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THE ROLE OF UNCERTAINTY IN INVESTMENT: AN EXAMINATION OF COMPETING INVESTMENT MODELS USING COMMERCIAL REAL ESTATE DATA

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Neoclassical investment decision criteria suggest that only the systematic component of total uncertainty affects the rate of investment, as channeled through built asset price. Alternatively, option-based investment models suggest a direct role for total uncertainty in investment decision making. To sort out uncertainty's role in investment, we specify and empirically estimate a structural model of asset market equilibrium. Commercial real estate time series data with two distinct measures of asset price and uncertainty are used to assess the competing investment models. Empirical results generally favor predictions of the option-based model, and hence suggest that irreversibility and delay are important considerations to investors. Our findings also have implications for macroeconomic policy and for forecasts of cyclical investment activity.

Investment policy has been central to economic theory and practice for over 200 years. Alfred Marshall first formulated investment decision criterion as a "net present value" rule, where investment cost is compared to the present value of certain cash flows that result from investment. More recently, the Marshallian approach has been extended to encompass uncertainty with respect to future investment productivity. Expected cash flows are discounted at a rate that is adjusted for systematic project risk. Only the systematic risk component of total uncertainty is predicted to shift the demand schedule, since non-systematic risk is diversifiable and hence not priced in equilibrium. In the neoclassical view, supply is thought to be independent of risk except as channeled through developed asset price. This implies that the investment hurdle value (analogous to Tobin's (1969) *q*) is unaffected by risk, since value associated with waiting to resolve future uncertainty is irrelevant.

Beginning with Keynes (1936), economists have expressed various degrees of concern with ignoring the timing effects of uncertainty on real investment. Indeed, for there to be no possible benefit associated with waiting to invest, it must be that, i) investment is completely reversible or ii) investment cannot be delayed. Complete reversibility suggests that physical and financial resources are fully recoverable at any time after investment. The ability to swap the ongoing cash flows from investment—at zero cost and at any time—for the original investment cost amount is clearly unrealistic for most types of investments. The alternative extreme assumption of irreversible investment implies that investment cost is sunk once investment is undertaken.[1] Although many investments are not completely irreversible, positive (ex post) adjustment costs often result in investment that is effectively irreversible (see, e.g., Dixit (1989), Grenadier (1995), Childs et. al. (1996)).

The second requirement of inflexible investment timing is also typically unrealistic, and would require circumstances such as perfect industry competition (Leahy (1993), Dixit and Pindyck (1994)), first-mover advantages and entry deterrence in imperfectly competitive markets (Spence (1977)), or the imminent threat of the taking of investment rights through regulation (Riddiough (1997)). Many real investments are protected from these "now-or-never" investment forces due to, for example, proprietary R&D effort, spatial-product differentiation, and well protected property rights. Irreversibility and timing flexibility are therefore common characteristics of many investment opportunities, thus violating assumptions underlying the neoclassical investment criterion.

A vast amount of theoretical work has been done in recent years to extend the neoclassical investment model to account for irreversibility and delay. Arrow and Fisher (1974), Henry (1974a, 1974b) and Bernanke (1983), among others, correctly recognize that the (ex ante) payoff function to irreversible investment is generally convex due to the ability to wait to invest in order to avoid low value realizations.[2] Increases in total price uncertainty therefore increase investment option value due to Jensen's inequality. Significantly, the threshold value for investment must also be modified to account for the fact that irreversible investment eliminates option value associated with waiting to invest. Bernanke refers to the increase in the option-based investment hurdle as the "bad news principle," in which the developer has an incentive to wait to reduce the odds of making an ex post regrettable investment decision.[3]

The channels through which uncertainty affects investment therefore differ in the neoclassical versus option-based investment models. In both models, an increase in *systematic* investment risk will typically increase the rate at which expected cash flows are discounted to decrease investment value. All else equal the threshold investment value (cost) remains constant in the neoclassical model, resulting in a demand-induced decline in the rate of investment. Alternatively, *total* investment risk is also predicted to impact investment behavior in the option-based investor model. The ability to delay investment suggests that an increase in total risk shifts the supply schedule leftward to decrease the rate of investment—an effect that is incremental to the asset price effect.

Although both the neoclassical and option-based models of investment are well developed theoretically, relatively little empirical research has focused on differentiating between these models. An exception is a recent paper by Leahy and Whited (1996), who furnish evidence supporting the option-based investment model. Using panel data on publicly traded firms from a variety of industries, the authors regress periodic real investment on Tobin's *q*, total uncertainty and a CAPM-based measure of systematic risk. They find evidence that the relationship between total risk and investment is statistically significant and inverse, and that total risk is more important than systematic risk as a determinant of investment. This leads the authors to conclude that:

> These results argue in favor of theories in which uncertainty affects investment directly rather than working through covariances, and in favor of models in which the marginal revenue product of capital is concave.…This leaves irreversibilities as the most likely explanation of the relationship between investment and uncertainty. [Leahy and Whited, p.66]

In this paper we provide further evidence on the role of uncertainty in investment by focusing on a particular class of real assets: commercial real estate. Besides being a large and important asset type (there is estimated to be over $5 trillion of commercial real estate in the U.S.), focusing on a single, capital-intensive industry offers several advantages in a test of alternative investment models. First, data aggregation problems are often less severe and the determinants of asset price and real investment are probably more homogeneous—and therefore more easily specified—within a particular industry. Furthermore, commercial real estate is fixed in location, is highly durable and is relatively insensitive to non-capital factors of production. Irreversibility is therefore likely to be an important investment characteristic, which suggests that commercial real estate sector is an attractive natural laboratory to contrast the option-based investment model with the neoclassical investment model.[4]

We take a somewhat different approach than Leahy and Whited (1996) in constructing our test of alternative investment models. First, in addition to uncertainty, we explicitly control for several other factors that are predicted to affect investment—including interest rate, construction cost and expected growth rate of asset cash flows. Furthermore, we explicitly model asset market equilibrium by specifying a structural equation model in which built asset price and aggregate investment are simultaneously determined. Taking a structural modeling approach—as opposed to expressing investment as a reduced form—allows us to better isolate the supply and demand channels through which uncertainty impacts investment. Indeed, our approach produces a well specified (and potentially definitive) test of competing investment models.

We empirically examine the uncertainty-investment relationship using aggregate construction data (quarterly time series data from 1972 through 1992) on various categories of commercial real estate, including apartments, office, retail and industrial properties. After controlling for the effects of built asset price, systematic risk and other related factors, we find a statistically and economically significant short-term negative relationship between total uncertainty and the rate of investment for most types of commercial real estate included in this study. These results are robust to two independent measures of asset price, systematic risk and total uncertainty. Our findings thus support the contention that investors consider irreversibility and delay to be important factors in their decision making. The results also suggest that explicit consideration of total uncertainty may lead to a better understanding of cyclical investment behavior, to improved forecasts of investment activity and in improved macro-level investment policy.

