Real Options and Development: A Model of Regional Supply and Demand

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The holding of vacant land can be viewed as a real option to develop a completed building at a future date.[1] Previous works by Titman [1985], Geltner [1989] and Williams [1991] have used this analogy to develop models that use financial call option methodology to explain the valuation of land and the factors that affect the development/construction decision. These real-option models show that the source of value for vacant land comes from the right to obtain an underlying asset, a completed building, by paying the exercise price as represented by the costs of construction.

These real-option models have highlighted the importance of uncertainty about future real estate values in making the development decision. Because investment in a completed building is irreversible, i.e., the construction costs are "sunk" and cannot be fully recovered, uncertainty about real estate values gives the holder of land an incentive to defer construction. Thus, the option to wait to develop the property is valuable, because as time passes, the developer can gain information on the evolution of built property values.

The real-option model also predicts that there are other economic and real estate variables, in addition to the level of uncertainty that will determine the likelihood of development. For example, development is more likely as property values increase over time. Another important factor is the payout or capitalization rate on the built property (i.e., the cash flow yield on an unlevered property). Holding all other factors constant (including the property value), an increase in the capitalization rate increases the opportunity cost of deferring development, increasing the likelihood of development.

Because of the significance of commercial real estate construction activity to local, regional, and national economies, it is important to study the linkage between underlying economic and real estate variables to develop a better understanding of commercial real estate development cycles. Indeed, to the extent that uncertainty and other variables cause investment inertia, there may be an opportunity to use current trends for these variables to predict future development activity.

In a recent study of real estate development, using the real-option model as their theoretical foundation, Holland, Ott, and Riddiough [2000] specify and empirically estimate a structural model of asset market equilibrium. Using aggregate U.S. commercial real estate data, they found that the real-option model and the uncertainty variable in particular, had significant power in explaining development cycles. Their empirical results generally favor the predictions of the real-option-based model, and suggest that irreversibility and the option to wait are important considerations to investors.

Because the Holland, Ott, and Riddiough paper empirically tests for the determinants of invest1ment at the aggregate national level, a logical extension of their work would be a microeconomic study using local and/or regional data. Since it is often economic variables at the firm level that directly affect the real investment decision, a regional study can provide additional empirical evidence about the factors that affect development, and may avoid some of the problems of data aggregation and simultaneity. Building upon the work of Holland, Ott, and Riddiough [2000], we test an econometric model of real estate supply and demand for South Carolina that uses both regional and state-level data to determine the effectiveness of the real-option-based econometric model in explaining real estate construction activity at a regional level.

Similar to the results of Holland et al., we find evidence that the real-option model has a high degree of explanatory power in explaining real estate development. Volatility and other variables that are included in the regression based on the real-option model of land development are found to strongly influence changes in South Carolina construction activity over the time period studied. The general results hold for all of the commercial real estate property types that are examined. Based on the results of this study and Holland et al., real-option-based variables should be considered and included in any econometric model that is used to explain or forecast either national or regional changes in construction.

The remainder of the article is organized as follows: The next section briefly describes the real-option model and the underlying variables that are theoretically important in predicting development. The third section describes the data, data sources, and the procedures used in determining property value and volatility estimates that are used in the empirical tests of the model. The fourth section details the econometric model and provides the results of the tests. Finally, the last section provides a summary and conclusion.

DISCUSSION OF THE REAL-OPTION MODEL OF DEVELOPMENT

Before moving to empirical specification, we will briefly review the standard real-option model and its empirical predictions in the context of land and commercial real estate development. The option-based empirical variables are contrasted with the relevant variables of the traditional (NPV) model of investment.

The holding of vacant land can be viewed as an option to develop a completed building at a future date. Titman [1985], Capozza and Helsley [1990], Williams [1991] and Grenadier [1995], among others, have used this analogy to develop models to explain the valuation of land and the factors that affect the development decision. These models show that uncertainty is relevant because the developer often has an option to wait. The value of this option increases with increases in uncertainty about the future value of the built property.

