UNCERTAINTY AND THE RATE OF COMMERCIAL REAL ESTATE DEVELOPMENT*

Prepared for the Real Estate Research Institute

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Current Draft: January 1995

*The authors gratefully acknowledge the funding received for this project form the Real Estate Research Institute. We would also like to thank the American Council of Life Insurance, F.W. Dodge and the National Council of Real Estate Investment Fiduciaries for supplying data.

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Abstract

This paper examines the relationship between uncertainty and investment in the context of the real options model. Specifically, we analyze the role of built property value volatility in determining the rate of commercial real estate construction. To focus on the uncertainty/investment relationship, we extend the standard model to determine the probability of investment over a particular time horizon. In doing so we find that an increase in asset volatility can either increase or decrease the probability of development, although the anticipated negative relationship is confirmed when the land is "ripe" for development (i.e., near the development hurdle value). The role of uncertainty in determining the rate of real investment is then tested using aggregate data. By developing two measures of property value volatility--an implied volatility estimate using commercial mortgage spreads and the volatility of quarterly REIT returns--we empirically confirm the expected strong relationship between uncertainty and development activity. We also find a relatively high degree of inertia in property value volatility, which suggests that uncertainty measures may be useful in predicting construction activity.

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Introduction

Investment under uncertainty, which addresses the opportunity to acquire real assets, has been studied extensively using option pricing techniques (see e.g. McDonald and Siegel [1896], Pindyck [1991] and Dixit and Pindyck [1994]). Previous works by Titman[1985] and Williams[1991] have also used option pricing to explain the valuation of land and the factors that affect the development decision. These land option models show that the source of value for vacant land comes from the right to obtain an underlying asset, a productive building in this case, by paying the exercise price (the costs of construction), and have also highlighted the importance of uncertainty in making the real estate development decision.

Because investment in a completed building is irreversible, uncertainty about future real estate values gives the landholder an incentive to defer development when the completed project value exceeds the cost of construction. To determine whether to wait or not, the option holder compares lost operating income from waiting with the benefits of reducing the chance of an "incorrect" development decision. The uncertainty/development relationship has been studied using the concept of a development hurdle ratio, defined as $\mathbf{P}/\mathbf{K}$, where $\mathbf{P}$ is the property price or value of the completed development project and $\mathbf{K}$ is the cost of construction. The real option model predicts that development will not occur until the value of the completed property equals or exceeds the cost of construction plus the value of the developer's option to wait. Thus, there exist a critical development hurdle ratio ($\mathbf{P}^*/\mathbf{K}$ -- greater than one) above which ($\mathbf{P} \geq \mathbf{P}^*$) it is optimal to proceed with development immediately, and below which ($\mathbf{P} < \mathbf{P}^*$) it is optimal to defer development. Based on this logic, the option model predicts that increases in uncertainty will increase the development hurdle ratio thereby reducing the likelihood of immediate development.

To date there have been few empirical tests of the theoretical predictions provided by the real option models. Some of the studies that have tested the relationship between aggregate levels of investment and uncertainty include Pindyck [1991] Federer [1993] and Pindyck and Solimano [1993]. Pindyck found that the level of stock market uncertainty, as measured by the quarterly variance of stock returns (NYSE index), has a significant negative relationship with the growth in real aggregate investment. Federer uses the risk premium embedded in the term structure of interest rates as a measure of uncertainty and finds a significant negative relationship between durable equipment expenditures and orders for new plant and equipment, and the level of uncertainty. Pindyck and Solimano also find a negative relationship between aggregate investment and uncertainty for a cross-section of countries. Thus, each paper finds a significant negative relationship but none looks specifically at investment in commercial real estate--a major class of assets.

Other empirical studies have tested the validity of the real option model by comparing the valuation of real assets--using the real option approach--to standard valuation using discounted cash flow (DCF) analysis. Using data from market transactions, these studies determine if the value of these assets include the value of real options. Paddock, Siegel and Smith [1988] examine the value of offshore oil tracts and determine that government estimates of value using DCF underestimate industry bids for the tracts. The authors' computed option valuations were closer to the industry bids, providing evidence that the option values are embedded in the value of these assets. Another such study is Quigg [1993] who performed an empirical analysis of land values to determine if there existed an option value inherent in the price of individual parcels of vacant land. She found the option model to have explanatory power when compared to intrinsic value (computed using DCF) in predicting land transaction prices. Therefore, this latter group of papers are also generally supportive of the real option model, but do not directly examine the link between uncertainty and aggregate investment.

The objectives of this paper are two-fold. First, we recognize that the effect of a change in uncertainty and other relevant variables on the optimal development hurdle ratio--$\mathbf{P}^{*}/\mathbf{K}$--is, by itself, *not* sufficient to make conclusions about the directional change in the rate of development. This is because the value of the completed project, as reflected by **P**, may also be affected by a change in the underlying variables which might overcome the simultaneous increase in the hurdle ratio. Consequently, the question of how the overall rate of commercial real estate development is affected by relevant input parameters--the central question of this paper--cannot be answered given the standard option model formulation. To do so properly requires that the probability of development over a particular time frame be calculated. Thus, we extend the previously developed option models by deriving a probability of development function that determines the probability of investment over a future time period. Comparative statics of this function provide empirically testable implications about how changes in variables affect the probability or rate of investment. Of particular interest is our finding that there is indeed a negative relationship between property value volatility and the probability of development when the land is ripe for development (i.e., when built property value is near the development hurdle).

Our second objective is to empirically test the effects of changes in uncertainty on the rate of commercial real estate development (investment) over time. Because of the significance of commercial real estate construction activity to the economy and the long term, capital intensive, irreversible nature of real estate investment, it is important to study the linkage between underlying economic and real estate variables--especially the property value uncertainty variable--to develop a better understanding of commercial real estate development cycles. Indeed, to the extent that uncertainty displays some inertia, there may be an opportunity to use current trends of property value uncertainty to predict future development activity.

Our data set includes aggregate construction data on the various categories of commercial real estate including apartments, office, retail and industrial properties using quarterly time series data from 1972 through 1993. To test for the uncertainty/development relationship, we develop two proxies for the level of uncertainty in real property values. First, we develop a forward looking estimate of uncertainty by computing the implied volatility of property prices using the spread in commercial mortgage rates over comparable duration treasury bonds. Our second volatility measure is derived by computing the standard deviation of quarterly rates of return on equity Real Estate Investment Trusts (REITs). Additionally we develop measures for other variables that are relevant to the option model, including property price, capitalization rate (cash flow yield), and cost of construction.

We find that, as predicted, there is a significant negative relationship between uncertainty and the rate of investment for all types of commercial real estate included in this study. This result is robust in that it holds using either of the two types of uncertainty measures. Our results also indicate that uncertainty provides greater power in explaining levels of investment than the other relevant real estate variables included in the study. These findings provide additional evidence of the negative relationship between uncertainty and investment for a large and influential class of assets--commercial real estate. Finally, we also find evidence of persistence in our property value volatility measures, which provides some preliminary evidence that uncertainty may be an important factor for predicting construction cycles.

The remainder of the paper is organized as follows. The next section develops the basic model of real option valuation for real estate and also derives probability (or rate of) development function. Section II 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. Section III details the econometric models and provides the results of the tests.

Section IV discusses a procedure for using the empirical model to forecast future construction activity. Finally, Section V concludes and summarizes.