The main body of the paper is organized as follows. To further illuminate the effects of irreversible investment and delay in the context of commercial real estate investment, the following section reviews the relevant theoretical and empirical option-based investment literature. Then, in the subsequent section, we describe the structural characteristics of commercial real estate asset market equilibrium. We also describe the data, data sources and the procedures used in determining property value and uncertainty estimates that are used in the empirical test of the model. The penultimate section details the econometric model specification and provides empirical results that are used to differentiate between investment models. The final section summarizes the paper and provides suggestions for future empirical work.

Further Discussion of the Uncertainty-Investment Relationship and Related Literature

In this section we more thoroughly examine the implications of irreversibility and delay on predicted investment behavior. This analysis will serve to highlight differences and similarities of commercial real estate investment relative to other types of investment. We also discuss model sensitivity within the commercial real estate sector as a function of differences in property type (e.g., office versus apartment). We finish by reviewing the empirical literature that has focused on testing the implications of the option-based investment model.

Irreversibility

Complete irreversibility requires that cost is sunk once initial investment occurs. Irreversibility combined with timing flexibility generally implies that increased uncertainty leads to an leftward shift in the supply schedule and hence a short-run decrease in the rate of investment. Irreversibility is an extreme assumption, as there may be several reasons why partial reversals might occur. These include the ability to decrease accumulated capital stock (Caballero (1991)), construction lags with the option to abandon or in which investment cost is uncertain (Bar-Ilan and Strange (1996), Ott and Thompson (1996)), or an ability to switch between alternative factors of production (Oi (1961), Abel (1983), Childs et al. (1996)).

Primarily due to its durability and its relatively low marginal costs of operation, decreasing the capital stock in the commercial real estate sector to a significant degree is unlikely. Conversely, construction lags, possible abandonment and cost uncertainty are quite relevant. However, using realistic parameter values, both Bar-Ilan & Strange and Ott & Thompson find that construction lags must be extremely long—in excess of six years—before the uncertainty-investment relationship becomes positive. Construction periods for most types of commercial real estate are well short of six years, with the possible exceptions of large retail and office projects. Consequently, in the aggregate we would not expect construction lags to significantly change the anticipated negative uncertainty-investment relationship, although we might expect there to be some parameter sensitivity across property types.

The possibility of realizing convex payoffs from switching between alternative factors of production raises several interesting issues in the context of commercial real estate. First, although commercial real estate prices are relatively insensitive to non-capital factor inputs, zoning controls many times do allow for alternative uses. This implies that reversibility may affect the standard uncertainty-investment relationship. Childs, et al. (1996) examine this issue in detail, and show that when there are decreasing returns to scale and a low price correlation between alternative uses, convex payoffs to switching can occur. However, for these switching benefits to be realized, three basic conditions must hold: i) economically viable alternative uses must exist, ii) flexibility must be incorporated into structural design at the time of initial development to keep adjustment costs within reasonable limits, and iii) alternative uses must not be too highly correlated with one another. This rules out many types of projects, and leads us to conclude that, although convex payoffs to alternative factors of production are certainly feasible, they probably do not occur often enough in the aggregate to significantly affect the negative uncertainty-investment relationship predicted by the standard option-based model.

Delay

Investment timing flexibility can be limited in several ways. Because of locational differentiation associated with commercial real estate, the investment environment is often imperfectly competitive. In a duopolistic industry with declining returns to scale, Dixit and Pindyck (1994) and Grenadier (1996) show that competition reduces timing flexibility to potentially result in dynamically inefficient overinvestment. Increased (but still imperfect) competition furthers this effect. However, a change in total uncertainty nevertheless has the standard supply-side effect since market participants will jointly delay investment when uncertainty increases. More generally, for competitive market structure to possibly alter the usual uncertainty-investment relationship, changes in relative market competitiveness would have to be directly related to changes in price uncertainty. This is contrary to what is typically observed (see, e.g., Shleifer and Vishny (1992)). Thus, dynamics of industry competition under uncertainty are such that changes typically exacerbate—rather than mitigate—the usual negative relationship between uncertainty and investment.[5]

Positive payoff and informational externalities from competitive investment are also potentially relevant, and will encourage clumping of investment activity. For example, if positive payoff externalities in a sequential investment setting are strong enough, they can swamp incentives to delay. However, locally positive payoff externalities cannot be a universal phenomenon; otherwise, aggregate supply would explode in “good news” markets. In the case of information externalities with strategic entry, model predictions tend to reinforce the uncertainty-investment relationship since there is an increased tendency to delay initial investment as uncertainty (with respect to both current and future payoffs) increases (Childs et al. (1997)).

Timing flexibility may also be limited by regulation that threatens to delay investment, or by some other "sudden death" mechanism that renders the ex ante investment opportunity worthless. Riddiough (1997) shows that imminent sudden death results in an investment hurdle that approaches the neoclassical hurdle, even when uncertainty and irreversibility are relevant considerations. An important issue in this case is whether the rate of sudden death is correlated with changes in asset price uncertainty. Indeed, it may be that increased price uncertainty is a cause of increased regulation (or vice versa) in the commercial real estate sector. Although this is an open empirical question and an effect that could impact the anticipated uncertainty-investment relationship, we suspect that the sudden death-uncertainty relationship is relatively inelastic in the short-run.

Option-Based Empirical Literature

A small but growing empirical literature has attempted to examine the relationship between total uncertainty and investment. This literature often uses aggregate data, specifies a reduced form supply equation, and examines a cross-section of firms or countries.[6] Relevant studies in addition to Leahy and Whited (1996) include Pindyck (1990), Federer (1993), Huizinga (1993), Cabellero and Pindyck (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 his uncertainty measure and both durable equipment expenditures and orders of new plant and equipment. Huizinga tests whether inflation uncertainty—as associated with uncertainty in real wages, real output price and profit rates—affects the allocation of resources in U.S. manufacturing investment. He finds that aggregate investment declines with increased uncertainty, but obtains mixed results when testing the uncertainty-investment relationship for individual manufacturing industries. Cabellero and Pindyck and Pindyck and Solimano also find a negative relationship between aggregate investment and uncertainy for a cross-section of countries and industries.

Although the negative uncertainty-investment relationship documented in this literature is suggestive, it generally fails to fully isolate the role of uncertainty in investment. This is because many of these models are reduced forms in which asset price is implicit. If total uncertainty is correlated with asset price, price effects as opposed to shifts in the supply schedule may be responsible for a negative uncertainty-investment relationship. The major distinction between our paper and the related literature is our attempt to fully distinguish between alternative uncertainty-investment channels. By employing a structural model of industry asset market equilibrium, we can *specifically* test whether irreversibilities and delay affect investment decisions.