The option to wait is valuable, because as time passes the developer can gain additional property value information. For example, if property values increase, the developer is more certain that it is worthwhile to proceed with construction of the project. Conversely, if values decline, the developer has avoided, by deferring construction, a potential loss on the investment in the project. Thus, the combination of asset value uncertainty, irreversible development, and the flexibility to wait suggests that the development of land will not occur until the value of the completed property exceeds the cost of construction by a "waiting-time" option premium.

The models developed that explore the uncertainty/development relationship use the concept of a development hurdle ratio (analogous to Tobin's q) defined as P/K, where P is the value of the completed development project (both land and building) and K is the cost of construction. The model predicts that there is a critical development hurdle ratio (greater than one) above which it is optimal to proceed with development immediately, and below which it is optimal to defer investment in the project. The model also predicts that an increase in the uncertainty about future real estate values will increase the development hurdle ratio. That is, the value of the completed project must be higher at higher levels of uncertainty before it is optimal to proceed with construction. This follows because increased uncertainty results in a higher value in the option to defer investment.

Traditional models of valuation and investment—such as the NPV rule that uses the CAPM to determine the appropriate discount rate—predict an *indirect* relationship between uncertainty and investment; i.e., the level of uncertainty may affect the discount rate, which is used to determine the value of the property. To the extent that a change in uncertainty reflects a change in the systematic risk of a project, and hence a higher required rate of return, uncertainty and investment will be negatively related. However, unlike the traditional model, the irreversible investment assumption of the option model implies that all uncertainty, whether systematic or not, will have a *direct* effect on investment (an effect independent of any changes in the value of the property). This occurs because the

EXHIBIT 1

Short-Run Predicted Supply Relationships (Equation 1b)

Variable	Traditional NPV Model	Real-Option-Based Model
P (Developed Asset Price)	Positive	Positive
K (Construction Cost)	Negative	Negative
r (Risk-Free Rate of Interest)	No Direct Effect	Positive
g (Expected Growth Rate in Rents)	No Direct Effect	Negative
$\sigma_{P,M}$ (Systematic Risk)	No Direct Effect	Positive
σ (Total Uncertainty)	No Direct Effect	Negative

undeveloped asset (land) is an option with value that depends directly on the developed asset value.

The predictions of the real-option model and the traditional NPV model are consistent in two respects. First, in both models, development is more likely as built property values increase over time. Additionally, increases in construction costs will provide an incentive to defer construction. However, in contrast to the NPV model, the real-option model also predicts that there are other economic and real estate variables, in addition to the level of uncertainty that will determine the likelihood of development. An important factor is the rate of cash flow payout from the built property, also known as the capitalization rate. Cash flow from the completed project represents an opportunity cost of holding the land undeveloped. Therefore, independent of its effect on price, increases in the cash flow yield decrease the development hurdle ratio and increase the likelihood of development. Other relevant variables in the real-option model include the interest rate and expected rent growth.

The interest rate, capitalization rate, expected rent growth, systematic risk and total asset price uncertainty are traditionally modeled in an NPV framework as affecting built asset price, and therefore are often omitted as direct contributors to construction in econometric supply equation specifications (see, e.g., Wheaton [1987], Wheaton and Torto [1990]). Alternatively, the option-based model suggests that these variables may impact investment independently of price through the value of the option to wait; thus, these variables should be included as independent variables in the econometric specification.

EMPIRICAL METHODOLOGY AND DATA

Based on the relevant variables in the option-based model, and using the previous work of Holland, Ott, and Riddiough [2000] as a guide, we can now specify a structural model of supply and demand to describe commercial real estate asset market equilibrium. Because the rate of investment is expected to interact with the price of commercial real estate, we specify the following simultaneous equations model of asset market equilibrium:[2]

$$P_t = f_D(C,R,r,g,\sigma_{P,M},\sigma) \quad (1a)$$

$$C_t = f_S(P,K,r,g,\sigma_{P,M},\sigma) \quad (1b)$$

Equation (1a) represents the demand to purchase developed property. A downward sloping (short-run) demand curve would suggest a negative relationship between built asset price (P) and the supply of new construction (C). Traditional factors used to detect shifts in the demand curve, that are directly related to the price of real estate, are the expected rent level (R) as determined in space market equilibrium, interest rate (r), expected growth in rent (g), and a measure of systematic risk associated with owning developed real estate assets. ($\sigma_{P,M}$). In this model, built asset price depends on capitalized rent levels, where the capitalization rate is a function of the risk-free interest rate, expected rent growth, and a risk premium as determined in general capital asset market equilibrium. In addition to these traditional factors we also include total uncertainty (σ) with respect to built asset return. The option-based investment model suggests this variable may be relevant if redevelopment or abandonment are feasible options embedded in asset price (see, e.g., Childs et al. [1996], Williams [1997]).