I. A Model of the Probability of Development

A. The Basic Option Valuation Model

Improved property value returns are assumed to evolve continuously over time and follow a normal distribution, specified as follows:

$$\boxed{\frac{dP}{P} = (\mu - \delta)dt + \sigma dz} \qquad (1)$$

where **P** is current property value, μ is the total annualized expected return to the property, δ is the rate of payout on the built property, $\sigma>0$ is the annual standard deviation of return to the property, and **z** is a standardized Wiener process. The rate of payout can be interpreted as a capitalization rate, defined in practice as net operating income divided by property value. This represents the opportunity cost of holding the land undeveloped. Thus the quantity, μ-δ, is the appreciation component to the return that accrues to the undeveloped landowner. Once the property is developed, the total return μ accrues to the investor. Also note that σdz represents the instantaneous unanticipated return from the property. As σ increases, so does the "risk" associated with the built property.[1,]

To keep the model as simple as possible while still capturing the essential features necessary to explain development activity in a real options context, we impose the following additional structure to the model. Assume that the property can be developed to its highest and best use, at the maximum allowable density, at any time for a fixed cost, **K**.[2] Unrestricted

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[1] Note that this risk is idiosyncratic to the particular property; it is not market risk. Market risk is reflected in the required expected rate of return, μ (a point we will return to shortly). Idiosyncratic risk is pertinent here because land values are contingent on improved property value, whose movements depend on σ.

[2]Implicit here is that the land is zoned for a single use only. The presence a multiple use zoning, a common occurrence in many urban markets, can impact development decisions and land value, especially when

ownership implies that the option to develop is perpetual.[3] Once the property is developed, we assume that the investment is irreversible (i.e., development costs are sunk once the investment is made). This is a reasonable assumption with real estate in which the physical asset is long-lived and switching costs to alternative uses (assuming they are allowable) are quite high.[4] Finally, standard option pricing assumptions regarding property and financial markets are assumed to hold.[5,6]

Given these assumptions, equilibrium arguments in which riskless arbitrage profits are not possible--and in which both the land and built property value are assumed to be traded assets--result in the land being priced as a contingent-claim, the value of which is derived from dynamics associated with the improved property value at a given construction cost.[7] Land value dynamics as a function of the improved property value, L(P), can now be expressed as the following differential equation:

$$\boxed{\frac{1}{2}\sigma^2 P^2 L_{PP} + (r - \delta) P L_P - rL = 0} \quad \textbf{(2)}$$

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alternative uses have similar values. However, as Geltner et al. [1994] show, comparative statics with respect to development timing are similar between single versus multiple use zoning.

[3]This is generally a reasonable assumption, although restrictive land use laws can sometimes result in perverse development incentives when local land use regulators restrict development flexibility through exactions or threats of uncompensated regulatory takings. We will ignore these possible distortionary effects.

[4] See Childs et al. [1995] who consider conditions for which mixing uses and redevelopment are economically feasible and how such flexibility impacts land value and development activity.

[5] That is, markets are assumed to be complete and frictionless with trading occurring continuously through time and where short sales can occur. All investors are price takers. There is also a market for instantaneous borrowing and lending at a rate of interest, r. This rate is assumed to be certain and constant over time.

[6] We ignore the optimal capacity decision. Williams [1991] and Quigg [1993] consider the optimal capacity question when per unit development costs are marginally increasing in scale. This structure can produce optimal densities that are less than the maximum allowable. As a practical manner, most new development maximizes density since most urban zoning is relatively restrictive (i.e., marginal revenues typically exceed marginal costs at the density constraint). Note also that Williams and Quigg consider development costs that evolve stochastically. This adds richness to the model, but changes comparative statics little, so that a fixed cost assumption is suitable for our purposes.

[7] The assumption of land and constructed property being traded assets is made for convenience. If marketability is restricted in any way, market completeness allows for the substitution of otherwise identical assets to determine value.

where subscripts denote derivatives with respect to improved property value and **r** is the riskless rate of interest. Note that risk preferences, as reflected in the required expected property return, μ, are not required to value the land. By "risk-adjusting" the required expected property returns, discounting occurs at the riskless rate of interest (see Cox and Ross [1976] and Harrison and Kreps [1979]).

Subject to the appropriate boundary conditions equation (2) can be solved in an analytical form, where land value can be expressed as,[8]

$$\boxed{\mathbf{L(P)} = \left(\frac{\mathbf{K}}{\eta - \mathbf{1}}\right)\left(\frac{\mathbf{P}}{\mathbf{P}^*}\right)^{\eta}} \tag{3}$$

where,

$$\boxed{\eta = \frac{\frac{1}{2}\sigma^2 - (\mathbf{r} - \delta) + \sqrt{\left(\mathbf{r} - \delta - \frac{1}{2}\sigma^2\right)^2 + 2\sigma^2\mathbf{r}}}{\sigma^2} > 1} \tag{3a}$$

and

$$\boxed{\mathbf{P}^* = \frac{\mathbf{K}\eta}{\eta - \mathbf{1}}} \tag{3b}$$

The parameter η is land value elasticity with respect to changes in built property value and, as noted, is strictly greater than 1 for finite parameter values.

As discussed by Dixit and Pindyck [1994,p.153], "investment is highly sensitive to volatility in project values, irrespective of investors' or managers' risk preferences, and irrespective of the extent to which the riskiness in project value is correlated with the market." In other words, as σ increases so does P*, the development hurdle value. This

[8] The boundary conditions are: i) L(0)=0 (i.e., the land is worthless if built property value ever becomes worthless), ii) $L(P^*)=P^*-K$ (i.e., land value equals built property value less construction costs, where P^* is the "hurdle" value--which obviously must be at least K--at which it is optimal to develop the property), and iii) $L_P(P^*)=1$ (i.e., property and land value movements are one-for-one at the point of option exercise). See Samuelson and McKean [1965], who first formulated this problem. The solution shown in equation (3) is the risk-neutral version of their solution.

follows because increased uncertainty results in a higher probability that property values will decline in the future, which increases the likelihood of an "incorrect" investment decision.

It is important to recognize that an increase in P* by itself is *not* sufficient to conclude that a reduced rate of development will result, however. This is because land values also increase for increases in σ, which might overcome the simultaneous increase in P*, to result in a greater likelihood of development. Moreover, exercise of the development option is observed is "real" terms, not risk-adjusted terms, so that market risk preferences are required to properly capture the dynamics of actual development activity. Consequently, the question of how the overall rate of commercial real estate development is affected by property value uncertainty--the central question of this paper--cannot be answered given the present formulation. To do so properly requires that the probability of development over a particular time frame be calculated. This is the purpose of the subsequent section .

B. Measuring Development Activity by Calculating the Probability of Development

Inferences regarding the rate of development activity can be made by calculating the probability of development occurring within a particular time in the future. The probability of development is determined as follows. First, recognize that the development hurdle value, P*, remains fixed over time due to the perpetual nature of the development option. Because development occurs when built property value equals P*, development probabilities can be calculated as a first passage time through a fixed barrier that is above the current price. Based on this and the dynamics of built property value expressed in (1), we can state the dynamics of the cumulative probability distribution of development occurrence over the next τ years, $F(P,\tau;P^*)$, as the following Kolmogorov backward equation:[9]

$$\boxed{\frac{1}{2}\sigma^2 P^2 F_{PP} + (\mu - \delta) P F_P - F_\tau = 0} \qquad \textbf{(4)}$$

[9]For background on the Kolmogorov backward equation see Karlin and Taylor [1981].

Keeping in mind that P* is determined from the valuation equation (3) and that the development boundary is approached from below, the required boundary conditions are:

$$\mathbf{F(0,\tau) = 0} \tag{4a}$$

$$\mathbf{F(P^*,\tau) = 1} \tag{4b}$$

$$\mathbf{F(P,0) = 0} \tag{4c}$$

where P is currently less than the hurdle value, P*.