Lastly, it is relevant to distinguish between cross-sectional versus time series approaches when measuring the uncertainty-investment relationship. In the cross section, differences in total uncertainty between two otherwise identical markets are often interpreted as resulting in *steady state* differences in new investment.[7] Alternatively, when examining the same market over time, unanticipated changes in total uncertainty are predicted to result in *short-run* changes in new investment. Unfortunately, when using a time series approach to analyze the data, there is little we can say about the steady state without knowing more about the true underlying asset price process. In particular, how volatility moves over time and what it responds to are of fundamental economic concern. We will specifically revisit this issue in the next section when analyzing our uncertainty measures.

Empirical Model Specification, Data Sources and Total Uncertainty Estimates

Model Specification and Data

We will now specify a structural model to describe commercial real estate asset market equilibrium as well as describe the data used in estimation. Because the aggregate rate of investment is expected to interact with the aggregate price of commercial real estate, we specify the following simultaneous equations model of asset market equilibrium:[8]

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

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

Equation (1a) represents the demand to purchase developed property. In this model built asset price (P) depends on capitalized rent levels (R), where the capitalization rate is a function of the risk-free interest rate (r), expected rent growth (g), and a risk premium to the risk-free rate as determined in general capital asset market equilibrium ($\sigma_{P,M}$). In addition to these traditional demand-shift factors we also include total uncertainty with respect to built asset return (σ). The option-based investment model suggests this variable may be relevant if redevelopment or abandonment are feasible options embedded in the asset price (see, e.g., Childs et al. (1996), Williams (1991)).

The supply of new construction (C) is also included in the asset market demand equation. Although price is often thought to be independent of supply effects in efficient financial asset markets, real asset markets such as that for commercial real estate are often capital constrained and are subject to transaction costs and information frictions that affect liquidity. Moreover, because of forward contracting and related factors, commercial real estate rental rates and capitalization rates are notoriously sticky. All of these factors suggest that, in aggregate and in the short-run, asset market demand may be directly sensitive to the supply of newly constructed commercial real estate. As a result we specify a general model of asset market equilibrium that imposes no *a priori* restrictions on the slope of the demand curve.[9]

The supply equation (1b) describes the behavior of the real estate developer. We expect a positively sloped to near-vertical short-run supply curve. The neoclassical investment model also suggests that movements in construction cost (K) may shift the supply curve. Interest rate, expected rent growth, systematic risk and total asset price uncertainty are traditionally modeled as being embedded in built asset price, and therefore are often omitted in 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 vis-à-vis the 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 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.

Our focus in this paper is on the estimated supply equation, since the neoclassical versus option-based investment models differ most sharply in terms of predicted short-run supply effects. Table 1 summarizes the predicted *direct* relationships between the rate of investment and the right-hand side variables shown in equation (1b). Most relevant for our purposes is that the option-based model predicts a negative short-run relationship between investment and total uncertainty, whereas the traditional model allows for no independent role for total uncertainty. This critical difference enables us to fully isolate the role of uncertainty in investment.

Table 1 About Here

Interest rate, expected rental growth rate and systematic risk are also relevant to differentiating between investment models. 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 rightward to partially offset the usual price-induced supply effect. Similarly, an increase in systematic risk has the usual predicted effect of decreasing asset price to depress investment. However, because an increase in systematic risk is expected to increase the risk-adjusted rate at which future cash flows are discounted, delay is less valuable and the aggregate supply curve shifts to the right. Lastly, an increase in expected rent growth is predicted to shift the supply curve leftward to decrease investment. This follows because higher expected future cash flows decrease the opportunity cost of delay to temporarily depress investment.

In order to test the model as specified we use a time series of aggregate variables. Quarterly data that serve as measures for the variables described in Equation (1) are as follows.

1. We use the log of the square feet of actual construction starts for various categories of commercial

real estate (supplied by F.W. Dodge) as the measure of the level of new investment, C. Because new construction is a real variable, all of the remaining variables will also be expressed in real terms.

2. We develop two measures for the real price of commercial real estate, P. Our first measure is the log of the unsmoothed NCREIF capital price index divided by the CPI. We correct for appraisal price smoothing in the NCREIF index by applying a standard desmoothing methodology (see Appendix 1 for details). Our second measure is the log of an inflation-adjusted price index on equity REITs (adjusted for dividends). Equity REITs invest in income producing real estate, principally office buildings, shopping centers, industrial properties and apartments. Consequently, it can be argued that the return on equity REITs represents the return on the underlying real estate held by the REITs.[10] We use the value-weighted NAREIT equity REIT index to generate this alternative asset price measure.

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 obtained from F.W. Dodge.

4. Expected real rent, R, is calculated as inflation-adjusted net income realized one quarter hence. We use estimated prices and dividend yields provided in the NCREIF and NAREIT data 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 Citibase.

6. The expected growth rate of real rents, g, is proxied by lagged values of the growth rate of real GDP. Since the demand for space is derived from aggregate economic activity, a broad indicator of growth is employed.[11] Current and future values of real GDP growth cannot be used because of endogeneity

problems (i.e., they are affected by the dependent variable, construction growth).

7. Systematic risk, $\sigma_{P,M}$, is proxied by the covariance of returns to commercial real estate and returns to the market. Two different measures are developed, depending on whether the NCREIF index or the equity REIT data series are used to estimate built asset value. With respect to the NCREIF data, covariance is estimated using the most recent five quarters of property and S&P 500 returns (including the current return). In the case of the REIT data series, we use CRSP data tapes to first calculate indexed REIT returns 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.

8. Because of its centrality to our analysis, the level of total uncertainty, σ, is proxied by two independent measures: (i) the implied volatility of built property prices (a forward-looking measure) for various categories of commercial real estate and (ii) the standard deviation of daily rates of return on equity REITs (a contemporaneous measure). The next subsection provides a detailed explanation of the development of each of the total uncertainty measures.

Estimating Total Uncertainty

Measuring Implied Volatility of Returns from Commercial Mortgage Interest Rates. A forward-looking estimate of total uncertainty is desirable in a rational expectations sense. To obtain the first of our volatility estimates, we exploit the fact that property price uncertainty is embedded in default risk-adjusted commercial mortgage rates of interest. Titman and Torous (1989) have analyzed the commercial mortgage as a contingent-claim, and find that modeled risky rate spreads above the riskless bond rate closely match observed rate spreads. Rather than value the mortgage, we take observed commercial mortgage interest rates (prices) as given—along with other observable model input variables—and calculate the volatility that is implicit in property return. A detailed description of this approach is provided in Appendix 2. American Council of Life Insurance (ACLI) data is used to obtain mortgage spreads as well as several other variable inputs that are used in the implied volatility calculation.

Figure 1 displays our implied volatility estimates from the first quarter of 1979 through the third quarter of 1992 for office and retail property types as well as for all property types. Note that the total uncertainty measure itself is rather volatile, generally ranging from 15 to 25 percent over the reported time period. This range is similar to levels documented by Quigg (1993) who empirically estimates implied volatilities from a land option value model, and close to what Geltner (1993) infers using desmoothing techniques with respect to property level appraisal-based returns.

