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The Asset Approach to Pricing Urban Land: Empirical Evidence

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Many papers have attempted to explain intermetropolitan variations in the price of housing using multi-equation models of the metropolitan housing market. This paper uses a long-run equilibrium urban asset model to explain such variations. The model builds upon previous models that introduce uncertainty into the dynamic urban model of land conversion. The empirical results strongly support the asset approach to valuing land in urban areas.

INTRODUCTION

This paper presents an empirical test of the simple dynamic models of land conversion under certainty and uncertainty in Capozza and Helsley (CH) [3], [4]. CH present models of a growing urban area, designed to highlight the implications of growth and uncertainty on prices and rents in an urban area.

The models can be applied to explain the wide variation in land and housing prices among metropolitan areas in North America. For example, the average price of a house in Calgary in 1981 was more than twice that in Winnipeg.[1] Similarly, the average house price in San Diego, $97,500, was twice Detroit's $48,000 in 1981.[2] The Detroit/San Diego illustration is quite striking since Detroit is a much larger city and one normally might expect larger cities to be more costly.

This inter-urban area price variation has attracted a number of

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[2]National Association of Realtors, *Monthly Report*, April 1984.

empirical studies recently, including Nellis and Longbottom [11], Buckley and Ermisch [2], Ozanne and Thibodeau [12], and Fortura and Kushner [6]. The model underlying these papers is a supply and demand model. In each study, a large number of variables enter the reduced form equation. These variables include incomes, number of households, demographic characteristics, prices of non-housing goods, amenities, taxes, public utilities, interest rates, expected inflation, etc.

By contrast, this paper tests models of long-run equilibrium urban asset values. In the models, small open urban areas are subject to equilibrating migration between urban areas within the country. As a result, a different and smaller list of variables enters the reduced form for prices and rents. This list includes: city size, city growth, the user cost of capital, the cost of conversion, and agricultural rent levels. In the uncertainty case, the variance of growth is also included.

The remainder of the paper is divided into four sections. Section two describes the models. In the third section, we specify the empirical model used to test the hypotheses derived from the theoretical model. We also discuss our data sources in this section. Our results are presented in section four. Section five concludes the paper and gives some suggestions for future research.

THE THEORETICAL MODEL

Cities are assumed to be small, open, circular, and situated on a homogeneous plain. Not all land can be developed, but that which can be developed is located in an arc of 2ϕ radians. All employment and production is concentrated in the Central Business District (CBD), hence all employees must commute daily to the CBD. Locations are differentiated by their distance from the CBD, where the unit of distance is defined so that it costs one dollar to commute one unit of distance.

Household Equilibrium

We assume that at each time $t \in \mathcal{R}_+$ households derive their utility from the consumption of housing and a composite, numeraire good.[3] In addition, all households are identical, and no other factors affect household utility. It is further assumed that each household rents exactly one unit of housing.

Households allocate their income to housing rent, the consumption

[3]The following notation is adopted: $s \in \mathcal{R}_+$ means $0 \leq s < \infty$ and $s \in \mathcal{R}_{++}$ means $0 < s < \infty$.

of the composite good, and transportation costs to and from the CBD. The problem facing an individual household is to choose the location z which maximizes its indirect utility. The first order condition governing this choice is $-r_z(z, t) = 1$, where r_z is the partial derivative of the housing rent function with respect to z. Thus, a household locates at the point where the decrease in housing rent from moving a marginal unit further from the CBD is just offset by the increase in commuting cost. Hence we can write

$$r(z, t) = r(0, t) - z \tag{1}$$

The Developer's Problem

To investigate pricing we assume that future rents follow the normal diffusion process

$$dr(z, t) = \mu dt + \sigma dB(t) \qquad (z, t) \in \mathcal{R}_{+} \times \mathcal{R}_{++} \tag{2}$$

where μ and $\sigma > 0$ are the mean and variance of the process, respectively, and $B(t)$ is a standard Brownian motion. Since this is a normal process, μ gives the growth in rents. The assumption that $B(t)$ is a standard Brownian motion implies that rents follow a random walk around the constant growth. In the limit as $\sigma \to 0$, the uncertainty model collapses to a certainty model with annual growth of rents μ.