A unique solution to equation (4) can be obtained, with the cumulative probability of development over the time period τ, expressed as,

$$\mathbf{F(P,\tau;P^*) = N\left[\frac{-\ln\left(\frac{P^*}{P}\right) + \left(\mu - \delta - \frac{1}{2}\sigma^2\right)\tau}{\sigma\sqrt{\tau}}\right] + e^{\frac{2\ln\left(\frac{P^*}{P}\right)\left(\mu-\delta-\frac{1}{2}\sigma^2\right)}{\sigma^2}} N\left[\frac{-\ln\left(\frac{P^*}{P}\right) + \left(\mu - \delta - \frac{1}{2}\sigma^2\right)\tau}{\sigma\sqrt{\tau}}\right]} \tag{5}$$

where N[·] is the area under the cumulative standard normal distribution to point.[10]

Comparative statics resulting from equation (5) produce the theoretical basis upon which the predicted signs (+/-) for the relevant empirical variables can be obtained. In all cases except for changes in costs of construction, we are unable to definitively sign the

[10] This solution is similar to that shown in Ingersoll [1987,p.353] subject to the following modifications. First, in our application, state prices are log-normally distributed rather than normally distributed. This results in property price entering as a logarithm and with expected returns to the built property being reduced by a factor of $1/2\sigma^2$. In addition, because the boundary is being approached from below rather than from above, the drift term must be reversed. Once these transformations are performed, Ingersoll's formulation directly applies.

derivative due to the complex nature equation (5).[11] Instead, we determine sensitivity numerically over a broad range of reasonable parameter values, with the following results:

[11] Detailed derivation of the comparative statics are available from the authors by request.

$$\boxed{\frac{\partial \mathbf{F}}{\partial \mathbf{P}} > \mathbf{0}} \qquad \boxed{\frac{\partial \mathbf{F}}{\partial \mathbf{K}} < \mathbf{0}} \qquad \boxed{\frac{\partial \mathbf{F}}{\partial \delta} <> \mathbf{0}}$$

$$\frac{\partial \mathbf{F}}{\partial}$$

$$\boxed{\frac{\partial \mathbf{F}}{\partial \mathbf{r}} < 0} \quad \boxed{\frac{\partial \mathbf{F}}{\partial \sigma} <> 0} \qquad \mathbf{(6)}$$

These results are for the most part intuitive. Increases in property value (P) result in land that is "riper" for development than before the increase. On the other hand, an increase in construction cost (K) increases the opportunity cost of development, and hence lowers development probability. There are two effects to consider with respect to payout rate (δ). A higher payout rate increases the opportunity cost of holding the land undeveloped, which reduces the hurdle value. On the other hand, a higher payout rate reduces the appreciation rate of the property, which results in a lower probability of hitting the barrier. In general, either effect can dominate, although the sign is positive for almost any reasonable combination of parameter values. An increase in the total expected rate of return to the built property (μ) unambiguously increases development probabilities since the asset drift rate increases, while the hurdle value, P*, remains independent of μ. An increase in the riskless rate, r, increases both property value and the hurdle value since the present value of construction costs decrease for increases in r. Since the real drift rate is independent of r, the derivative is negative. Lastly, the effect of property volatility (σ) in general is ambiguous due to the offsetting effects of an increase in P* for increases in volatility versus a higher likelihood of large movements in property value over the period τ.

Since we are particularly interested in the effects of built property volatility on development activity, some further analysis is required since the sign is indeterminate in general. First it should be noted that our indeterminate finding is contrary to conventional wisdom in the real options area (which suggests that development probabilities always decrease for increases in σ). Because construction activity presumably occurs when built property values are near the development hurdle value (i.e., the property is ripe for development), we will focus on the relative differences between P and P* to sort out the effects. Figure 1 illustrates the property volatility/development probability relationship given two different current levels of improved property values relative to the development hurdle value. Development probability is over a 2 year time interval given a construction cost of 100. Given reasonable parameter values for the expected property return, volatility, risk free rate and cap rate, a development boundary of P*=$162 is calculated.[12] When P=100, the development option is well below the development boundary. In this case, development probabilities increase slightly for increases in property volatility until a point at which σ becomes quite large. On the other hand, when P=140 (i.e., it is relatively close to the development boundary), development probabilities uniformly decline as σ increases. Indeed, this relationship holds over a relatively broad range of parameter inputs.

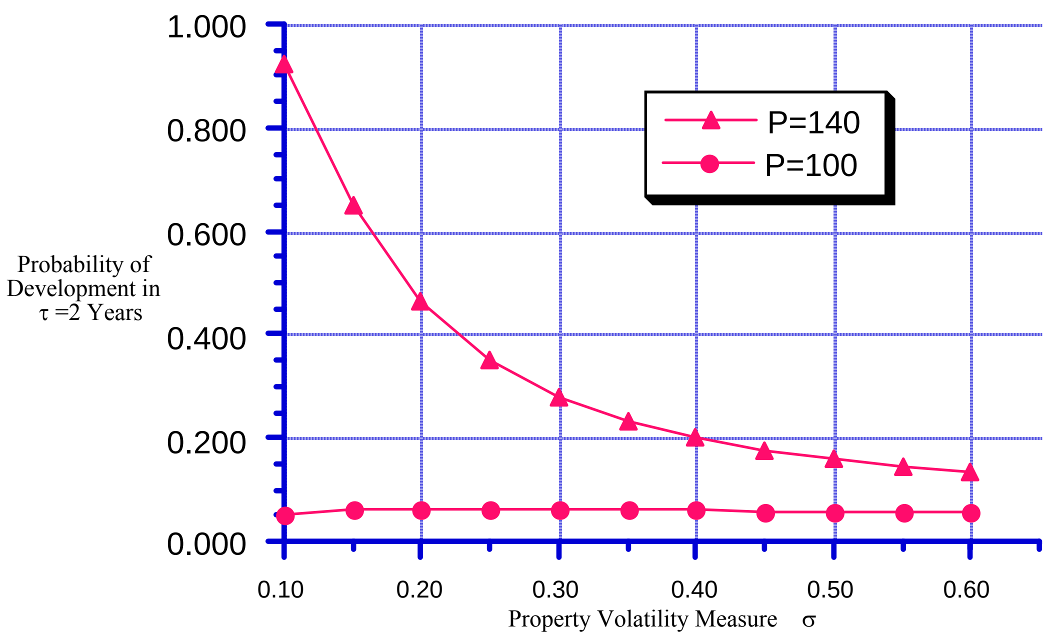

Figure 1- Probability of Development Within the Next 2 Years for Given Levels of Uncertainty. P*= $162

Hence, changes in development probability depend critically on the relationship of current improved property value with the hurdle value. The further current property value is

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[12]In this example we use the following parameter values: expected property return μ=14%, risk-free rate r= 10%, cap rate δ = 8% and property volatility σ=15%.

below the development hurdle value, the more the volatility effect dominates the hurdle value effect. However, properties that are nearer to the hurdle value are more sensitive to increases in P^* since the land was previously quite "ripe" for development. This suggests that $\partial F/\partial \sigma < 0$ for property that is ripe for development, which is what presumably shows up in the construction data and is therefore relevant. Hence, the conventional wisdom is confirmed, although for reasons more complex than focusing only on the hurdle value as indicative of investment activity.

II. Data and Empirical Methodology

A. A Regression Model Based on Aggregate Variables

Based on the real option model developed in the previous section, the hypothesis of this study--i.e., the negative relationship between asset volatility and construction activity--is tested by specifying the following relationship:

$$\boxed{\mathbf{F_t = f(P, \mu, \delta, r, K, \sigma)}} \tag{7}$$

where **F** is the probability of developing the land, **P** is the value of the developed land (the built property), **μ** is the expected rate of appreciation in the value of the developed property, **δ** is the capitalization rate, **r** is the risk-free interest rate, **K** is the cost of construction, and **σ** is the standard deviation of the property's return.[13]

In testing the real option model developed in the previous section, it is important to note that it is microeconomic in nature and is derived in a partial equilibrium framework with the assumption that the value of the property is exogenous and is unaffected by changes in

[13]Time subscripts for the independent variables in (7) 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 and discuss our results in the following section.

development activity. That is, the model predicts the actions of an individual holder of undeveloped land. However, in order to test the model's predictions, the closest counterparts to the variables specified in (7) are a set of aggregate variables. Thus, it is clear that development decisions are made in general equilibrium since it is likely that the variables that affect the aggregate rate of development will also affect the aggregate price of real estate. We admit this bit of realism and control for the potential endogeniety of the property price in the development of the empirical models that are discussed in the following section. However it should be noted that the comparative static results gleaned from the real option model should continue to hold--at least in the short run--despite using aggregate data. This follows from the fact that development hurdles (P*) for individual properties will change in tandem with any change in the independent variables in equation (7).[14]

Our set of aggregate quarterly data that will serve as measures for the variables is as follows.