Figure 1 About Here

Observe that total uncertainty peaks several times in the early 1980's, again in 1986, and once again in the early 1990's. The early 1980's peaks correspond to a period of significant change in monetary policy, and in which bank deregulation and the 1981 income tax reforms were implemented. The second peak corresponds with 1986 tax reform, in which generous depreciation and personal income loss offset provisions were eliminated. The third peak corresponds to the depths of a serious commercial real estate recession in which debt capital was severely rationed, partly as a result of zealous bank and insurance company regulation. Visual inspection of Figure 1 thus suggests that changes in tax, monetary, or regulatory policy flow through to impact price uncertainty, which in turn may affect the overall rate of investment.[12]

The fact that uncertainty itself is time-varying violates the constant volatility assumption made in most option-based investment models. Hassler (1996) has examined the relative effects of time-varying uncertainty on the robustness of model predictions, and concludes that the sign of the uncertainty-investment relationship is typically unaffected. Indeed, the strength of the relationship actually increases. This is because a relatively high level of current uncertainty provides additional incentive to delay, since uncertainty levels are expected to decrease in the future. Empirical documentation of time-varying total price uncertainty is noteworthy, as it may have implications for studies that assess the normality of returns to commercial real estate, for models that attempt to explain real estate supply cycle behavior, and for further development of option-based models of real investment.

Finally, we should note that there are several potential sources of bias in our implied volatility estimates. Most importantly, the contingent-claims model measures default risk only in debt markets that are assumed to be frictionless. If the observed commercial mortgage interest rate reflects other risks or frictions, such as foreclosure transaction costs or a certain degree of mortgage market illiquidity, estimated property volatility may be higher than true asset price volatility. However, if the relationship between default risk and other priced factors is relatively constant through time, the upward bias will not affect inferences drawn from the empirical analysis. In the other direction, any frictions that the borrower encounters may result in what appears to be “sub-optimal” default, which could reduce the required risk premium. This would have the effect of lowering implied volatility estimates. All told, we conjecture that our volatility measure is somewhat upwardly biased, but probably close to actual total uncertainty that underlies property return.

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 construct an equally weighted index and compute the daily returns for this index as follows,

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

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

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

where D is the number of days in the quarter and $\overline{R}_{index(Q)}$ is the average daily return for the REIT index in the quarter.[13]

The annualized standard deviation of daily REIT return provides our second estimate of total uncertainty. 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. This measure differs from uncertainty that is computed based on a return time series covering many years, which tends to smooth as well as lag changes in total uncertainty.

The pattern of volatility generated from this measure is displayed in Figure 2. Note that this time series broadly corresponds with the implied volatility graph seen in Figure 1, with several apparent differences. First, REIT volatility levels are typically lower than those determined using implied volatility. These differences may be because, i) the implied volatility estimate is upwardly biased, as previously discussed, ii) the REIT index is a composition of individual REITs, each of which is a portfolio of assets, which lowers price volatility relative to the single asset case, or iii) liquidity and turnover of REIT stocks were low over the sample period, as the REIT sector was relatively small in terms of total size as well as in terms of individual company sizes. Second, peaks and valleys roughly correspond between the two figures, with the exception of fourth quarter, 1987. Recall that this was the quarter in which the October 1987 stock market crash occurred. Also note that the volatility peaks of the mid-1970's correspond with the occurrences of the oil price shocks and a short but severe commercial real estate recession.

Figure 2 About Here

Model Estimation

Preliminaries

Given the simultaneous equation specification in equation (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.[14] As a result, we specify a linear model of asset market equilibrium as follows:

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

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

where $\Delta\varepsilon_P$ and $\Delta\varepsilon_C$ are assumed to have independent normal distributions.[15] To estimate changes in construction a 2SLS procedure is employed.

Because real estate requires time-to-build, we examine current and lagged values of all the exogenous variables.[16] 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 GDP 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. We do this 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 the construction of real estate, the supply equation also includes seasonal dummies.

Empirical Results

Estimates Obtained Using NCREIF Data and the Implied Volatility of Property Price. Supply equation estimates obtained using NCREIF data and the implied volatility of commercial real estate return as a measure for total uncertainty are displayed in Table 2. As seen by the column headings, three categories of built real estate assets are analyzed: Total, Office and Retail. The number of lags to include in each equation is determined by maximizing adjusted-R^2, with the constraint that we include all of the lagged values up to the highest-order lag. 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 sometimes happens that neither the current nor any of the lagged values of a variable are included in the final regression equation.[17]

Table 2 About Here

Given our focus on the total uncertainty-investment relationship, we will start with the $\Delta\sigma$ coefficient and work our way up the table. Change in total uncertainty, $\Delta\sigma$, enters both the Total and the Office categories with a coefficient that is negative and significantly different from zero at the six and one percent levels, respectively. The sizes of the coefficients in these two equations suggest that change in total uncertainty has an economically significant effect on supply, independent of any price effects. For example, a one-standard-deviation increase in σ for the Total category results in roughly a 3% reduction in total new construction of commercial real estate.[18] Increasing volatility from .15 to .25 reduces total construction by about 8%. The effects are even stronger in the Office property category. A one-standard-deviation increase in σ results in roughly a 13% reduction in total new office construction. Increasing volatility from .15 to .25 reduces total construction by about 37%.

Total uncertainty enters the Retail supply equation with a positive and sizable coefficient that is statistically insignificant. This finding is inconsistent with hypothesized role of total uncertainty in the option-based model. Effects that are idiosyncratic to the retail property type may be responsible for this outcome, however.. In the case of large retail projects, development does not typically proceed until a large anchor tenant signs a very long-term (e.g., 25 year) lease. Once signed, a significant amount of project specific uncertainty is resolved. It is possible that this effect may not be fully reflected in our aggregate price uncertainty measure. In addition, the retail sector has experienced significant structural change over the sample period that is partially unrelated to macroeconomic fundamentals. This may also have decreased retail investment sensitivity to asset price uncertainty.

With one exception, neither the systematic risk ($\Delta\sigma_{P,M}$), expected rental growth (Δg) nor the interest rate (Δr) variables exert a statistically significant effect on supply in this set of regressions. As previously discussed, the neoclassical model posits no role for these variables once built asset price and construction cost are controlled for. Thus our findings are not inconsistent with predictions of the neoclassical model of investment. Alternatively, as seen in Table 1, the option-based model does allow for price-independent effects. However, at capitalization rate levels experienced in the commercial real estate sector over our sample period (in the range of eight percent), investment sensitivity to changes in systematic risk, expected growth and interest rate is relatively weak (see Dixit and Pindyck (1994, pp.157-58). It may indeed be that the relationships are sufficiently weak as to result in statistically insignificant relationships.

The construction cost variable (ΔK) has the predicted negative effect on investment in all property type categories, although the effect is not terrribly strong from a statistical standpoint. It is possible that, given the long lead times with office and large retail construction, cost-sensitive forward contracts or other risk management techniques are used that affect the estimated cost-investment relationship. It may also be that we have not lagged our data for a sufficiently long period of time to adequately capture the time-to-deliver effect.