In a certain world, the price of a developed plot of land at time t is given by the present value of future rents

$$P^d(z, t) = \int_t^{\infty} r(z, \tau)e^{-\rho(\tau-t)}d\tau \tag{3}$$

$$t \in [t^*, \infty]$$

where ρ is the constant rate of time preference and t^* is the time at which the land was developed. If the plot of land has not yet been developed, and is in agricultural use, its present value is

$$P^a(z, t, t^*) = \int_t^{t^*} ae^{-\rho(\rho-t)}d\tau + \int_{t^*}^{\infty} r(z, \tau)e^{-\rho(\tau-t)}d\tau +$$

$$Ce^{-\rho(t^*-t)}t \in [0, t^*] \tag{4}$$

In this equation, a is the opportunity cost of land (agricultural land rent) and C is the cost of transforming the land from agricultural to urban use. Both are assumed to be constants.[4] The first term in (4) is

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[4]The assumption that a and C are constants can be relaxed. Similar results are realized. See Capozza and Li [5]. Also it should be noted that two interpretations of C are possible. If we take C to be the cost of servicing land for urban use, then P is the price of serviced land. If C is assumed to include the cost of a structure, then P is the price of housing. In either case a fixed capital/land ratio

the present value of agricultural land rents between t and the date of conversion. The second term is the present value of urban housing rents from the date of conversion onwards. The last term is the present value of the conversion cost.

In a certain world, the developer's problem is to choose a date $t^* \in [t, \infty]$ on which to convert land at the periphery of a city into developed urban land. The optimal date of conversion is the date that maximizes P^a. Differentiating (4) with respect to t^* yields the first order condition

$$r(z^*, t^*) = a + \rho C \tag{5}$$

where z^* is the location of the boundary of the city. Development occurs when the rent in urban use equals the opportunity cost of land plus the opportunity cost of the capital funds needed to effect the conversion to urban housing.[5]

Equation (5) only holds at the edge of the city, i.e., at z^*. The location of the boundary of the city at time t^* is the point within which all households consume their unit of housing. In a circular city with 2ϕ radians of developable land and containing $N(t^*)$ households

$$z^*(t^*) = \left[\frac{N(t^*)}{\phi}\right]^{\frac{1}{2}} \tag{6}$$

When the future is uncertain, a risk-neutral developer will maximize the expected present value of future rents, $EP^a(z, t, t^*)$. This problem can be solved either as a first hitting time problem (CH [4]) or as an optimal stopping problem (Capozza and Li [5]). To begin, let

$$t_{\bar{r}} = inf\{s \geq 0; r(t + s) > \bar{r}\} \tag{7}$$

be the first time the stochastic process $r(t)$ exceeds $\bar{r}$. The time $t_{\bar{r}}$ is known as the first hitting time with respect to the value $\bar{r}$. Because $r(t)$ is stochastic, $t_{\bar{r}}$ is stochastic and has a probability density function induced by the probability that $r(t) > \bar{r}$. In the case of a Brownian motion with drift, both the probability density function and the moment generating function for $t_{\bar{r}}$ are well known (Karlin and Taylor [9] 362-63). The solution strategy is to first use the probability density for $t_{\bar{r}}$ to calculate the expected value of developable land conditional on $\bar{r}$. The second step entails choosing $\bar{r}$ to maximize the expected value of the developed land.

Since $\bar{r}$ determines the expected value of $t_{\bar{r}}$, choosing $\bar{r}$ optimally gives the optimal expected date of development.

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is implicitly assumed. We have taken the latter interpretation for the empirical specification.

[5]The second order condition for this problem is: $\dot{r}(z^*, t^*) > 0$. This condition implies that rents must be rising faster than the opportunity costs of development which, in this case, are constant. See CH [3].