1. In place of the probability of development (F) we use a measure of the level of new development, the log of the square feet of actual construction for various categories of commercial real estate (supplied by F.W. Dodge), which we denote as C. Because C represents real (i.e., actual) levels of construction, all of the remaining variables will also be expressed in real terms.

2. . We develop two measures for P**,** the real price of commercial real estate. First, the unsmoothed price index for various categories of commercial real estate divided by the Consumer Price Index (CPI) where we use the Russell/NCREIF index of commercial property capital returns.[15,16]See Appendix 1 for details on the procedures we used for unsmoothing this index. Second, we calculate the average quarterly rate of return (excluding

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[14]For a similar argument and further discussion of the applicability of the model's predictions to aggregate data, see Pindyck and Solimano [1993].

[15] We use the capital return component of the Russell/NCREIF index to reflect the ex-dividend changes in property value, which is the relevant measure for our analysis.

[16]The base year for CPI is 1985 (data from International Financial Statistics).

return from dividends) on equity REITs minus the CPI inflation rate.[17] Recall that the property price is expected to be positively related to the rate of construction.

3. No good proxy exists for μ, the expected property appreciation rate. Consequently, we will assume that the total expected property return is constant.[18] This means that changes in the appreciation rate are presumed to be perfectly (or at least highly) correlated with changes in the payout (capitalization) rate. Hence, the payout rate is assumed to reflect appreciation rate as well as dividend payout.

4. The expected real capitalization rate, δ, is measured by the capitalization rate for various categories of commercial real estate, minus expected inflation. This measure is obtained from the commercial real estate loan data provide by the American Council of Life Insurance (ACLI) and is calculated by dividing current net operating income by estimated current property value. Data is compiled at the individual property level by reporting companies to ACLI and reported as an average. The individual cap rates are weighted by property value. This measure is expected to be positively related to the level of construction.

5. The expected real risk-free interest rate is proxied by the ten-year Treasury bond rate minus expected inflation (which is itself proxied by the fitted value from a first-order autoregression for the CPI inflation rate). 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 reasonable period of time. The data source is Citibase. The interest rate is expected to be negatively related to the rate of construction.

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[17]We calculated the quarterly returns for each REIT by using daily returns for each equity REIT reported on the Center for Research in Securities Prices (CRSP) file from January 1, 1972 to December 31, 1992. REITs are essentially closed end investment companies with publicly traded stock that own exclusively real estate related assets. Equity REITs have direct ownership of income producing real estate, principally, office buildings, shopping centers, industrial properties and apartments. Therefore, it can be argued that the return on equity REITs represents the return on the underlying real estate held by the REIT. For a review of the financial economics literature on REITs see Corgel, McIntosh and Ott [1995].

[18]Surveys in almost every year that are completed by real estate professionals indicate expected total property returns of about 12 percent. See, for example, Emerging Trends in Real Estate published by Equitable Real Estate and the Real Estate Research Corporation.

6. The real cost of construction, K, is measured by the log of the cost per square foot for various categories of commercial real estate divided by the CPI. This data is obtained from F.W. Dodge. The cost is expected to be negatively related to the rate of construction.

7. The level of uncertainty, σ, is proxied by (1) implied volatility of prices for various categories of commercial real estate and (2) the standard deviation of daily rates of return on equity REITs. The next subsection provides a detailed explanation of the development of each of the uncertainty proxies. The option model predicts a negative relationship between construction activity and uncertainty when land is ripe for development.

B. Development of the Volatility Measures

1. Measuring Implied Volatility of Prices From Commercial Mortgage Interest Rates

Investors will rationally base their development decisions on relevant factors that are expected to occur over the investment horizon. The real options model of investment decision-making emphasizes the importance of uncertainty; thus, a forward looking estimate of property volatility is desirable.

To obtain the first of our volatility estimates, we calculate property volatilities that are implied in commercial mortgage rates as reported by ACLI. The idea here is to treat the commercial mortgage as a contingent-claim, whose value depends on the developed property price that serves as collateral to the loan. The risk of default is analogous to a put option owned by the borrower, whose value is priced into the equilibrium loan rate. Epperson et al. [1985] and Titman and Torous [1989] were the first to employ this approach in a commercial mortgage context, and the latter authors find that predicted risky rate spreads above the riskless bond rate match observed rates quite nicely. Rather than price the mortgage, we take observed commercial mortgage rates (prices) as given, along with other observable model input variables, and calculated the volatility that is implicit in property value to produce observed loan rates. This is precisely the same approach that Titman and Torous [1989] employ as part of their analysis, the difference being that we employ actual market data as input parameters rather than relying on arbitrary inputs.

To implement this approach, assume that built property values evolve as defined in equation (1). The mortgage contract is assumed to lock-out prepayment, which is generally consistent with how these loans are written.[19] Payments are fixed over the loan term with no amortization occurring. This again is consistent with most mortgages written in the last 15 years, which are fixed rate with little or no amortization. Since prepayment is locked out, default is the only termination risk that requires pricing. When default occurs, the borrower exchanges the property in return for release of liability on the loan. Hence, when deciding whether to default or not, the borrower compares the market value of the property with the market value of the mortgage, inclusive of the option to default. Default occurs when property value equals or falls below mortgage value.

This logic can be formalized by applying standard equilibrium arguments with mortgage value as a function of property value and time to loan maturity. Given the additional assumption of constant interest rates, the resulting pricing equation is,[20]

$$\boxed{\frac{1}{2}\sigma_P^2 P^2 \frac{\partial^2 M}{\partial P^2} + (r-\delta)P\frac{\partial M}{\partial P} - \frac{\partial M}{\partial \tau} + m = rM} \tag{8}$$

where M is mortgage value, τ is time left to mortgage maturity and m is the continuous rate of mortgage payment.[21] The equilibrium mortgage rate is implicit in m, the continuous rate of mortgage payment. Boundary conditions involving property value are similar to those

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[19]Prepayment lockouts essentially eliminate prepayment risk. Thus the pricing of this risk can be ignored when computing implied volatility.

[20] Childs, et al. [1994] examine the constant versus stochastic interest rate assumption in the context of commercial mortgage valuation and conclude that there is little difference between approaches, as long as the current term structure is adequately represented. This conclusion is also consistent with results obtained by Buser et al. [1990], Kim et al. [1993] and McConnell and Singh [1994] who consider other interest rate sensitive contingent-claims.

[21] Kau et al. [1993] examine the sensitivity of mortgage value to continuous versus discrete mortgage payment assumptions and conclude that there is almost no difference in mortgage value.

found in Titman and Torous [1989] (i.e., equations (4), (5), (6) and (7) on p.348). As discussed above, of particular importance is the default/free boundary condition which requires that $M(P,\tau)=P$ for default to occur. Alternatively, if $M(P,\tau)<P$, the borrower continues making payments on the mortgage.

Because of the complexity of this valuation problem, numerical methods are required to obtain mortgage value solutions. Solutions are obtained using standard binomial model techniques in which 50 payment intervals per year are assumed. When the problem is discretized, it is important to note that it is one of solving for a compound contingent-claim, in which the "entry fee" for continuing with the mortgage is the periodic mortgage payment. Once mortgage value solutions are determined for a given mortgage payment, we iterate over alternative mortgage rates (as reflected in m) until mortgage value equals the initial loan amount (i.e., we price the mortgage at par).

To implement this approach in which we determine property volatility implicit in the loan rate, we use observed ACLI mortgage origination rates given that these mortgages are originated at par.[22] Implied property volatility is estimated each quarter based on weighted average commercial mortgage rates for new originations as reported by ACLI, where weights are adjusted depending on loan size. In addition, we require the following additional data to fully parameterize the model. The risk-free rate is determined from Treasury bond yields. Based on average mortgage loan maturity as provided by ACLI, the riskless rate is obtained by maturity matching the average loan term with the Treasury rate. When average loan maturities are greater than 10 years, the T-bond rate is obtained by interpolating between the 10 year and 30 year rate. When the average maturity is 10 years or less, yield is obtained based on year closest to the average ACLI maturity. Standardized measures of current property price and par loan amount can be obtained from the average loan-to-value ratio on

[22] Up-front charges are typical with commercial mortgages, but much of this cost is typically used to cover costs of origination rather to enhance the yield.

newly originated loans. This data is again obtained from ACLI. Average time to maturity and payout rate are also obtained from ACLI data.