Built asset price (ΔP) appears to exert a significant positive short-term effect on Retail construction, but not on the other two property type categories. In fact, for the Total and Office construction categories, the adjusted-R^2 criterion for the lag-length selection indicates that price should be excluded from the regressions. There are several possible explanations for the overall weakness of built asset price on construction. First, it may simply be that new supply of commercial real estate is relatively price inelastic in the short-run. In addition, errors-in-variables may present a problem with the estimates. If the regressors used in estimation are less than perfect measures of the variables in the model, the results may be biased toward zero and insignificance.

Another possible explanation depends on preemption in competitive investment markets. Fudenberg and Tirole (1985) and more recently Grenadier (1996) show that it may be rational to invest when prices decline in imperfectly competitive markets characterized by uncertainty and irreversible investment. For a price decline to increase investment, one must be in a "hot" asset market, in which built asset prices are already high and competitors are concerned about preemption when prices decline unexpectedly. Grenadier argues that this "recession-induced" investment behavior describes many commercial real estate markets in the 1980's. We tested for this possible effect by including a dummy variable to indicate "low" versus "high" price regimes in the interaction with our asset price variables. In no case was the interaction variable significant, leaving short-run supply inelasticities or errors-in-variables as plausible explanations for the weak price estimates.

Finally, some observers have argued that tax, regulatory and monetary policies of the 1980's may have created investment incentives that operated independently of fundamentals. To address this we added dummy variables to account for the possible effects of policy regime shifts on investment incentives. Two time regimes were considered: i) pre-1987 and ii) post-1986. The inclusions of the dummies did not alter the results and the dummy coefficients were generally not statistically significant. One reason for this may be that certain of the regressors—most particularly total uncertainty, as displayed in Figure 1—may already pick up policy regime effects in their values. This would seem to support arguments made by Lucas (1976) in his critique of traditional macroeconomic policy management: structural variables (and therefore investment) may adjust endogenously in anticipation of policy regime shifts to offset the intended effects of such change.

All told, our first set of regression results provide some—but by no means incontrovertible—initial support for the option-based model of investment. Change in total uncertainty exerts a significantly negative effect on supply for two of the three categories of commercial real estate construction. However, to this point, we do not find evidence of an independent role for systematic risk, expected cash flow growth or interest rate in the supply of commercial real estate. Although we have characterized these effects as weaker and hence secondary to the total uncertainty effect, it seems relevant to document some type of supporting role for these factors if a stronger case is to be made for the option-based model of investment.

Estimates Obtained Using Equity REIT Data. Supply equation estimates obtained using equity REIT data and the standard deviation of daily REIT returns can be seen in Table 3.[19] This data series has two clear advantages over the NCREIF data series: (i) the data are available over a longer sample period (covering almost 20 years), and (ii) we use two additional categories of real estate construction that were not previously available, Apartment and Industrial construction.

Table 3 About Here

Estimates generated using the REIT data provide significantly stronger support for the option-based model of investment. All categories of commercial real estate result in a negative total uncertainty coefficient that is significant at the 5 percent level. Furthermore, in all cases the sum of the coefficients for change in total uncertainty are larger in magnitude than coefficient estimates obtained using the NCREIF data. For example, a one-standard deviation increase in volatility results in approximately a 24 percent decrease in Total construction, a 26 percent decrease in Office construction and a 10 percent decrease in Retail construction. Interestingly, construction in the Apartment sector—perhaps the most spatially competitive of all property type sectors—seems especially sensitive to changes in uncertainty. As previously discussed, it may be that competitive market effects are negatively related to changes in uncertainty, which intensifies the hypothesized negative uncertainty-investment relationship. In addition, lease terms in the apartment sector are the shortest (typically one year or less) of the various property types considered here. This suggests that apartment investors may be exposed to greater relative price uncertainty than investors in non-apartment property types.

The coefficients for systematic risk and cash flow growth yield interesting results in this set of estimates. In three of the five supply equation specifications the sum of the coefficients for the covariance term are positive and statistically significant at the 8 percent level or less. These estimates are consistent with predictions of the option-based model of investment, and emphasize the importance of differentiating between systematic and total risk when analyzing investment decisions. Changes in cash flow growth are found to positively impact investment in three of the five supply equations. This is contrary to predictions of the option-based model (as well as the neoclassical model of investment). It may be that our proxy of expected cash flow growth, lagged changes in GDP, is picking up transitory as opposed to permanent changes in expected future cash flow. If this is true, an increase in cash flow growth may decrease the value of delay to increase investment—a result that is not inconsistent with predictions of the option-based model of investment.

The effects of construction cost and asset price are weak in this set of regressions. As previously discussed it may be that we are unable to lag our variables far enough back in time to incorporate time-to-build effects or that forward contracting mechanisms are employed that weaken the measured relationship between construction cost and investment. With respect to built asset price, we find a perverse negative relationship between change in asset price and investment in three of the regression equations, although the coefficients in all cases are insignificantly different from zero. We again suspect that short-run supply inelasticities or errors-in-variables problems may be responsible for this outcome.[20]

We interpret results reported in this section as providing strong evidence in support of the option-based model of investment. Total uncertainty estimates are consistently statistically and economically significant and in the direction predicted by the standard option-based model of investment. We also find supporting evidence in favor of the option-based model through the estimated effects of systematic risk and (properly interpreted) the rate of cash flow growth. When we combine results reported in this section with findings obtained using the NCREIF data, we conclude that total uncertainty appears to play a crucial role in determining investment behavior. This in turn highlights the importance of irreversibility and delay in investment decision-making.

Why were the results in this section significantly stronger than those generated using NCREIF data? Recall that NCREIF price data are based on private market transactions and updates that rely on appraisals. Investors and appraisers in this sector are notorious for their backward-looking price setting behavior (i.e., they are strong trend chasers). Although we attempt to correct for appraisal behavior, Fisher et al. (1994) find that the desmoothed NCREIF series still lags publicly traded real estate prices by up to a year. Conversely, the REIT series is composed of publicly traded firm-level market data. REIT managers are disciplined by real-time and relatively efficient capital pricing, and therefore might (on a comparative basis) be characterized as "informed traders" of real estate assets. Consequently, the REIT data series may more accurately proxy the information set upon which real estate developers rely when making their investment decisions.

Summary and Conclusions

Using commercial real estate data, this paper conducts an empirical test of the neoclassical versus option-based models of investment. Doing so requires specifying a structural model of asset market equilibrium so that uncertainty effects can be evaluated independently of simultaneous price effects. In comparison, most other tests of the option-based investment model rely on reduced form specifications. Because price is implicit in the right-hand side variables of a reduced-form investment equation, a specification of that type cannot fully isolate demand versus supply effects of uncertainty on investment and hence cannot generate a definitive test of competing investment models. We also take care in specifying the structural equations to include all variables deemed relevant in the determination of asset market equilibrium.

