Does the Theory of Irreversible Investments Help Explain Movements in Office-Commercial Construction?

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Focusing on the relevance of the modern investment theory in explaining movements in office-commercial construction, we attempt to advance existing empirical work in two respects. First, building on recent theoretical advances, we offer an extended empirical model of new construction that accounts for the full opportunity cost of irreversible investments in uncertain environments. Second, using updated time-series of office-commercial construction across the nation's largest markets, we empirically estimate such a model to (i) explore investment behavior during 1982-1998 and (ii) detect differences, if any, in such behavior between the pre- and post-recession years. Our empirical findings are fully consistent with the theory of irreversible investments. Such findings highlight both the relevance and relative importance of uncertainty in underlying demand factors in shaping movements in office-commercial construction, while pointing altogether to a more cautionary investment behavior during the post-recession years.

The growing economic significance and distinct behavior of U.S. office-commercial markets has spurred a growing volume of relevant empirical work. Building on the traditional Marshallian and new search-theoretic approaches, existing empirical studies have, among other issues, explored the role of the macroeconomy in shaping movements in office space demand (Wheaton 1987; Kling and McCue 1987); the speed of rental and/or vacancy adjustments in response to changes in market realities (Shilling *et al*. 1987; Voith and Crone 1988; Eppli and Shilling 1995); the microeconomic processes shaping equilibrium rents and vacancy rates (Wheaton and Torto 1994; Sivitanides 1997); and intertemporal movements in office rent-asset price relationships (Wheaton and Torto 1989; Sivitanidou and Sivitanides 1999).

Featured less prominently in the growing volume of empirical studies on office-commercial markets is the inherently cyclical and highly volatile office-commercial construction. Largely building on the traditional investment theory, empirical research on the latter has been relatively thin, with only a handful of academic papers on office-commercial investments published in economics or real estate journals since the early seventies. Most of the early, and rather dated, papers have employed stock-adjustment frameworks to examine nonresidential investment decisions (Bischoff 1970; Hambor and Morgan 1971a; 1971b). More recent ones, focusing on movements in office-commercial activity up to the early- or mid-eighties, have either examined new construction in the context of structural (econometric) models of office markets using established "q" theory (Wheaton 1987) or sought to probe into the macroeconomic determinants of office investments using exploratory methodologies not explicitly grounded in a particular theory (Kling and McCue 1987).

Recent advances in investment theory have provided a stimulus for taking a fresh look at the largely unexplored movements in office-commercial construction in recent years (Bernanke 1983; Dixit and Pindyck 1994). Focusing on irreversible investments in uncertain environments, the modern theory advances the notion that, in addition to those factors advocated by the deterministic "q" theory, economic volatility influences the opportunity cost of irreversible investments and, as such, must also play a role in influencing investment decisions. Such a proposition seems to be especially relevant to the case of office-commercial construction, given the irreversibility of office development and the increasingly volatile economic environment within which office-commercial investors are operating.

Against this background, our underlying objective in this paper is to explore the empirical relevance of the theory of irreversible investments in explaining movements in office-commercial completions. To this end, we build on this theory to extend the traditional empirical model of new construction to account for the volatility of underlying demand movements. Using updated time series of office-commercial construction across the largest U.S. metropolitan markets during 1982-1998, we then empirically estimate variants of such a model to (i) explore investment behavior during 1982-1998 and

(ii) detect differences, if any, in such behavior between the pre-recession and, (perhaps) more uncertain, post-recession years. Taken together, the empirical results highlight both the relevance and relative importance of volatility in demand factors in shaping movements in office-commercial construction, while pointing altogether to a more cautionary investment behavior during the post-recession period.