Figure 2 shows our implied volatility estimates from approximately the first quarter of 1979 through the fourth quarter 1993 for office and retail property types as well as for all property types, as reported by ACLI. Note that the volatilities generally range from 15 to 25 percent over the time period, which is approximately what Quigg [1993] found using an implied volatility estimate from a land option value model and what Geltner [1993] infers using "unsmoothing" techniques with respect to appraisal-based returns. Also note that volatility has been somewhat higher in recent years.

We should note that there are several potential sources of bias in our estimates. Most

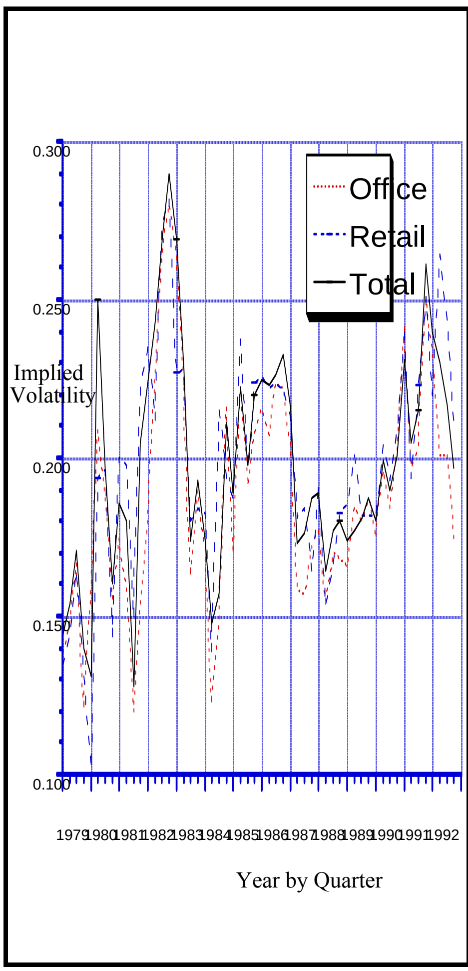

Figure 2 Implied Volatility Estimates for Commercial Real Estate

importantly, our model reflects default risk only in markets that are assumed to be frictionless. If the commercial mortgage rate reflects other risks or frictions, such as foreclosure transaction costs and less than perfect mortgage market liquidity, calculated property volatilities will be higher than "true" volatility. However, if the relationship between default risk and other priced factors are relatively constant through time it will not affect inferences drawn from the regression analysis. In the other direction, any frictions that the borrower encounters will result in "sub-optimal" default, which reduces the required risk premium. Rational lenders will price this into the required mortgage rate, which would have the effect of reducing implied volatility estimates. All told, we conjecture that our volatility measure is somewhat upwardly biased, but probably close to the true underlying property volatilities.

2. Measuring Volatility Using REIT Return Data

Using daily returns for each equity REIT reported on the Center for Research in Securities Prices (CRSP) file from January 1, 1972 to December 31, 1992, we constructed an equally weighted REIT return index and computed the daily returns for this index as follows,

$$\mathbf{R}_{\mathbf{INDEX(t)}} = \frac{\mathbf{1}}{\mathbf{n}}\sum_{\mathbf{j=1}}^{\mathbf{n}} \mathbf{R}_{\mathbf{jt}} \tag{9}$$

where n is the number of REITs in that are present in each quarter and where $\mathbf{R}_{\mathbf{jt}}$ is the daily return for REIT j for day t.

To obtain an uncertainty measure we calculated the standard deviation **S(t)** of the daily REIT index return for each quarter as follows,

$$\mathbf{S(t)} = \left(\frac{\mathbf{1}}{\mathbf{D}}\sum_{\mathbf{t=1}}^{\mathbf{D}}\left(\mathbf{R}_{\mathbf{Index(t)}} - \bar{\mathbf{R}}_{\mathbf{Index(Q)}}\right)^{2}\right)^{1/2} \tag{10}$$

where **D** is the number of days in the quarter and $\boxed{\bar{\mathbf{R}}_{\mathbf{Index(Q)}}}$ is the average daily return for the REIT index in the quarter.

The measure in equation (10) is the standard deviation of the daily return on the equity REIT index and represents our second measure of uncertainty. Figure 3 depicts the time series of the annualized equity REIT volatility measure.[23,24]

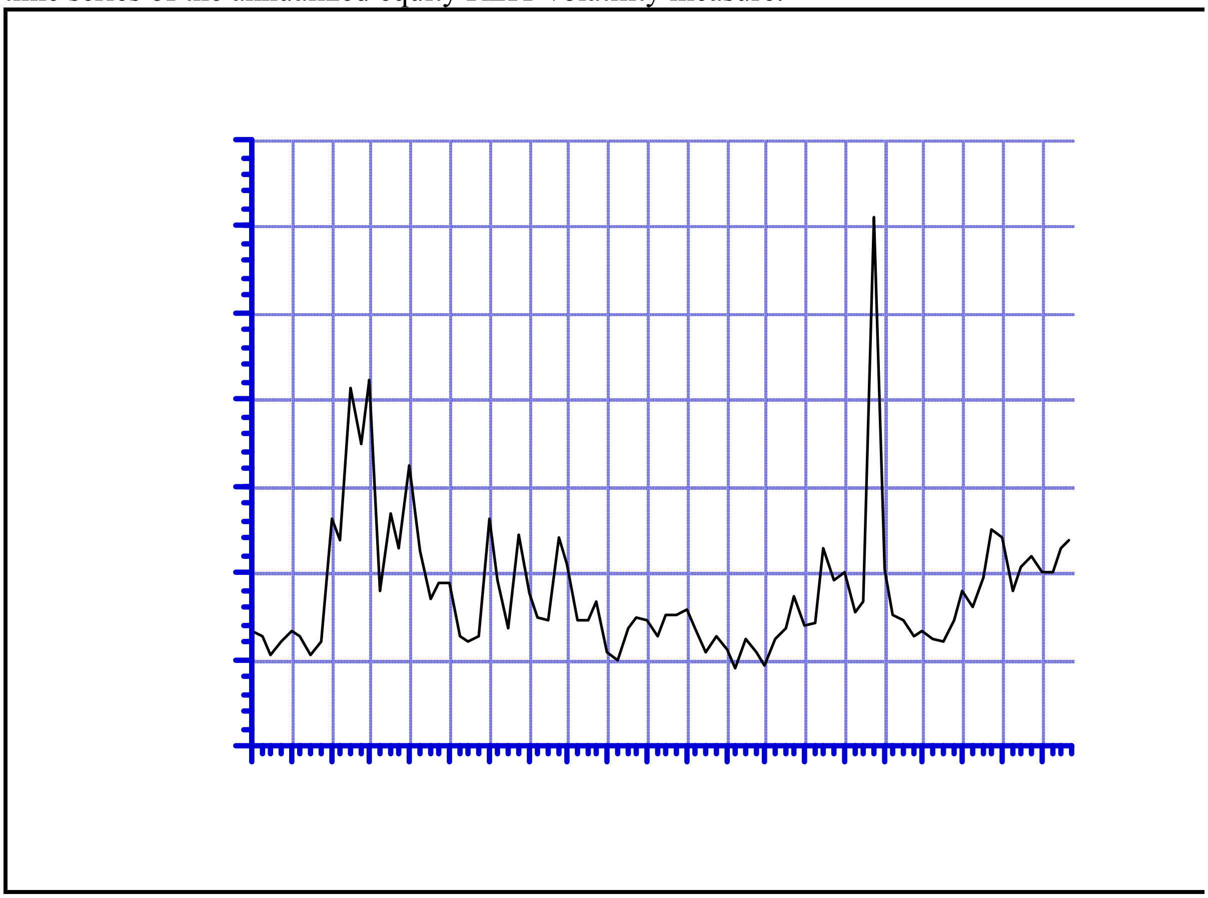

Figure 3 Annualized Equity REIT Volatility Measures

[23]REITs contain leverage which will create an upward bias in our measure of uncertainty relative to measures of unlevered property returns. This bias should not affect the significance of our empirical results since the degree of equity REIT leverage remains relatively constant over short (2 to 3 quarter) time frames.