Using up to 20 years of aggregate time series data to estimate the model, we find that change in total uncertainty exerts a negative, price independent, effect on investment in seven of the eight supply equations we estimate. Examination of other (second order) factors that can be used to differentiate between investment models produce suggestive but less consistent results. Primarily based on the strength of our findings with respect to total uncertainty, we conclude that the evidence favors the option-based model over the neoclassical model. This in turn suggests that irreversibility and delay are important aspects to investment decision-making.

Perhaps our most puzzling result is the consistent finding of short-run supply inelasticities with respect to changes in asset price (traditionally considered to be a first-order effect), but highly elastic supply responses to changes in price uncertainty (traditionally considered to be a second-order effect). It may be that, in real asset markets, changes in price volatility more quickly summarize information that are useful to investors than do changes in price levels. For example, a visual examination of the time-varying volatility measures shown in Figures 1 and 2 suggests that asset price uncertainty is positively related to changes in tax, regulatory and monetary policy, and that causality may run from policy change to uncertainty and then to investment. This in turn suggests that, from a broader policy perspective, relative transparency and stability may be important factors in encouraging investment and sustaining macroeconomic growth. Certainly, given the consistently negative uncertainty-investment relationship identified in our analysis, it seems relevant to include measures of total asset price uncertainty in models and forecasts of commercial real estate asset market equilibrium.

This line of inquiry can be extended in several directions. One logical extension might be to use property level data to further examine the role of uncertainty in investment. This would allow researchers to conduct a more sensitive analysis of factors that lead to partial reversals in investment (e.g., payoff convexities with respect to alternative factors of production) or timing inflexibility (e.g., the relationship between regulation and price uncertainty). In addition, a more detailed examination of the impact of payoff and informational externalities on strategic investment would be interesting. For example, the continued trend towards "suburbanization" of real estate development suggests that traditional agglomeration economy relationships may be changing. The use of panel data that picks up competitive "market-wide" effects may be especially valuable in this regard. Finally, it may be important to explicitly account for the structural effects of debt and equity finance on aggregate investment. For instance, due to the effects of binding budget constraints on many developers, easy versus tight money regimes are often thought to influence investment decisions in the commercial real estate sector.

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Appendix 1

Development of the Desmoothed Property Price Index

Price estimates (appraisals) substitute for market transactions when assets are remain untraded for long intervals of time. Backward-looking appraisal behavior results in estimated prices that lag true property prices as well as the smoothing of property volatility. Although both the lagging and smoothing of prices are concerns in ascertaining "true" property values, we are most concerned with correcting the lag problem. This is because lags will bias parameter estimates as well as affect the efficiency of the price coefficient estimate, whereas reduced volatility only affects the size of the regression coefficient, not its significance level. Note, however, that we will address both factors with our desmoothing methodology.

We follow the desmoothing procedure of Fisher, Geltner and Webb (1994). First, we specify an auto-regressive relationship between smoothed and desmoothed returns:

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

where r_t^* is the appraisal-based return at time t and r_i, i=1,..,t, is the desmoothed (i.e. true) return. Recursive substitution allows (A1) to be rewritten as:

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

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. Using this lag structure, equation (A2) is inverted to result in,

$$r_t = \frac{1}{w_0}\left(r_t^* - z_1 r_{t-1}^* - z_4 r_{t-4}^*\right) \qquad \text{(A3)}$$

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

The parameter w_0 is chosen to induce an appropriate amount of volatility into the desmoothed returns. As discussed above the choice of w_0 is not critical to the analysis that follows since w_0 simply scales the size of the property price parameter estimate. Consequently, we specify w_0 such that the standard deviation of returns equal 12 percent for office and retail categories and 9 percent for all other property categories.

Given this setup, the estimated "true" return equations are

Office: $r_t = 3.2(r_t^* - .2281r_{t-1}^* - .6201r_{t-4}^*)$ (A4)

Retail: $r_t = 5.62(r_t^* - .2806r_{t-1}^* - .6271r_{t-4}^*)$ (A5)

Total: $r_t = 4.1(r_t^* - .3158r_{t-1}^* - .6372r_{t-4}^*)$ (A6)

Lastly, once the desmoothed capital return series is generated, we create an index of property values for use in estimating equation (1).

Appendix 2

Measuring Implied Volatility of Asset Prices

In this appendix we describe a methodology that generates a forward-looking measure of total asset price uncertainty. This is done by using commercial real estate debt prices as well as other observable input values. Because commercial real estate debt is generally subject to prepayment restrictions, default is the only termination risk that is incorporated into the analysis. When determining 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 is formalized by expressing secured debt value as a function of property value and time to loan maturity. Given the additional assumptions of log-normal collateral property prices, constant interest rates and fixed loan payment, the resulting pricing equation is[21]

$$\frac{1}{2}\sigma_P^2 P^2 \frac{\partial^2 M}{\partial P^2} + (r - \delta) P \frac{\partial M}{\partial P} - \frac{\partial M}{\partial \tau} + m = rM \qquad \text{(A7)}$$

where M is mortgage value, τ is the remaining loan term-to-maturity, δ is the property payout rate, and m is the continuous rate of mortgage payment. The equilibrium mortgage rate is implicit in m. Boundary conditions involving property value are similar to those found in Titman and Torous (1989) (i.e., equations (4), (5), (6) and (7) on p.348).

The following data are used in model estimation. Mortgage rate is obtained from new loan originations as reported by the American Council of Life Insureres (ACLI). This rate is a weighted average, where weights depend on loan size. 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 associated Treasury bond maturity. When average loan maturities are greater than 10 years, the Treasury bond rate is obtained by interpolating between the 10 year and 30 year interest rate. Standardized measures of current property price and par loan amount can be obtained from the average loan-to-value ratio on newly originated loans. This data is again

Because the debt valuation problem has no closed-form solutions, numerical methods are required to obtain mortgage values and implied volatilities. Solutions are obtained using standard binomial model techniques in which 50 payment intervals per year are assumed. Given empirical estimates of P, M, r, δ and m, we iterate to an implied volatility estimate such that mortgage value equals the initial loan amount (i.e., we price the newly issued mortgage at par). Implied property volatility is re-estimated on a quarterly basis with updated model inputs.

Endnotes

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[1] It is worth noting the difference between sunk cost and specific investment. Sunk costs are irrecoverable in their original form, but imply nothing more as to the nature of the asset once investment has taken place. Specific assets are those whose value may be worth more on a go-forward basis to certain parties than to others. Specificity may therefore expose the investor to opportunism or hold-up by outside agents or investors (Williamson (1985)). For example, in a real estate context, development of either office or industrial property will result in sunk costs. However, office buildings are generally quite generic and hence non-specific whereas industrial properties are often designed with a particular unique purpose in mind. These differences may affect asset liquidity and value ex post, and therefore may affect investment decisions ex ante.

[2] Others who have recently examined investment decisions in this context include McDonald and Siegel (1986)], Pindyck (1991) and Dixit and Pindyck (1994).

