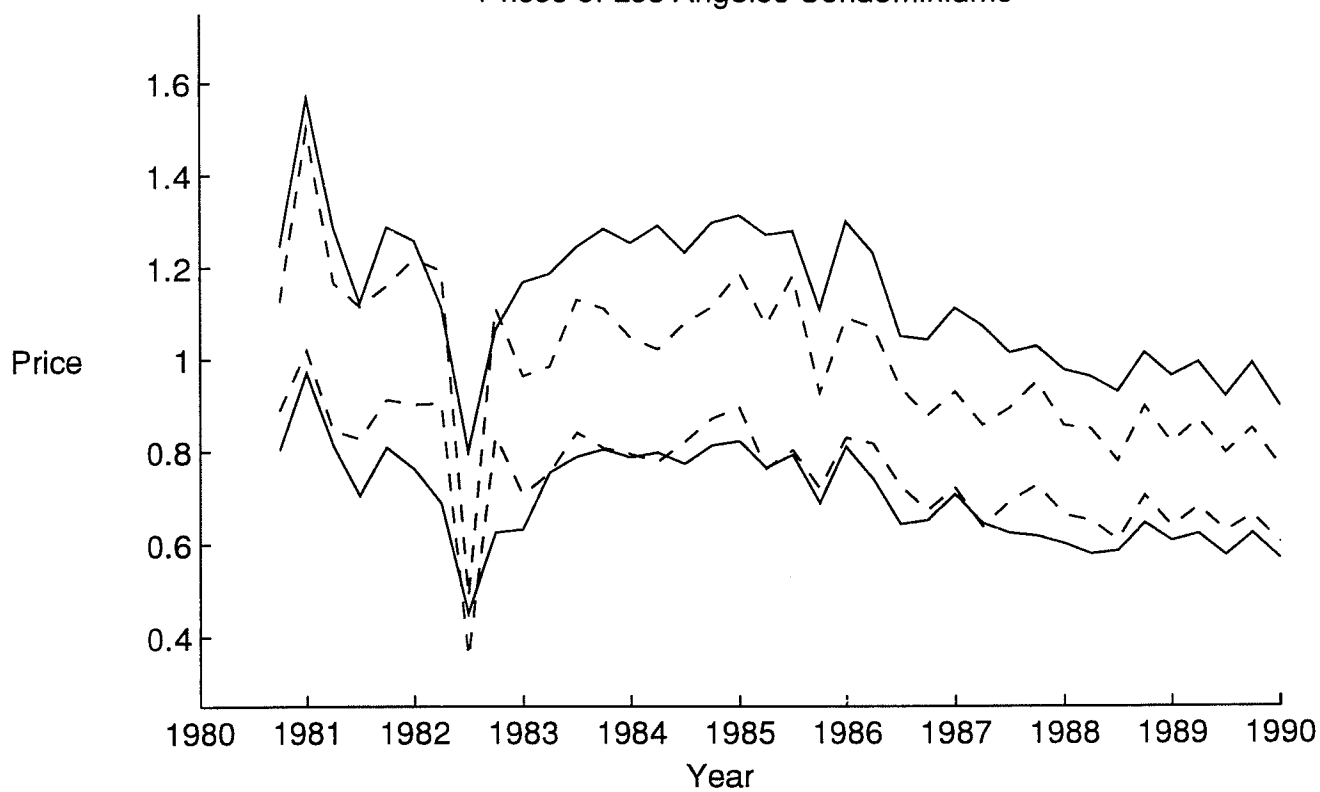
Note: Solid line represents OLS estimate.
Broken line represents GLS estimate.

associated with the GLS estimate (regression IX). It is clear in this instance that the confidence interval is tighter when the information obtained from multiple sales is utilized in the estimation process. This additional information is used to estimate the individual specific component of variation as well as the determinants of the variance in housing prices.

IV. Summary

This paper has presented a simple methodology for combining information on single sales and on multiple sales in the estimation of housing price indexes. The methodology combines the advantages of large samples available in cross sections of individual sales with the increased precision available in samples with repeated observations on individual dwellings.

The model incorporates an explicit error structure which assumes a random walk in housing prices and a dwelling unit specific component of variation. Estimation of the model relies upon robust linear techniques, rather than maximum likelihood estimation, to achieve asymptotic efficiency.

The technique is illustrated using a unique sample representing virtually all sales of downtown Los Angeles condominium dwellings in a twelve-year period. The sample includes a large number of repeat sales, and the results suggest that recognition of this feature of the data has a substantial effect upon the precision of estimation of an index of condominium prices. In this application, the incorporation of

the multiple sales nature of the data substantially reduces the standard errors and the confidence interval of the price index.

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