[24] This measure reflects uncertainty for a given quarter so that immediate changes in uncertainty, and its effect on the development boundary P*, can be measured across quarters. Most REIT measures of uncertainty are computed based on a return time series covering many years which tends to smooth changes in REIT volatility and may not accurately reflect contemporaneous changes in uncertainty.

III. Development of the Empirical Model and Empirical Results

As described in the previous section, the available data are for aggregate 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 following models: 1) a simultaneous equation model utilizing two-stage least squares; and, 2) a reduced form model. By specifying two models, we can provide an indication of the robustness of our results.

III.A Simultaneous Equation Model

We specify the following linear simultaneous equation model. In general terms, the model postulates that

$$\mathbf{P_t = \alpha_0 + \alpha_1 r + \alpha_2 \delta + \alpha_3 g + \alpha_4 C + \varepsilon_p} \qquad \mathbf{(11a)}$$

$$\mathbf{C_t = \beta_0 + \beta_1 P + \beta_2 K + \beta_3 \sigma + \varepsilon_c} \qquad \mathbf{(11b)}$$

where the variables are as defined above and ε_p and ε_c are disturbance terms. The variable **g** is the expected growth rate of real net operating income, proxied by lagged values of the growth rate of real GDP. Thus the independent variables in (11a) include those that are prevalent in the standard discounted cash flow pricing model with the addition of the construction variable to reflect its endogeneity within the model.[25]

Given the specification in (11), the first step in the 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 is never rejected for any category of commercial real estate for the log of square feet of construction, the log of the real cost of construction, the real capitalization rate, the real unsmoothed price, nor the real interest rate. Hence, we assume these series are nonstationary. On the other hand, implied volatility of prices for every category of commercial real estate, the growth rate of real GDP, and the standard deviation of returns on equity REITs 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. 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.[26] Therefore, the model defined in (11) becomes:

$$\Delta \mathbf{P_t} = \alpha_0 + \alpha_1 \Delta \mathbf{r} + \alpha_2 \Delta\delta + \alpha_3 \Delta \mathbf{g} + \alpha_4 \Delta \mathbf{C} + \Delta\varepsilon_p \qquad \textbf{(12a)}$$

$$\Delta \mathbf{C_t} = \beta_0 + \beta_1 \Delta \mathbf{P} + \beta_2 \Delta \mathbf{K} + \beta_3 \Delta\sigma + \Delta\varepsilon_c \qquad \textbf{(12b)}$$

where = $\Delta\varepsilon_p$ and $\Delta\varepsilon_c$ are assumed to have independent normal distributions.

---

[25]The discounted cash flow model for price determination assuming constant growth is simply $P = \frac{NOI(1+g)}{\mu - g} = \frac{NOI(1+g)}{\delta}$. Therefore, we added a proxy for the variable g (growth rate) in the equation for price as specified in (11a).

[26] 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 (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.

III.A.1. Two-Stage Least Squares Regression Results Using Implied Volatility of Real Estate Prices

We begin with the results of regressions based on implied volatility of commercial real estate prices as the proxy for uncertainty. Our initial approach is to estimate the equation for the first difference of the log of square feet of construction (ΔC) using two-stage least squares (instrumental variables). We include lagged as well as current values because the time period appropriate for analysis may be longer than a quarter.[27] In the construction equation, we write ΔC as a function of the current and three lagged values of the first differences of (1) uncertainty ($\Delta\sigma$), (2) the log of real cost (ΔK), and (3) the real price of commercial real estate (ΔP). Because ΔP is endogenous, we use as instruments current and lagged values of the exogenous variables from the ΔP equation. Specifically, the instruments are the current and three lagged values of the first differences of both the real interest rate (Δr) and the real capitalization rate ($\Delta\delta$) and three lagged values of the first difference of the growth rate of real GDP (Δg).[28] The first-stage estimates include these instruments plus all of the regressors from the construction equation except ΔP and its lagged values. Each estimated equation also includes a constant term and seasonal dummies. The number of lagged values is limited by the fairly small sample size.

Table 1 contains the results. In all cases the sample is the longest available given that data on implied volatility of prices are available from 1979:1 to 1992:4.[29] 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.

[27]Because real estate requires time-to-build, a change in any of the underlying variables may not immediately affect construction activity. Therefore there may be a lagged effect as developers adjust construction over time.
[28] We do not include the current value of ΔG because of potential endogeneity: an increase in commercial real estate construction causes an increase in real GDP growth by definition.
[29]Pre 1979 ACLI data is not available for computing implied volatility.

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.

Table 1.
Estimates of the Structural Equation for Construction Using Measures of Implied Volatility of Property Prices (Dependent variable: ^{2}C)

Sample	(1) Total 79:2-92:4	(2) Office 79:3-92:4	(3) Retail 79:2-92:4
Constant	**-.0713** (.0242)	**-.0681** (.0408)	**-.0698** (.0254)
Sum of Current & Lagged ^{2} σ	**-1.63** (.495)	**-2.29** (.806)	**-.516** (.374)
Sum of Current & Lagged ^{2}K	**-1.91** (.817)	**.407** (1.30)	**-.810** (.673)
Sum of Current & Lagged ^{2}P	**-.0062** (.0049)	----	----
ρ	----	**-.41** (.12)	----
R^2	**.69**	**.60**	**.70**
Adjusted R^2	**.63**	**.50**	**.66**
S.E.	**.08**	**.13**	**.09**
D.W.	**1.88**	**1.76**	**1.96**

*The coefficients of seasonal dummies are not shown. Standard errors are in parentheses. ρ is the estimate of the coefficient of first-order autocorrelation.

For total commercial real estate construction (column 1), the effect of uncertainty (current value only) on construction is negative and significant at less than the 1% level (t = -3.36). A one-standard-deviation increase in total price volatility results in roughly a 5% reduction in total new construction of commercial real estate.[30] Costs also have the predicted negative effect with the sum of the coefficients on current and lagged cost being significant at the 2% level (t = -2.34). The real price has an unexpected negative coefficient that is not statistically significant.

[30]The change in construction is calculated by multiplying the standard deviation of the volatility measure (in this case .0351) by the coefficient on volatility.

For office construction, maximizing adjusted R^2 results in the price variables being excluded from the equation altogether. Thus, there is no need to use a two-stage procedure. We use instead maximum-likelihood adjustment for first-order autocorrelation in a single-equation regression. The sum of the current and one lagged value of $\Delta\sigma$ is negative and significant at less than the 1% level (t = -2.85). A one-standard-deviation increase in office price volatility results in roughly a 7% reduction in new office construction. Overall, cost has an insignificant effect.

For retail construction, $\Delta\sigma$ (current value only) has a negative coefficient which falls short of standard levels of statistical significance (t = -1.38). A one-standard-deviation increase in retail price volatility results in less than a 2% reduction in new retail construction. Cost also has an insignificant effect. The price variables are excluded and estimation is by ordinary least squares.

III.A.2. Two-Stage Least Squares Regression Results Using the Standard Deviation of Returns on Equity REITs and Equity REIT Returns.

In this section we use the standard deviation of daily returns on equity REITs as the proxy for uncertainty. In addition to providing a check for robustness, this measure has two advantages over implied volatility of real estate prices: (1) the data are available over a longer sample period: 1972:1 to 1992:4, and (2) we can use two additional categories of real estate construction for which implied volatility of price is not available: apartment and industrial construction. The unsmoothed price of real estate, however, is not available for the longer sample period or for the two new construction categories. Therefore, we use the average quarterly rate of return on equity REITs (excluding dividends) minus the CPI inflation rate as the proxy for the change in the real price of commercial real estate.