Thus, the developer's maximization problem may be written as

$$\max_{t^*} EP^a(z, t, t^*) = \max_{\bar{r}} E\{P^a(z, t, \bar{r})|\bar{r}\} \tag{8}$$

This problem has the solution (see CH [4]),

$$r(z, t) = \begin{cases} a + \rho C + \dfrac{\rho - \alpha g}{\alpha \rho} + (z^* + z) & z \in [0, z^*(t)] \\ a & z \in (z^*(t), \infty) \end{cases} \tag{9}$$

where

$$\alpha = \frac{\sqrt{g^2 + 2\sigma^2\rho} - g}{\sigma^2}$$

Thus, rent at the edge of a city, $(z = z^*)$, is the sum of three components: the opportunity cost of land in terms of its competing use (i.e., agriculture), the opportunity cost for the funds used to convert the land to urban use, and an uncertainty premium, $\frac{\rho - \alpha g}{\alpha \rho}$. Inside the city boundary, $(z^* - z) \in [0, z^*)$ gives the location premium on housing closer to the CBD. It can be shown that the uncertainty premium is nonnegative for all $(\mu, \sigma^2) \in \mathscr{R}^2_+$ and only equals zero in the limit as $\mu \to \infty$ or $\sigma^2 \to 0$. It can also be shown that the uncertainty premium is a decreasing function of the growth rate in rents, and an increasing function of the variance in the stochastic process governing rents (CH [4]).

The economic intuition behind these results is straightforward. In a world where rents fluctuate, developers will wait for higher rents before converting to urban use in order to ensure that an increase in the rent is permanent and not merely a transitory spike in the stochastic process. Accordingly, the uncertainty premium decreases in the growth rate because the revenue lost from developing too soon is smaller when rents are growing quickly. Also, the uncertainty premium increases with the variance in rents because a larger variance increases the cost of making an error and developing too soon.

Before turning to the empirical model, it should be noted that the results above are not based on risk aversion. They are obtained even though investors are risk neutral. All that is required is that the investors know that rents are stochastic and, in a sense, are sceptical about the permanence of any rent increase.

EMPIRICAL MODEL

Equation (9) gives the rent that will trigger development at the edge of the city. Usually, one observes prices rather than rents. Hence, the analysis must be recast in terms of the price that will trigger development if it is to yield any empirically testable hypotheses.

Carrying out the same analysis on prices as on rents gives the price function

$$P(z, t) = \begin{cases} \dfrac{\pi}{\rho} + C + \dfrac{g}{\rho^2} + \dfrac{1}{\alpha\rho} + \dfrac{(z^* - z)}{\rho} & z \in [0, z^*] \\ \dfrac{a}{\rho} + \dfrac{g}{\rho^2} e^{-\alpha[z - z^*(t)]} + \dfrac{\rho - \alpha g}{\alpha\rho^2} e^{-\alpha[z - z^*(t)]} & z \in (z^*, \infty) \end{cases} \tag{10}$$

where z^* is given by equation (6). Equation (10) is illustrated in Figure 1.

These prices are increasing in both μ and σ^2. $P_\mu(z, t^*) > 0$ because the growth in rents over the time interval $[t^*, \infty]$ more than compensates for the reduction in the uncertainty premium at time t^* brought about by the increase in μ. $P_{\sigma^2}(z, t^*) > 0$ because $r_{\sigma^2}(z, t^*) > 0$; that is, because the uncertainty premium increases the rent at time t^*. In addition, simple differentiation shows that, for $\alpha > 1, P(z^*, t^*)$ is: (i) increasing in a, the opportunity cost of the land in its next best use, (ii) increasing in C, the cost of converting the land to urban use, (iii) increasing in $N(t^*)$, the number of households in the city at time t^*, and (iv) decreasing in ρ, the cost of capital.

All of these results are potentially testable. The primary limitation is in finding a data set which contains the variables in the model. We use a cross-section time-series data set. The cross-sections are formed by the Census Metropolitan Areas (CMAs) in Canada. The time-series span the years 1969 to 1984. The time-series are not all of the same length, however. For several CMAs, the available time-series was as short as 1975-1984. Rather than truncate all the cross-sections to conform to the shortest time-series or ignoring the CMAs with little time depth, a full information estimation technique is employed which uses all the available data points for all the CMAs.