The supply Equation (1b) describes the behavior of the real estate developer. The traditional investment model suggests that movements in price (P) and construction cost (K) may shift the supply curve. Interest rate, expected rent growth, systematic risk, and total asset price uncertainty are traditionally modeled as working through built asset price; however, the real-option model theorizes that they impact investment independently through the option value of delay.

Note that construction cost is excluded from the demand equation and that net rent is excluded from the supply equation. Space markets are broadly competitive in the sense that individual asset owners typically do not possess the market power to directly alter built asset price relative to cost. Consequently, it seems safe to assume that asset price depends on construction cost only as it enters through total supply. Expected rent level is clearly a determinant of built asset value, but is generally thought not to exert a supply effect that is independent of asset price.

Interest rate, expected rental growth rate, and systematic risk are also relevant to differentiating between investment models. For example, higher interest rates are traditionally thought to negatively impact asset prices and therefore new investment. However, the option model recognizes a potential offsetting effect that works directly through supply. Higher interest rates decrease the present value benefits of delay, and hence may shift the supply curve downward to partially offset the usual price effect. A similar dynamic is at work with the covariance term. An increase in systematic risk has the usual predicted effect of decreasing asset price to depress investment. However, because an increase in covariance is expected to increase the risk-adjusted rate at which future cash flows are discounted, delay is less valuable and therefore investment occurs earlier. Lastly, an increase in expected rent growth is predicted to shift the supply curve to decrease investment. This follows because higher expected future cash flows decrease the opportunity cost of delay.

Our focus in this article is on the estimated supply (development) equation. Exhibit 1 summarizes and compares the predicted direct relationships between the rate of investment (development) and the right-hand side variables shown in Equation (1b) for the real-option and traditional NPV model.

In order to test the model as specified, we use a time series of aggregate variables. Quarterly data for the periods 1977:4 through 1998:4 serve as measures for the variables described in Equation (1) and are as follows.

1. We use the log of the square feet of actual construction starts in South Carolina for various categories of commercial real estate (supplied by F.W. Dodge) as the measure of the level of new investment (C). The data are available for aggregated commercial property and for individual property types such as residential (apartments) industrial, office, and retail. Because new construction is a real variable, all of the remaining variables will also be expressed in real terms.
2. The measure for P, the real price of commercial real estate, is the log of a regional unsmoothed NCREIF price index divided by the CPI. The index is based on real estate prices in the east region-mideast division, as classified by NCREIF.[3] We correct for appraisal price smoothing in the NCREIF index by applying a standard desmoothing methodology (see the appendix for details). Again, the data is available for aggregated commercial property and for individual property types.
3. The cost of construction, K, is the log of the cost per square foot for various categories of commercial real estate divided by the CPI. The construction cost data are based on starts in South Carolina and is obtained from F.W. Dodge. The data are available for aggregated commercial property and for individual property types.
4. Expected real rent, R, is calculated as inflation-adjusted net income realized one quarter hence. We use estimated prices and income returns provided in the NCREIF east region-mideast division regional dataset to calculate periodic net income.
5. The expected real risk-free interest rate, r, is proxied using the ten-year Treasury bond rate minus expected inflation. This intermediate-term rate is chosen to reflect the perpetual nature of the development option while also recognizing that the land will typically be developed within a finite period of time. The data source is the Federal Reserve.
6. The expected growth rate of real net operating income, g, is proxied by lagged values of the growth rate in South Carolina real personal income. These data are obtained from the U.S. Bureau of Economic Analysis. Current and future values of South Carolina real personal income cannot be used because of endogeniety problems, i.e., that are affected by growth in construction.
7. Systematic risk, $\sigma_{P,M}$, is proxied by the covariance of returns to commercial real estate and the market return. We use Center for Research in Securities Prices (CRSP) data tapes to first calculate the daily returns for the index of REITs for each day in the most recent quarter as well as an average daily return

over the entire quarter. These returns are then matched with daily returns and the quarterly average daily return of a value-weighted CRSP-based market index to obtain a measure of covariance. This approach to determining covariance is similar to the one used to generate the total uncertainty measure, which we detail below. A systematic risk measure is developed for aggregated commercial property and for the individual property types.