The results, using the 2SLS technique described previously are presented in Table 2. The procedures for selecting the number of lags and the sample size are also the same.

Table 2.
Estimates of the Structural Equation for Construction Using the Standard Deviation of Returns on Equity REITs (Dependent variable: ^{2}C)

Sample	(1) Total 74:3-92:4	(2) Office 72:4-92:4	(3) Retail 73:3-92:4	(4) Apartment 73:3-92:4	(5) Industrial 73:3-92:4
Constant	-.107 (.022)	-.106 (.035)	-.124 (.024)	-.103 (.030)	-.100 (.031)
Sum of Current & Lagged ^{2} σ	-26.9 (16.4)	-37.1 (14.3)	6.88 (5.29)	-37.7 (22.7)	-52.7 (19.6)
Sum of Current & Lagged ^{2}K	-1.01 (.447)	.619 (.290)	----	-.264 (1.48)	-.265 (.17)
Sum of Current & Lagged ^{2}P	.00064 (.0010)	----	.00237 (.00126)	.00291 (.00130)	-.00203 (.00099)
ρ	----	-.28 (.108)	----	----	----
R^2	.71	.45	.70	.55	.60
Adjusted R^2	.66	.39	.64	.47	.53
S.E.	.086	.143	.105	.122	.126
D.W.	2.23	1.91	2.45	2.47	1.77

*The coefficients of seasonal dummies are not shown. Standard errors are in parentheses. ρ is the estimate of the coefficient of first-order autocorrelation.

For total commercial real estate construction (column 1), the effect of uncertainty (current and three lagged values) is negative and significant at the 10% level (t = -1.66). A one-standard-deviation increase in the standard deviation of returns on equity REITs results in roughly a 7% reduction in total new construction of commercial real estate (recall that the corresponding figure for implied volatility of price is 5%). Costs also have a negative and significant effect (t = -2.26). The real return on equity REITs has a positive but insignificant effect.

For office construction (column 2), maximizing adjusted R^2 results in the return variables being excluded from the equation. As in Table 1, there is no need to use 2SLS and we estimate a single equation using maximum-likelihood adjustment for first-order autocorrelation. The sum of the current and two lagged values of $\Delta\sigma$ is negative and significant at the 1% level (t = -2.59). A one-standard-deviation increase in the REIT uncertainty variable results in roughly a 9.5% reduction in new office construction (compared to 7% for price volatility). Cost has an unexpected positive coefficient that is significant at the 4% level.

For retail construction (column 3), uncertainty (current value only) has a positive effect that is not statistically significant (t = 1.30). Recall that in Table 1 the result is also not significant, though the sign of the coefficient is negative. Cost has an insignificant effect (not appearing in the final equation) and return has a positive effect, significant at the 6% level.

For apartment construction (column 4), uncertainty (current and three lagged values) has a negative effect that is significant at the 10% level. A one-standard-deviation increase in the REIT uncertainty measure reduces new apartment construction by roughly 9.5%. The overall effects of cost are negative but not significant and for returns are positive and significant.

For industrial construction, uncertainty (current and three lagged values) has a negative effect that is significant at the 1% level. A one-standard-deviation increase in the REIT uncertainty measure results in more than a 13% reduction in industrial construction. The effect of cost is negative but not significant at standard significance levels (t = -1.55). The effect of return has an unexpected negative effect that is significant at the 5% level (t = -2.05).

Overall, the results regarding the effects of uncertainty on construction based on the standard deviation of returns on equity REITs are similar but somewhat weaker than the results based on implied volatility of real estate prices.[31] Results regarding the effects of cost and return on construction are mixed. As in the two-stage regressions for price volatility, it

[31]The weaker results may be due to the ability to compute the implied volatility measure for each separate property type as opposed to one REIT volatility measure for all commercial property types.

may be that the instruments are not very good. Regressions of the real rate of return on the instruments yield values of R^2 that range from .17 to .25. Therefore, in the following section we also estimate a reduced-form equation for each category of construction.

III.B Regression Results Using a Reduced Form Model

For the purpose of comparison, we now test for the uncertainty/development relationship without specifying any equilibrium relationship as was defined by the structural equations given in (12). Continuing with the assumption that aggregate construction will affect the aggregate price of real estate, we now exclude P from our regression model and view the resulting equation as a reduced form.

Therefore, the model defined in (7) becomes

$$\Delta \mathbf{C_t} = \beta_0 + \beta_1\sigma + \beta_2\Delta K + \beta_3\Delta\delta + \beta_4\Delta \mathbf{r} + \Delta\varepsilon \qquad \textbf{(13)}$$

We assume that $\Delta\varepsilon$ has a normal distribution with constant mean. We include lagged as well as current values of the independent variables using the procedures described previously. The interpretation of the reduced form coefficients is that they represent the overall effect of each *exogenous* variables on construction. Since the price of real estate is not held constant in this model, the coefficients represent the effects when price is allowed to vary.

III.B.1. Reduced Form Regression Results Using Implied Volatility of Real Estate Prices

The regression results using implied volatility of real estate prices are presented in Table 3.

Table 3.
Estimates of the Reduced-Form Equation for Construction Using Measures of Implied Volatility of Property Prices (Dependent variable: ^{2}C)

Sample	(1) Total 79:2-92:4	(2) Office 79:3-92:4	(3) Retail 79:2-92:4
Constant	-.063 (.022)	-.069 (.041)	-.070 (.025)
Sum of Current & Lagged ^{2} σ	-1.23 (.34)	-2.29 (.81)	-.52 (.37)
Sum of Current & Lagged ^{2}K	-1.69 (.74)	.41 (1.30)	-.81 (.67)
Sum of Current & Lagged ^{2} δ	----	----	----
Sum of Current & Lagged ^{2} r	----	----	----
ρ	----	-.41 (.12)	----
R^2	.73	.60	.70
Adjusted R^2	.68	.50	.66
S.E.	.07	.13	.09
D.W.	1.78	1.76	1.96

*The coefficients of seasonal dummies are not shown. Standard errors are in parentheses. ρ is the estimate of the coefficient of first-order autocorrelation.

For total commercial real estate construction (column 1), the effect of uncertainty (current value only) on construction is negative and significant at less than the 1% level (t = -3.60). A one-standard-deviation increase in total price volatility results in roughly a 4 1/2% reduction in total new construction of commercial real estate. Costs also have the predicted negative effect with the sum of the coefficients on current and lagged cost being significant at the 3% level

(t = -2.27). Neither the capitalization rate nor the interest rate have any appreciable affect and they do not enter the final version of the equation.

For office construction (column 2), we use maximum-likelihood adjustment for first-order autocorrelation. The sum of the current and one lagged value of $\Delta\sigma$ is negative and significant at less than the 1% level (t = -2.85). A one-standard-deviation increase in office price volatility results in roughly a 7% reduction in new office construction. Overall, cost has an insignificant effect. Neither the capitalization rate nor interest rate enter the final equation.

For retail construction (column 3), $\Delta\sigma$ (current value only) has a negative coefficient which falls short of standard levels of statistical significance (t = -1.38). A one-standard-deviation increase in retail price volatility results in less than a 2% reduction in new retail construction. Cost also has an insignificant effect and the capitalization and interest rates do not enter the final equation.

III.B.2. Reduced Form Regression Results Using the Standard Deviation of Returns on Equity REITs.

Next we test the reduced form model using the standard deviation of daily returns on equity REITs as the proxy for uncertainty. Table 4 contains the results.

For total commercial real estate construction (column 1), the effect of uncertainty (current and three lagged values) is negative and significant at less than the 1% level (t = -3.09). A one-standard-deviation increase in the variability of returns on equity REITs results in roughly a 10% reduction in total new construction of commercial real estate (recall that the corresponding figure for implied volatility of price is less than 5%). Costs also have a negative and significant effect (t = -2.38). Both the capitalization rate and the interest rate have coefficients with unexpected signs that are significant at the 10% level at least.