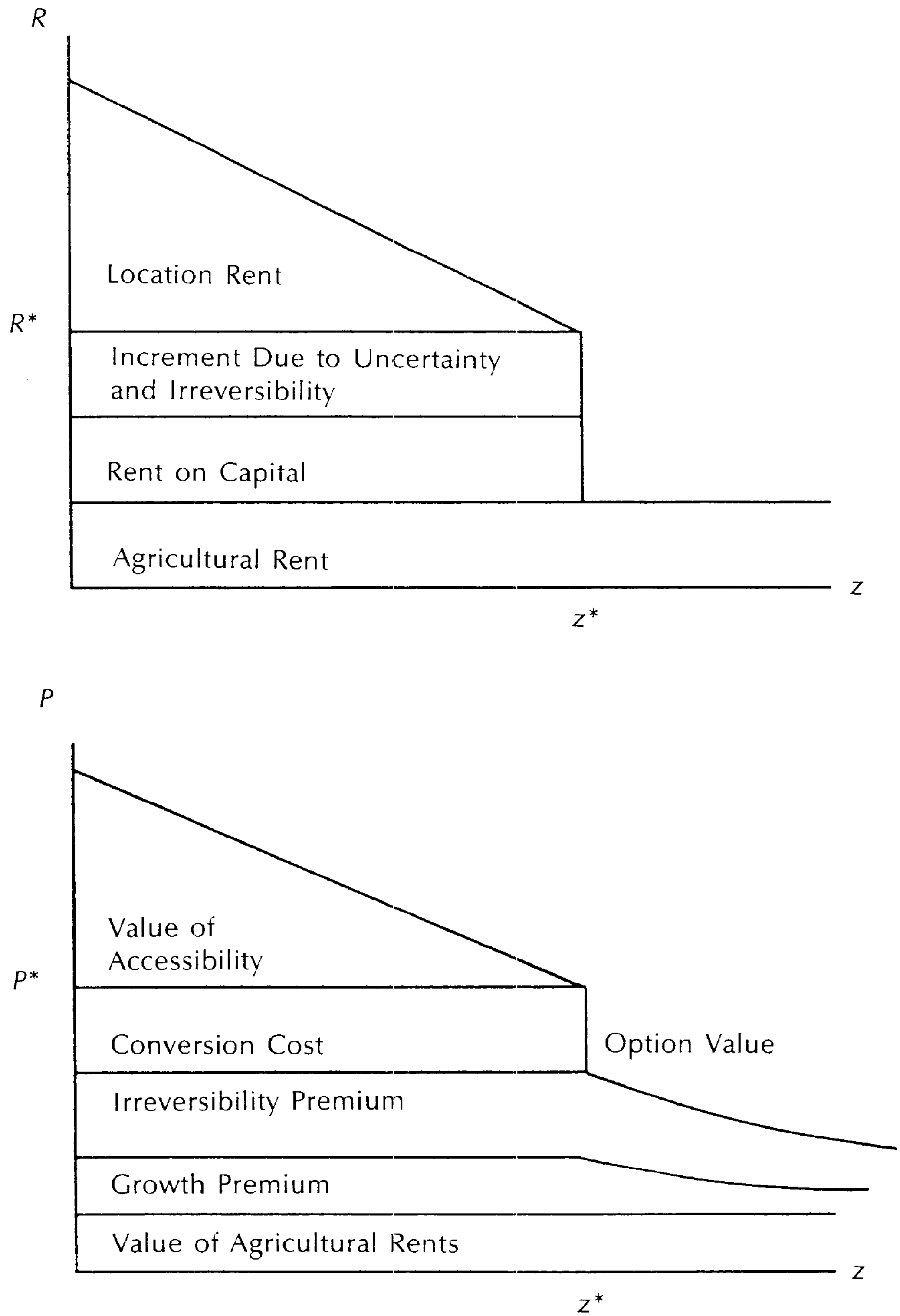
For each CMA, the data set contains the number of housing starts, housing completions, and housing units under construction for each year. It also contains a price index for newly completed dwellings, as well as subindexes for the land and construction cost components of a newly completed dwelling.

The price index for the land component of the price of newly completed dwellings corresponds closely to the land price $P(z^*, t^*)$ in equation (10) if we interpret C as the cost of servicing land.[6] Ideally, this

[6]The land price index includes more than the price of undeveloped, raw land. It includes various servicing costs associated with bringing the land on-stream for construction.