8. The level of total uncertainty, σ, is proxied by the standard deviation of daily rates of return on equity Real Estate Investment Trusts (REITs).[4] Using daily returns for each equity REIT reported on the Center for Research in Securities Prices (CRSP) file from January 1, 1978 to December 31, 1999, we construct an equally weighted index and computed the daily returns for this index as follows:

$$R_{index(t)} = \frac{1}{n}\sum_{j=1}^{n} R_{jt} \quad (2)$$

where n is the number of REITs included in the sample during each quarter and where R_{jt} is the daily return of REIT j for day t. An index is created for all commercial real estate (all equity REITs) and for the property types of retail, apartments and industrial/office. Indexes for each of the property types are calculated using only returns from equity REITs that are classified as owning that particular type of property.[5] To obtain an uncertainty measure we calculated the standard deviation, S(t), of the daily REIT index return for each quarter as follows:

$$S(t) = \sqrt{\frac{1}{D-1}\sum_{t=1}^{D}\left(R_{index(t)} - \bar{R}_{index(Q)}\right)^2} \quad (3)$$

where D is the number of days in the quarter and $\bar{R}_{index(Q)}$ is the average daily return for the REIT index in the quarter. This statistic measures uncertainty over the current quarter so that an immediate change in uncertainty, and hence its possible effect on investment, can be measured across quarters.

DEVELOPMENT OF THE EMPIRICAL MODEL AND EMPIRICAL RESULTS

The available data are a combination of aggregate state, regional, and national variables and it may not be reasonable to assume that the aggregate price of real estate is exogenous as we do for individual property values in the microeconomic model. Consequently, we modify the interpretation of the model developed in the previous section in response to the recognized endogeneity of price. Specifically, we assume that P, the price of commercial real estate, and C, the level of construction are *jointly* determined. Therefore to effectively test the effect of uncertainty on levels of commercial real estate development using aggregate data, and to account for the endogeneity of these two variables, we specify and test the simultaneous equation model utilizing two-stage least squares.

Given the simultaneous equation specification in (1), the first step in our preliminary analysis of the data is to examine each series for nonstationarity. Using the augmented Dickey-Fuller test (see Dickey and Fuller [1979, 1981]), nonstationarity cannot be rejected for all property type categories of the real asset price (P), the log of square feet of construction (C), the covariance between measures of property return and market index return ($\sigma_{P,M}$), the log of the real cost of construction (K), the real net rent level (R), nor the real interest rate (r). Hence, we assume these series are nonstationary. Conversely, the growth rate of real GDP (g) and the total uncertainty measures (σ) appear to be stationary.

Using Engle and Granger's [1987] method, we find no evidence of cointegration among the nonstationary series. Therefore, the error term in any regression with the log of square feet of construction as the dependent variable is likely to be nonstationary, implying biased and inconsistent parameter estimates. To make the error term stationary, it is necessary to use first differences of all of the nonstationary series. Consequently, in order not to change the economic meaning of the equations, it is also necessary to use first differences of the series that are already stationary.[6] As a result, we specify a linear model as follows:

$$\Delta P_t = \alpha_0 + \alpha_1\Delta C + \alpha_2\Delta R + \alpha_3\Delta r + \alpha_4\Delta g + \alpha_5\Delta\sigma_{P,M} + \alpha_6\Delta\sigma + \Delta\varepsilon_D \quad (4a)$$

$$\Delta C_t = \beta_0 + \beta_1\,\Delta P + \beta_2\,\Delta K + \beta_3\Delta r + \beta_4\Delta g + \beta_5\Delta\sigma_{P,M} + \beta_6\Delta\sigma + \Delta\varepsilon_S \quad (4b)$$

EXHIBIT 2

Empirical Results for the Structural Supply Equation (Dependent Variable: ΔC)