For office construction (column 2), using maximum-likelihood adjustment for first-order autocorrelation, the sum of the current and two lagged values of Δs is negative and significant at the 2% level (t = -2.44). A one-standard-deviation increase in the variability of REIT returns results in roughly a 9% reduction in new office construction (compared to 7%

for price volatility). Cost has an unexpected positive coefficient (current value only) that is significant at the 5% level. As with total construction, the capitalization and interest rates also have effects with unexpected signs and significant coefficients.

Table 4.
Estimates of the Reduced-Form Equation for Construction Using the Standard Deviation of Returns on Equity REITs (Dependent variable: ^{2}C)

Sample	(1) Total 73:4-92:4	(2) Office 72:4-92:4	(3) Retail 73:3-92:4	(4) Apartment 73:2-92:4	(5) Industrial 73:2-92:4
Constant	-.102 (.021)	-.093 (.035)	-.127 (.029)	-.088 (.032)	-.103 (.026)
Sum of Current & Lagged $^{2}\sigma$	-39.5 (12.8)	-34.7 (14.2)	-38.7 (13.9)	-69.4 (19.4)	-41.6 (15.3)
Sum of Current & Lagged ^{2}K	-.969 (.41)	.585 (.289)	----	-.801 (.68)	-.171 (.089)
Sum of Current & Lagged $^{2}\delta$	-.029 (.017)	-.051 (.025)	---	.053 (.044)	-.056 (.029)
Sum of Current & Lagged ^{2}r	.039 (.016)	.045 (.023)	----	-.029 (.042)	.031 (.029)
ρ	----	-.28 (.11)	-.23 (.11)	----	----
R^2	.72	.48	.65	.51	.76
adjusted R^2	.66	.41	.61	.41	.70
S.E.	.085	.141	.109	.129	.101
D.W.	1.77	1.98	1.92	1.85	1.94

*The coefficients of seasonal dummies are not shown. Standard errors are in parentheses.
ρ is the estimate of the coefficient of first-order autocorrelation.

For retail construction (column 3), using maximum-likelihood adjustment for first-order autocorrelation, uncertainty (current and three lagged values) has a negative effect that is statistically significant at less than the 1% level(t = -2.78). A one-standard-deviation increase in the variability of REIT returns reduces new retail construction by roughly 10% (compared to 2% for price volatility). Neither cost, capitalization rate, nor interest rate appears in the final equation.

For apartment construction (column 4), uncertainty (current and three lagged values) has a negative effect that is significant at less than the 1% level (t = -3.58). A one-standard-deviation increase in the variability of REIT returns reduces new apartment construction by roughly 17.5%. The overall effects of cost are negative but not significant. The sum of coefficients for the capitalization rate and interest rate have the expected signs (positive and negative, respectively), though neither is close to being statistically significant.

For industrial construction (column 5), uncertainty (current and three lagged values) has a negative effect that is significant at less than the 1% level (t = -2.71). A one-standard-deviation increase in the variability of REIT returns results in roughly a 10 1/2% reduction in industrial construction. The effect of cost is negative and significant as is the effect of the capitalization rate. The effect of the interest rate is positive but not significant.

Overall, the reduced form results regarding the effects of uncertainty on construction based on the standard deviation of returns on equity REITs are similar and somewhat stronger than the results based on implied volatility of real estate prices. Results regarding the effects of cost, capitalization rate, and interest rate are mixed. Thus, we consistently find significant negative effects of measures of uncertainty on total commercial real estate construction, office construction, apartment construction, and industrial construction. The only category of commercial real estate for which the results are not consistently significant is retail construction.

IV. Implications for Predicting Construction Activity

We find strong evidence that the two measures of aggregate value uncertainty are significantly negatively related to the level of construction of commercial real estate. Further examination of trends in uncertainty, shows that these measures follow a first order autoregressive process AR(1), implying forecastability of future volatility (see figures 2 and 3). The AR(1) models for the levels of volatility are, Implied Volatility for Total Construction

$$\boxed{\sigma_t = .079 + .605(\sigma_{t-1})} \quad \textbf{(14a)}$$

Implied Volatility for Office Construction

$$\boxed{\sigma_t = .071 + .626(\sigma_{t-1})} \quad \textbf{(14b)}$$

Implied Volatility for Retail Construction

$$\boxed{\sigma_t = .093 + .536(\sigma_{t-1})} \quad \textbf{(14c)}$$

Standard Deviation of Equity RIET Index Daily Returns

$$\boxed{\sigma_t = .0033 + .418(\sigma_{t-1})} \quad \textbf{(14d)}$$

where, for each equation, the coefficient on the lagged term is significant at less than the 1% level.[32]

The implication of this inertia in property volatility and the fact that volatility is found to strongly influence construction activity is that aggregate property value uncertainty 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. In the context of our results, since the reduced form equation provides the strongest empirical results and is parsimonious, it should provide a forecast with the least amount of forecast error (i.e., forecasting of variables in addition to volatility are minimized).

An extension of this paper could involve examining both the relationship between uncertainty and aggregate property price as well as the relationship between uncertainty and construction activity. While the paper examines uncertainty and construction activity with the presence of price (or instruments of price) as an explanatory variable(s) (see the structural model in section II), additional work using a more general framework is necessary to establish a link between changes in volatility and price.

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[32]Residuals from the AR(1) regressions were free of autocorrelation; therefore, it is doubtful that higher order terms could significantly increase forecast accuracy.

V. Summary and Conclusion

In this paper, we extend the previously developed option models by deriving a probability of development function that determines the probability of investment over a future time period. We find that there is a negative relationship between property value volatility and the probability of development when the land is ripe for development.

To empirically test the effects of changes in uncertainty/investment relationship on the rate of commercial real estate development (investment) over time, we develop two proxies for the level of uncertainty in real property values. First, we develop a forward looking estimate of uncertainty by computing the implied volatility of prices using the spread in commercial mortgage rates over comparable duration treasury bonds. Our second volatility measure is derived by computing the standard deviation of daily rates of return on equity Real Estate Investment Trusts (REITs). We find that these two measures of aggregate uncertainty about the value of commercial real estate are negatively and significantly related to the level of construction of commercial real estate. The result holds for total construction and for several individual categories of construction and is consistent with the predictions of the model.

We also find that the uncertainty measures follow a first order autoregressive process AR(1) implying forecastability of future volatility. Using the autoregressive models to forecast volatility, the empirical models in this paper could be modified and used to predict changes in construction.

Appendix 1

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 will address both factors in our unsmoothing.

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

$$\mathbf{r_t^* = w_0 r_t + w_1 r_{t-1} + w_2 r_{t-2} + \,.\,.\, + w_{t-1} r_1} \qquad \textbf{(A1)}$$

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 (A1) to be rewritten as:

$$\mathbf{r_t^* = z_1 r_{t-1}^* + z_2 r_{t-2}^* + z_3 r_{t-3}^* + \,.\,.\, + e_t} \qquad \textbf{(A2)}$$

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 values--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 (9) can be inverted to result in,

$$r_t = 1/w_0[r_t^* - z_1 r_{t-1}^* - z_4 r_{t-4}^*] \quad \textbf{(A3)}$$

Russell/NCREIF data can be used to estimate the relationship expressed in (A2), where the time series regression coefficients estimated in that equation can be substituted into equation (A3) to de-lag the property returns.

The parameter w_0 is chosen 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 percent for all property types and 12 percent 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,

Office: $\mathbf{r_t = 3.2[r_t^* - .2281r_{t-1}^* - .6201r_{t-4}^*]}$

Retail: $\mathbf{r_t = 5.62[r_t^* - .2806r_{t-1}^* - .6271r_{t-4}^*]}$

Total: r_t $\mathbf{= 4.1[r_t^* - .3158r_{t-1}^* - .6372r_{t-4}^*]}$

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.

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