Figure 1

Equilibrium Rents and Prices under Uncertainty



would have been the dependent variable in the empirical analysis. Unfortunately, the price subindexes are not available for the same time period as the main index and there are missing values within each series. Consequently, the composite price index for newly completed dwellings in real terms is used as the dependent variable. This corresponds to interpreting C as both the cost of servicing land and the cost of adding a structure. Since the land component is highly correlated (.94) with the composite price index, we expect our results using the composite index to be similar to results obtained using the land component.

The independent variables are more problematic. To begin, there are no data on the opportunity cost of land at the periphery of cities, nor is there any information on the value of the agricultural land surrounding the CMAs. In addition, the data on the costs of converting raw land to urban use are fragmentary at best. Thus, it is not possible to construct the term $\frac{a}{\rho} + C$ from observable data. The best we can do is to create a proxy for this term with a set of dummy variables for the Census Metropolitan Areas, $\tilde{a}_i$, $i = 1, \ldots, 21$, where $\tilde{a}_i = 1$ for CMA i, and is zero otherwise.

The number of households in each CMA is available directly from the Census of Canada for the census years 1966, 1971, 1976, and 1981. To fill in the number of households in each CMA for the remaining years, the census values were interpolated. This procedure is both reasonable and expedient since the number of households in a CMA changes slowly over time. Moreover, since we are dealing with long-run equilibrium prices, short-run fluctuations in the number of households brought about by transitory increases or decreases in net migration can be ignored safely.

Two variables are used to capture the discount rate or user cost of capital, ρ. The first is a real rate of interest variable (denoted by $\rho^{(1)}$). This variable was constructed by taking the difference between the average prime business loan rate for a year and the annual rate of inflation for that year. The second discount rate variable is the average nominal rate of interest on prime business loans (denoted by $\rho^{(2)}$).[7]

To complete the model, data are needed on the expected rate of growth of housing rents and the variance in the expected rate of growth. Since both of these are derived from developer expectations, they are latent variables. To obtain estimates for these variables, we model the expectations process.

A simple model of developer expectations is used. It is assumed that

[7]See Villani [15] for a discussion of the user cost of capital in a housing context. The tax subsidy to homeownership tends to increase as the inflation rate and nominal interest rate rise.

developers base their expectations of future growth rates in the rental price for urban housing on the expected values of a set of demand indicators. We use one indicator, the expected growth rate in housing stock in a CMA. The growth in the stock is measured by the ratio housing completions to the existing stock. This choice is motivated in part by the limits of the data. Nevertheless, the growth rate of housing stock is a reasonable measure of demand since an increase in demand will increase the flow rate of completions and, conversely, a decrease in demand will decrease the flow rate of completions.

We assume that the growth rate in housing completions, denoted by $g(t)$, follows the ARIMA (0, 1, 1) process

$$g(t) = g(t - 1) + \zeta(t) + \theta\zeta(t - 1) \tag{11}$$

where $\zeta(t)$ is white noise with mean zero and variance ω^2, and θ is a parameter. This process is nonstationary. Given (11), the expected growth rate in housing completions for period $t + 1$ can be written as

$$\bar{g}(t + 1) = (1 + \theta) - \left(\sum_{j=0}^{t-1} (-\theta)^j g(t + j) + (-\theta)^t g(0) \right) \tag{12}$$

where $g(0)$ is the (unknown) initial value of the dynamic process. Thus, the expected growth rate in housing completions is an exponentially weighted moving average of the previously observed growth rates in housing completions.[8] The expression (12) can be rearranged to give the well-known recursion formula

$$\bar{g}(t) = \lambda g(t - 1) + (1 - \lambda)\bar{g}(t - 1) \tag{13}$$

where $\lambda = 1 + \theta$. Written in this way, the forecast has a strong intuitive appeal. Equation (13) shows that a developer's expected growth rate is an average of the observed growth rate in the preceding period and the developer's accumulated experience, up until the previous period. The parameter λ gives the weight accorded each component. When $\lambda \to 1$, all evidence from previous observations is ignored and the expected growth rate follows a random walk. At the other extreme, when $\lambda \to 0$, almost no weight is given to current observations and the expected growth rate equals that of the previous period. Beyond its intuitive appeal, such a forecast is easy to implement.