Sample Quarters	Total Commercial Property Version 1 79:1 to 98:4	Total Commercial Property Version 2 79:1 to 98:4	Apartments 86:4 to 98:4	Industrial 79:1 to 98:4	Office 79:3 to 98:4	Retail 79:1 to 98:4
Constant	-0.1038 (0.061)	-0.0602 (0.0584)	0.1338 (0.2381)	0.2278 (0.1269)	-0.0818 (0.1264)	0.1594 (0.0919)
Sum of Current & Lagged ΔP	0.2838 (0.550)	0.2475 (0.5263)	0.7266 (0.8427)	0.9664 (0.7248)		
Sum of Current & Lagged ΔK	-2.6628 (0.836)	-2.0105 (0.6945)	-1.2279 (0.7804)	-1.0084 (0.6711)	-1.8667 (0.4369)	-1.5547 (0.2538)
Sum of Current & Lagged Δr	-0.0181 (0.044)		0.1540 (0.2449)	0.0383 (0.1265)		-0.1138 (0.0666)
Sum of Current & Lagged Δg	0.04925 (0.074)		-0.4711 (0.1887)	0.1229 (0.1528)	-0.1828 (0.0529)	0.1086 (0.0640)
Sum of Current & Lagged $\Delta\sigma_{P,M}$	6.492 (2.566)	6.311 (2.399)	-4.571 (4.506)	-7.015 (4.233)	1.762 (1.164)	1.286 (0.628)
Sum of Current & Lagged Δσ	-144.104 (64.882)	-138.008 (60.189)	-49.409 (30.590)	47.906 (37.528)		
ρ	-0.3625 (0.1429)	-0.4486 (0.1224)	-0.6562 (0.1684)	-0.2758 (0.1367)	-0.5059 (0.1079)	-0.4137 (0.1203)
R^2	0.5754	0.5531	0.8743	0.6772	0.4517	0.5600
Adjusted R^2	0.3673	0.4042	0.7172	0.5283	0.3661	0.4775
Durbin-Watson	2.049	2.070	1.901	1.998	2.283	2.258

Note: The first entry is the value of the coefficient. The standard error of the coefficient is shown in parenthesis. The coefficients of seasonal dummies are not shown. ρ is the estimate of the coefficient of first-order autocorrelation in the error term.

where $\Delta\varepsilon_D$ and $\Delta\varepsilon_S$ are assumed to have independent normal distributions.

Because real estate requires time-to-build, we examine current and lagged values of all the exogenous variables.[7] We write ΔC as a function of the current and three-quarters of lagged values of the first differences of all variables except the expected cash flow growth variable, Δg, and the rent variable, ΔR. We include lags but do not include the current value of Δg because of potential endogeneity: an increase in commercial real estate construction causes an increase in real personal income growth by definition. In the case of rents, we include the one-quarter forward realized change in rent as well as current and two lagged values. This is because, in theory, price depends on next period's capitalized income. The number of lagged values is limited by the fairly small sample size. Lastly, due to anticipated effects of seasonality on construction of real estate, the supply equation also includes seasonal dummies.

Exhibit 2 contains the results. In all cases the sample is available from 1977:4 to 1998:4. However the usable sample is shortened due to the determination of the unsmoothed price, which uses lagged values, and by the availability of NCREIF data for some of the property types. The number of lags to include in each equation is determined by maximizing adjusted R^2 with the constraint that all of the lagged values up to the highest-order lag are included. For example, a third-order lag is only included if the current value and the first- and second-order lags are included. With this method, it often happens that neither the current nor any of the lagged values of a variable are included in the final regression equation.

For total commercial real estate construction, we perform two regressions. In Column 1, all of the variables are included in the regression, while in Column 2 the variables are chosen to maximize the adjusted R^2. In both regressions (Columns 1 and 2), the effect of uncertainty (current value and three lags) on construction is negative and significant at less than the 5% level. For the regression that maximizes adjusted R^2 (version 2), a one-standard-deviation increase in total price volatility results in roughly a 27% reduction in total new construction of commercial real estate.[8] Costs also have the predicted negative effect with the sum of the coefficients on current and lagged cost being significant at the 1% level (t = -2.91). The real price has an expected positive coefficient that is not statistically significant. The covariance has an expected positive sign and is significant at the 1% level (t = 2.63). Overall the adjusted R^2 values are quite impressive at 40%, showing that the option-based model has significant merit in explaining South Carolina development.