[3] Uncertainty is not required to result in an investment trigger that exceeds the neoclassical threshold. Jorgenson (1963) shows that irreversibility of investment and timing flexibility in a certain world may also result in delay.

[4] For further background on the option-based model in a real estate and urban economic context, see Titman (1985) and Capozza and Helsley (1990).

[5] Certain property types are more or less subject to local competition in the commercial real estate sector. Multi-family and warehouse space are more commodity-like and locational differentiation is less important than with other property types. This results in greater relative competition and perhaps less timing flexibility. At the other extreme is large retail investment, which has monopolistic characteristics due to extreme locational sensitivities. In between is office and smaller retail uses. Thus we might expect the strength of the uncertainty-investment relationship to vary across property types in the empirical analysis.

[6] A few studies have used project specific data to examine implications of the option-based investment model. See, for example, Paddock, Siegel and Smith (1988) and Quigg (1993).

[7] This also requires a change in the rate at which new investment opportunities approach the long-run investment threshold, which is often a reasonable expectation. If a rate change does not obtain, cross-sectional differences are better viewed as resulting in short-term investment effects.

[8] 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 and discuss our findings in the following section.

[9] This approach is consistent with most econometric model specifications of aggregate real investment, in which supply and demand are estimated simultaneously based on a structural model of asset market equilibrium or in which supply is estimated as a reduced form.

[10] For a review of the financial economics literature on REITs see Corgel, McIntosh and Ott (1995).

[11] We also considered using an ARIMA-type forecast of rent to measure expected cash flow growth. We found that an AR(1) process best described the rental income data. However, after converting rents to a growth rate, a forecast of this type potentially introduces perfect co-linearity with rents when working in first differences. As a result we decided not to employ this alternative measure of expected rent growth.

[12] This simple visual analysis does not establish cause and effect. For example, it could be that policy changes are a reaction to other factors that are the true cause of increases to aggregate uncertainty. However, the fact that uncertainty peaks usually occur shortly *after* policy is implemented suggest that cause and effect largely flow from policy change to aggregate uncertainty.

[13] We create our own index of equity REIT returns using CRSP data, since NAREIT returns are available only on a monthly basis. Using quarterly returns from 1972-92, the two equity REIT indices (ours and the NAREIT index) are cross-correlated with a value of .85.

[14] 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.

[15] For further discussion of the relevance and robustness of a linear specification, see Leahy and Whited (1996) and Pindyck and Solimano (1993).

[16] 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.

[17] It can also sometimes happen that a variable is included in the regression for which the sum is statistically insignificant. This is often the result of individual lags that have sizable coefficients (and hence are required to be included in the model),

but are of opposite sign and hence partially cancel out over the sum.

[18] The percentage change in construction is calculated by multiplying the standard deviation of the volatility measure (which is .0355 for Total, .0354 for Office and .0362 for Retail) by the sum of coefficients on the current and lagged uncertainty variables.

[19] We also estimated the equations using the standard deviation of weekly returns on equity REITs. The results were essentially the same as those reported in the text.

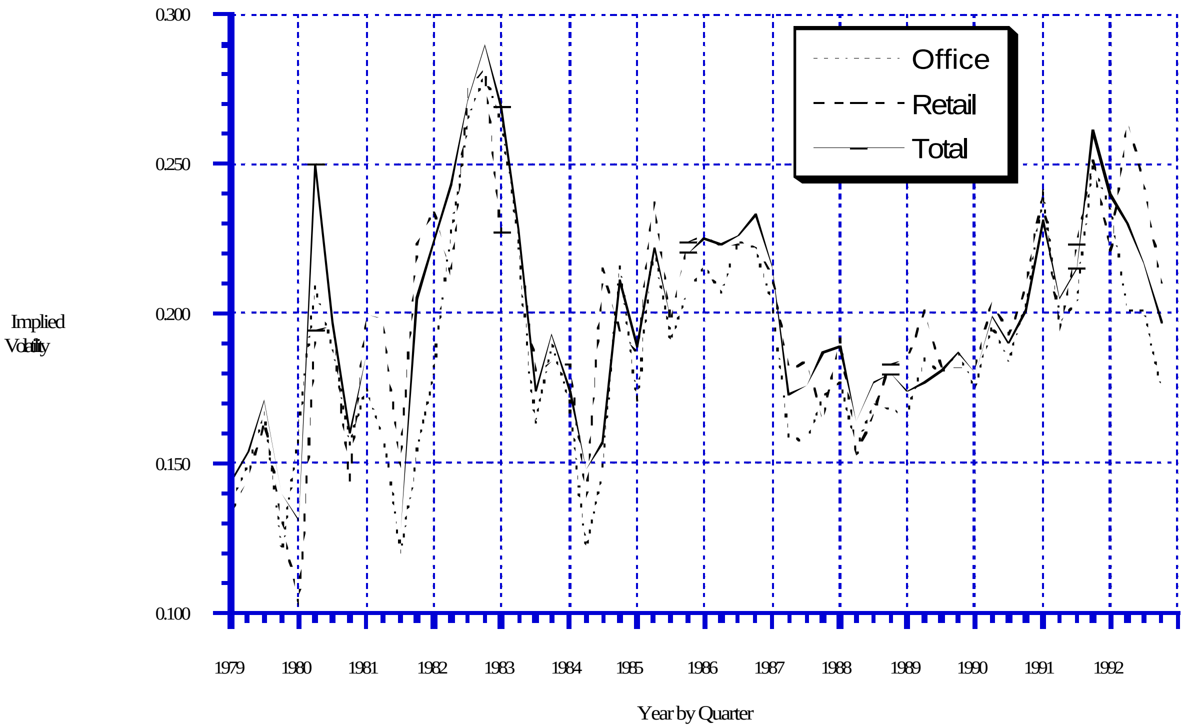
[20] We also checked for high/low price regime effects in this set of regressions, but did not find anything. Tax/regulatory regime dummies were also included in a separate set of regressions, in this case covering the pre-1981, 1981-86 and post-1986 time periods. Again, there were no statistically significant effects.

[21] Childs, Ott, and Riddiough (1996) 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 of interest rates is adequately represented.

Table 1 ■ Short-Run Predicted Supply Relationships (Equation (1b)).