For each CMA, equation (11) is estimated by maximum likelihood. There are three parameters in each equation: θ, ω^2, and $g(0)$.

The first two are the standard parameters of an ARIMA (0, 1, 1) process; the last is not. Normally, $g(0)$ is replaced by the expected value of ζ, which is zero. Rosenberg [13] argues against this procedure since

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[8]Because of the exponentially declining weights in equation (12), the values of the process are sometimes referred to as "exponentially smoothed" values.

the errors in the initial conditions for nonstationary processes will not be washed out as time progresses, as is the case with stationary processes. Therefore, $g(0)$ should either be included as a parameter or it should be estimated from data. See Harvey [7], p. 113. We have adopted the first solution.

The maximum likelihood procedure requires the computation of the expected growth rates and the variances of the expected growth rates for each time period in the estimation for all parameter settings. To compute these values, the model is recast in state space form and the Kalman filter is used to recursively generate the values. Once the model is estimated, the Kalman filter is used to compute the estimates of the expected growth rate and its variance used in the house pricing equation. It should be noted that the Kalman filter gives minimum mean square error estimates of these values (Harvey [7], pp. 104-10).

Using the data described above, we estimate the following model.

$$P(t) = \tilde{a}_0 + \sum_{i=1, i\neq 19}^{21} \tilde{a}_i + \beta_1\rho^{(1)}(t) + \beta_2\rho^{(2)}(t) + \beta_3 N(t)^{\eta} + \beta_4\bar{g}(t) + \beta_5 V(t) + \beta_6 t + \epsilon \quad (14)$$

where the $\tilde{a}_i$ are the CMA dummy variables described above (the dummy variable for Toronto is omitted to avoid singularity), $\rho^{(1)}$ is the real interest rate variable, $\rho^{(2)}$ is the nominal interest rate variable, N is the number of households in a CMA, $\bar{g}$ is the expected growth rate, V is the variance in the expected growth rate, and t is a time trend. Because of the term $N(t)^{\eta}$, this equation is nonlinear in the parameters. The number of households was included in this manner because it enters the land price equation (10) nonlinearly. The time trend is an afterthought. It is included to capture an increase in agricultural rents or conversion costs.

Stochastic Assumptions

The disturbance term in the regression equation (14) is assumed to be cross-sectionally heteroscedastic and timewise autoregressive. The possibility of heteroscedastic disturbances can be seen clearly in plots of house prices versus city size. As the number of households increases, the spread in house prices about a trend line increases. This is the pattern one would expect if the variance in house prices increases with city size.

The growth and uncertainty effects on housing prices may be intertwined with factors causing heteroscedasticity in regression disturbances. This in turn suggests that there may be a significant signal extraction problem associated with disentangling the separate effects. Because of this, and to assess the extent of the signal extraction problem, the model is also estimated under the assumption of a scalar variance-covariance matrix. We assume that the disturbances are timewise autoregressive to capture the net effects of omitted variables.

THE RESULTS

The regression equation (14) is estimated by nonlinear least squares, in the case of a scalar variance-covariance matrix, and by iteratively reweighted nonlinear least squares, in the case of cross-sectionally heteroscedastic and timewise autoregressive errors. The latter procedure is the nonlinear variant of the procedure presented in Kmenta ([10], pp. 618-22) for linear equations. Tables 1 and 2 present the coefficients from the regressions.

In the scalar covariance matrix model, the coefficients support the model. The real interest rate has a statistically significant negative sign, as it should. The nominal interest rate has a statistically signifi-

TABLE 1

Scalar Covariance Matrix Model

Variable		Coefficient	T-Statistic
$\rho^{(1)}$	Real Rate	−4.85	−8.77
$\rho^{(2)}$	Nom. Rate	1.32	3.67
N	Households	10.91	3.35
η	Curvature	.17	n.a.
$\bar{g}$	Growth	6.13	3.38
V	Variance	2.83	.35
t	Time	−2.38	−2.36
Constant		−428.47	−2.98
		CMA Dummy Variables	
Calgary		68.01	2.00
Edmonton		64.57	2.62
Halifax		182.64	4.24
Hamilton		113.62	4.23
Kitchener		160.37	3.65
London		148.93	3.58
Montreal		−63.98	−2.54
Ottawa-Hull		89.00	4.57
Quebec City		101.73	3.85
Regina		194.17	3.59
St. Catharines		163.62	4.07
Saint John		231.83	3.67
St. John's		212.26	3.57
Saskatoon		178.04	3.06
Thunder Bay		226.98	3.82
Vancouver		−57.44	−2.31
Victoria		148.26	3.45
Windsor		172.99	3.90
Winnipeg		90.43	4.13