For apartment construction, the sum of the current and three-lagged values of $\Delta\sigma$ is negative but not significant. A one-standard-deviation increase in apartment price volatility results in roughly a 25% reduction in new office construction. Overall, cost has a negative but insignificant effect. The real price has an expected positive coefficient that is not statistically significant. The growth variable shows up as negative and significant at the 2% level (t = 2.50), which is predicted by the option-based model. The adjusted R^2 value, at 72%, indicates the strength of the model in explaining apartment development in South Carolina.

For industrial construction, $\Delta\sigma$ (current and three-lagged values) has an unexpected positive coefficient but falls short of standard levels of statistical significance (t = 1.28). Costs also have the predicted negative effect with the sum of the coefficients on current and lagged cost being significant at the 1% level (t = -2.91). The real price has an expected positive coefficient that is not statistically significant. The covariance has an unexpected negative sign and is significant at the 10% level (t = –1.66). The adjusted R^2 value is very high at 53%.

For office construction, maximizing the adjusted R^2 value results in $\Delta\sigma$ (current and three-lagged values) and the real price (current and three-lagged values) being excluded from the regression. Costs also have the predicted negative effect with the sum of the coefficients on current and lagged cost being significant at the 1% level (t = –4.27). The growth variable shows up as negative and significant at the 1% level (t = 3.45), with the negative effect predicted by the option-based model. The adjusted R^2 value is 37%.

For retail construction, maximizing the adjusted R^2 value results in $\Delta\sigma$ (current and three-lagged values) and the real price (current and three-lagged values) being excluded from the regression. Costs also have the predicted negative effect with the sum of the coefficients on current and lagged cost being significant at the 1% level (t = –6.13). The covariance has an expected positive sign and is significant at the 5% level (t = 2.05). The adjusted R_2 value is significant at 48%.

The implication of these regressions is that the real-option model has significant explanatory power in explaining real estate development in South Carolina. Volatility and other variables that are included in the regression based on real-option theory are found to strongly influence construction activity. Therefore, these variables may be able to be used to predict changes in construction for several quarters into the future. Construction cycles, at least in the short run, could then be anticipated.

SUMMARY AND CONCLUSION

Based on earlier work by Holland, Ott, and Riddiough [2000], who used aggregate U.S. commercial real estate data, this article tests an econometric model of supply and demand for South Carolina to determine the effects or real-option-based variables on regional real estate development. State and regional data is used for a time series that covers quarterly periods from 1978 through 1998. Using this data, we test the model with respect to five categories of real estate: total commercial property, apartments, industrial, office, and retail properties. We find that the real-option model has significant power in explaining real estate development in South Carolina. In general, volatility and other real-option-based variables affect construction as predicted by the real-option model. The general results hold for all of the commercial real estate property types that are examined. This study provides additional empirical evidence that real-option-based variables should be considered in any econometric model used to forecast changes in construction.

APPENDIX

DEVELOPMENT OF THE UNSMOOTHED PROPERTY PRICE INDEX

The problem with the property price proxy using the Russell/NCREIF index is that it is subject to appraisal smoothing, which results in the index lagging true changes in property prices as well as smoothing property volatility (Geltner [1989], Ross and Zisler [1991]). While both issues are a concern in ascertaining "true" property values, we are most concerned with correcting the lag problem, since lags will bias parameter estimates as well as affect the significance level of the variable, whereas reduced volatility only affects the size of the regression coefficient, not its significance level. Note, however, that we will address both factors in our discussion of unsmooth returns.

We rely on the methodology of Fisher, Geltner, and Webb [1994] to unsmooth the Russell/NCREIF returns. In brief, the following autoregressive relationship between smoothed and unsmoothed returns is hypothesized:

$$r_t^* = w_0 r_t + w_1 r_{t-1} + w_2 r_{t-2} + .. + w_{t-1} r_1 \quad \text{(A-1)}$$

where r_t* is the smoothed return at time t and r_i, i = 1,..,t, is the unsmoothed return reported in the index. Simple substitution allows (A-1) to be rewritten as:

$$r_t^* = z_1 r_{t-1}^* + z_2 r_{t-2}^* + z_3 r_{t-3}^* + .. + e_t \quad \text{(A-2)}$$

where $e_t = w_0 r_t$.