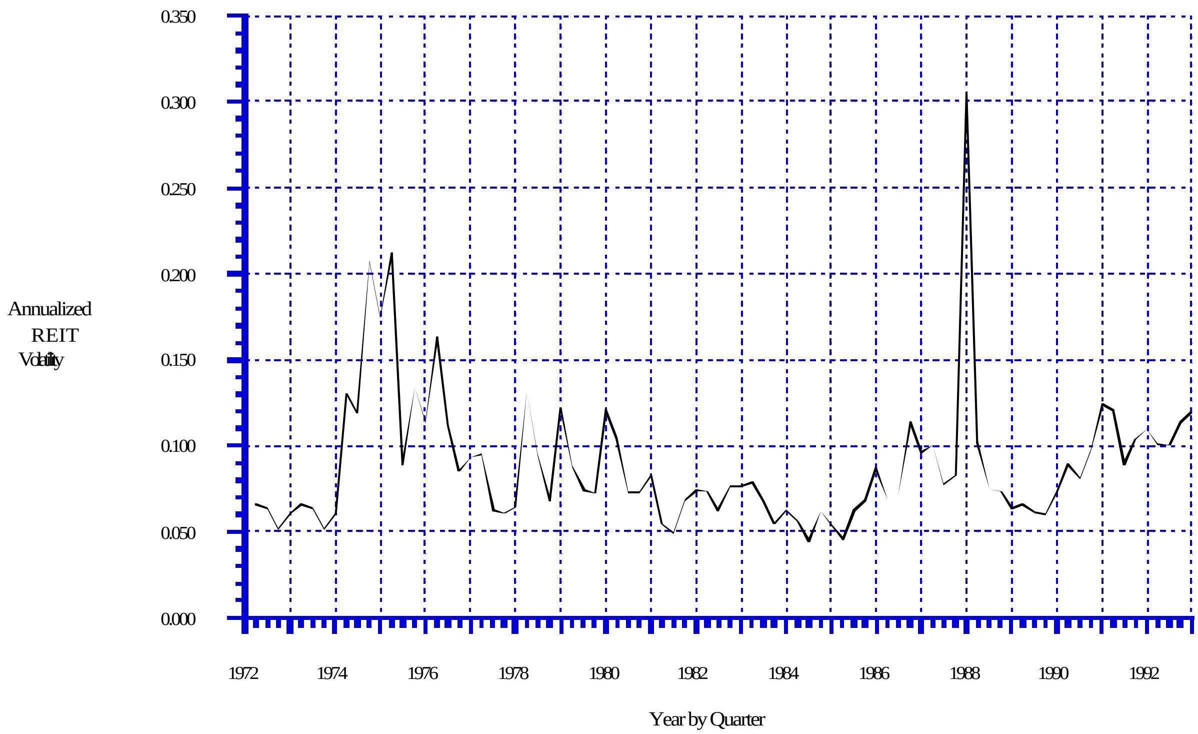
Variable	Neoclassical Model	Option-Based Model
P (Built Asset Price)	Positive	Positive
K (Construction Cost)	Negative	Negative
r (Risk-free Rate of Interest)	No Effect	Positive
g (Expected Growth in Rents)	No Effect	Negative
$\sigma_{P,M}$ (Systematic Risk)	No Effect	Positive
σ (Total Uncertainty)	No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

Figure 1 ■ Implied Volatility Estimates for Commercial Real Estate.



This figure graphs implied volatility (standard deviation) of commercial real estate return from 1979 through 1992, by quarter. Three categories of property types are shown: office, retail and total. A detailed explanation of the implied volatility calculation can be found in Appendix 2.

Figure 2 ■ REIT Volatility Estimates for Commercial Real Estate.



This figure graphs volatility (standard deviation) of equity REIT return from 1972 through 1992, by quarter. The methodology for determining volatility is explained with equations (2) and (3) in the text.

Table 2 ■ Estimates of the Structural Supply Equation Using NCREIF Data and Implied Volatility of Property Price Return (Dependent Variable: ΔC)

Sample	(1) Total 81:1-92:4	(2) Office 81:1-92:4	(3) Retail 81:1-92:4
Constant	-.060 (.021)	-.070 (.050)	-.066 (.031)
Sum of Current & Lagged ΔP (Price)	----	----	1.47 (.57)
Sum of Current & Lagged ΔK (Constr. Cost)	-1.43 (.74)	-.81 (.98)	-1.40 (.90)
Sum of Current & Lagged Δr (Interest Rate)	----	.025 (.031)	----
Sum of Current & Lagged Δg (Growth Rate)	.050 (.020)	----	-.014 (.034)
Sum of Current & Lagged $\Delta \sigma_{P,M}$ (Syst. Risk)	8.43 (34.6)	8.20 (34.4)	2.97 (33.2)
Sum of Current & Lagged $\Delta \sigma$ (Total Uncertainty)	-.79 (.41)	-3.69 (1.03)	3.92 (2.69)
ρ	.30 (.14)	-.43 (.13)	----
R^2	.86	.71	.75
Adjusted-R^2	.80	.55	.64
S.E. of Regression	.060	.13	.10
Durbin-Watson	2.16	1.79	2.50

The dependent variable is the change in log square feet of construction starts for the three categories of commercial real estate. The coefficients of seasonal dummies are not shown. Coefficient standard errors are in parentheses. ρ is the estimate of the coefficient of first-order autocorrelation in the error term. In the Retail equation estimation, the Durbin-Watson statistic suggests the possibility of first-order serial correlation in the residuals. We tested for this using the Gauss-Newton iterative method and found that the coefficient was never close to statistical significance and its inclusion did not substantially affect the results.

Table 3 ■ Estimates of the Structural Supply Equation Using Equity REIT Data and the Standard Deviation of Equity REIT Return (Dependent Variable: ΔC)

Sample	(1) Total 73:3-92:4	(2) Office 73:3-92:4	(3) Retail 73:3-92:4	(4) Apartment 73:1-92:4	(5) Industrial 73:3-92:4
Constant	-.067	-073	-.124	-.103	-.056
	(.025)	(.042)	(.038)	(.031)	(.035)
Sum of Current & Lagged ΔP (Price)	-.167	-.39	.002	----	-.34
	(.163)	(.28)	(.155)		(.21)
Sum of Current & Lagged ΔK (Constr. Cost)	----	1.31	----	----	-.14
		(1.24)			(.10)
Sum of Current & Lagged Δr (Interest Rate)	----	----	-.015	.008	----
			(.017)	(.012)	
Sum of Current & Lagged Δg (Growth Rate)	.023	.052	----	.028	.006
	(.012)	(.023)		(.014)	(.014)
Sum of Current & Lagged $\Delta\sigma_{P,M}$ (Syst. Risk)	26.25	33.1	----	39.6	----
	(11.0)	(18.9)		(15.4)	
Sum of Current & Lagged Δσ (Total Uncertainty)	-5.90	-6.55	-2.42	-8.61	-2.56
	(1.41)	(2.45)	(1.23)	(1.96)	(1.14)
R^2	.73	.56	.55	.57	.70
Adjusted-R^2	.66	.40	.46	.48	.63
S.E. of Regression	.085	.144	.128	.12	.112
Durbin-Watson	2.09	2.65	2.52	1.96	2.01

The dependent variable is the change in log square feet of construction starts for the five categories of commercial real estate. The coefficients of seasonal dummies are not shown. Coefficient standard errors are in parentheses. In the Office and Retail equation estimations, the Durbin-Watson statistics suggest the possibility of first-order serial correlation in the residuals. We tested for this using the Gauss-Newton iterative method and found that the coefficients were never close to statistical significance and their inclusion did not substantially affect the results.