cant positive sign, also as expected, since the interaction of inflation with income taxes tends to reduce the user cost of capital and cause individuals to adjust their portfolios, giving higher weights to real assets like real estate.

The number of households in a CMA exerts a statistically significant positive force on housing prices. This force is highly nonlinear in the number of households though, as the estimated power transform coefficient, η, is .169.

The expected rate of growth in urban housing prices has the expected positive sign and the coefficient is statistically significant. The variance in the expected growth rate is not significant but does have a positive effect as predicted.

The results from the cross-sectionally heteroscedastic and timewise autoregressive are the same with two exceptions. First, the estimated power transform coefficient η on the number of households is much larger—.575. This value is not significantly different, in the statistical sense, from the .5 indicated by equation (6). Second, the coefficient on

TABLE 2

Cross-sectionally Heteroscedastic and Timewise Autoregressive Model

Variable		Coefficient	T-Statistic
$\rho^{(1)}$	Real Rate	−1.63	−6.27
$\rho^{(2)}$	Nom. Rate	.38	2.69
N	Households	.048	.67
η	Curvature	.58	5.08
$\bar{g}$	Growth	6.08	6.78
V	Variance	−.68	−.17
t	Time	−3.11	−8.92
Constant		−134.72	−2.91
	CMA Dummy Variables		
Calgary		117.31	4.18
Edmonton		118.25	4.64
Halifax		191.52	5.57
Hamilton		173.32	6.63
Kitchener		183.53	5.53
London		202.05	6.58
Montreal		3.48	.44
Ottawa-Hull		153.72	6.54
Quebec City		160.26	6.18
Regina		211.32	6.07
St. Catharines		200.41	6.49
Saint John		233.99	6.31
St. John's		217.63	6.02
Saskatoon		207.95	5.79
Thunder Bay		233.93	6.48
Vancouver		83.50	5.13
Victoria		187.10	5.94
Windsor		206.36	6.48
Winnipeg		152.86	6.03

the variance in the expected growth rate in housing rents is negative in this model, although still statistically insignificant. Thus, the results of this study are inconclusive as to the effect of rent variability on urban housing prices.

Perhaps the lack of significance of the variance of expected growth variable is not too surprising. In the model, variance of expected growth enters the third term of (10). This term is the option value of being able to hold land in agricultural use until a time when it is profitable to convert it to urban use. We expect risk to have a positive effect on option value. However, the model assumes that individuals are risk neutral and discount cash flows at the risk-free rate. In a more complete model, with risk-averse investors, the cash flows would be discounted at a higher rate in a city with more systematic risk than in a less risky city. This would tend to lower prices and offset the option value effect in the model presented here. Development of a more sophisticated model may resolve this issue.

CONCLUSION

In this paper we have tested a model of urban pricing in long-run equilibrium. In the model, developer/builder decisions about land conversion are based on their knowledge of the expected growth of future rents and the variance the expected growth. Urban prices in the model decompose into four parts: the value of agricultural land, the cost of conversion, the value of accessibility, and an uncertainty premium which depends on the growth and variance of the growth of rents.

Key variables in the model include interest rates, city size, city growth, and the variance of growth. Two empirical versions of the model were estimated. In the first, the regression equation was estimated by nonlinear least squares with a scalar variance-covariance matrix assumption. In the second, the equation is estimated by iteratively reweighted nonlinear least squares with cross-sectionally heteroscedastic and timewise autoregressive errors assumed. The results strongly support the asset approach to valuing land in urban areas. However, given the insignificance of the uncertainty variable, the results provide stronger support for the certainty version of the model.

Additional theoretical and empirical work on the separate effects of systematic and unsystematic risk in a model with risk aversion may resolve the variance issue.

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