As argued by Fisher et al., the relevant lags to examine are at t-1 and t-4. This follows because external appraisals on institutionally owned properties are required once a year (i.e., every four quarters)—and hence reflect valuable information as to actual property value—while internal appraisals are done quarterly, where the previous quarter's appraisal provides a benchmark from which to adjust the current property value. Using this lag structure, Equation (A-2) can be inverted to result in,

$$r_t = 1 / w_0 [r_t^* - z_1 r_{t-1}^* - z_4 r_{t-4}^*] \quad \text{(A-3)}$$

Russell/NCREIF data can be used to estimate the relationship expressed in (A-2), where the time series regression coefficients estimated in that equation can be substituted into Equation (A-3) to de-lag the property returns.

The parameter w_0 is chosen to induce the appropriate amount of volatility into the unsmoothed returns. As discussed above, the choice of w_0 is not critical to the econometrics that follow since this parameter simply scales the size of the property price parameter estimate. Thus, we specify w_0 such that the standard deviation of returns equal to 9% for all property types and 12% for office and retail properties. These numbers are chosen to be realistic given the fact that the Russell/NCREIF index is a large portfolio of properties and that aggregation by particular property type is somewhat less diversified than when all properties are lumped together.

The estimated equations are as follows:

Total: $r_t = 5.3[r_t^* - 0.289741 r_{t-1}^* - 0.273791 r_{t-4}^*]$
Office: $r_t = 8.64[r_t^* - 0.235852 r_{t-1}^* - 0.148973 r_{t-4}^*]$
Retail: $r_t = 5.41[r_t^* - 0.086918 r_{t-1}^* - 0.292698 r_{t-4}^*]$
Apartments: $r_t = 5.44[r_t^* + 0.009878 r_{t-1}^* - 0.564887 r_{t-4}^*]$
Industrial: $r_t = 6.7[r_t^* - 0.253453 r_{t-1}^* - 0.24377 r_{t-4}^*]$

Lastly, once the unsmoothed capital return series is generated, we create an index of property values, the initial value of which is equal to 100.

ENDNOTES

Steven Ott gratefully acknowledges the funding received for this project from the Center for Applied Real Estate Education and Research at the University of South Carolina. We would also like to thank F.W. Dodge and the National Council of Real Estate Investment Fiduciaries for supplying some of the data.

[1]Options on real assets, as opposed to financial assets, are termed "real options."

[2]Time subscripts for the regressors in Equation (1) are not shown. Because of the time-to-build for real estate, the effect of a change in the independent variables may lead any change in the dependent variable. We empirically examine the extent of any lead-lag relationship and report these findings in the following section.

[3]The east region-mideast division contains real estate price information aggregated from the District of Columbia and the states of Kentucky, Maryland, North Carolina, South Carolina, and Virginia. Exclusive South Carolina data was available but it covered a shorter time series for many of the property types; therefore, the larger regional sample was used.

[4]Equity REITs have equity interests in (own and operate) real estate properties. For a review of the literature on REITs, see Corgel, McIntosh, and Ott [1995].

[5]We use the classification system of the National Association of Real Estate Investment Trusts to determine the type of property that a REIT owns.

[6]The consequences of over-differencing (assuming a series is nonstationary when it is really stationary) are known to be much less severe than the consequences of under-differencing (i.e., assuming a series is stationary when it is really nonstationary). See Stock and Watson [1988] for a discussion of the consequences of estimating regressions with nonstationary variables.

[7]In using quarterly data, it may be that the current price is not correlated with the current error term. However, that does not solve the endogeneity problem. In a distributed lag model the price and error term must be uncorrelated at all leads and lags to get unbiased coefficient estimates.

[8]The change in construction is calculated by multiplying the standard deviation of the volatility measure (in this case

0.00199 for total commercial real estate, 0.00261 for retail, 0.00515 for apartments and 0.00686 for industrial office) by the coefficient on volatility.

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