Our research clearly falls in the category of studies that build on the new investment theory to highlight the role of uncertainty and risk in real estate markets. Empirical studies examining the role of uncertainty outside the real estate realm have been growing in number in recent years (see, for example, Leahy and Whited 1996; Tufano 1998) yet the only existing study on the role of uncertainty in influencing commercial real estate investment (that came to our attention after our research had been completed) is a forthcoming paper by Holland, Ott, and Riddiough.[1] Our research differs in several respects from the aforementioned study. First, our work is explicitly motivated by a model of competitive industry equilibrium, where, in light of investment irreversibility, uncertainties regarding movements in tenant demand for office-commercial space reduce the value of investing relative to not investing. Second, we use a dataset that incorporates metropolitan-specific, as opposed to national, data on new construction and its hypothesized determinants, including a space-market-specific uncertainty variable in accordance with the theoretical model outlined in the text. Third, our study includes a rather extensive section discussing, and testing for, changes in the effect of uncertainty and other construction determinants in the years following the most recent recession.

The remainder of this paper is structured as follows. In the following section, we summarize a simple model of competitive industry equilibrium, which features the factors driving investor entry and helps establish the theoretical relevance of demand volatility (see Dixit and Pindyck 1994; Caballero and Pindyck 1996). We then build on the conclusions of this theoretical discussion to present an extended empirical model that accounts for the full range of factors that potentially drive movements in office-commercial construction. In the next section, we proceed with the description of the data and variables employed in the empirical estimation and we present the estimation results of the base model and several of its variants. In what follows, we offer a test for the existence of differences in variable responses in the pre- and post-recession years. We conclude the paper with few interpretive comments and a brief discussion of avenues for future research.

Modeling Nonresidential Construction

Nonresidential investments can be studied drawing on one of two broader theoretical perspectives: (1) "traditional" perspectives which involve Jorgenson's (1963) neoclassical theory and Tobin's "*q*" theory along with their various extensions; and (2) new investment theories accounting for the role of investment irreversibility in light of uncertainty and risk. Emphasizing the processes through which investment takes place and the economic rules that motivate these processes, each of these theoretical perspectives is briefly described below.

Traditional Perspectives

The neoclassical approach views investment as the means through which a firm's actual capital stock adjusts to a desired level. Firms are assumed to maximize the expected present value of their future net cash flows subject to a capital accumulation equation that often involves an *ad hoc* lag adjustment process. Assuming constant returns to scale and an exogenously given output, this optimization behavior yields the firm's desired capital stock as the stock at which the *marginal* profit from an incremental unit of capital equals the expected marginal cost of using this capital.[2] Such an investment rule sets the stage for formulating empirical real estate investment functions in terms of expected output, expected price of space relative to the price of output, and the lagged real estate (capital) stock.[3]

Building on Tobin's perspective, adjustment cost theories postulate that investment in new construction is driven by demand fluctuations in the face of a rising supply curve for new space. Representing a point on the construction supply curve, investment can only be triggered when q, the ratio of the value of the marginal unit of capital to marginal investment cost, exceeds a critical value, q^*, which equals unity. Hayashi (1982), among others, has demonstrated convincingly the equivalence between Tobin's q formulation and Jorgensonian variants accounting for adjustment or installation costs. Used, by and large, in a macro context, this theory has set the stage of defining aggregate investment functions in terms of q or its components.[4]

Modern Perspectives

As several authors have suggested, investment theory should explicitly account for certain defining features of investments, such as their (partial or complete) irreversibility, uncertainty over future profit flows, and, as such, the option of postponing entry in order to obtain more information. Early theoretical analyses of the role irreversibility plays in affecting investment decisions have been presented by, among others, McDonald and Siegel (1986), Majd and Pindyck (1987), Pindyck (1988), Dixit (1989), and Dixit and Pindyck (1994).

Notably, most of existing modeling efforts have focused on the decision process of *monopolistic* firms to invest in discrete projects; expand existing capacity; start and complete a multi-stage project; or invest sequentially in the face of adjustment costs. Given the option value of waiting before making irreversible investment decisions, investment in all of these models seems to be justified only when the marginal profit reaches a threshold *greater* than the marginal cost (in contrast to the neoclassical rule) or only when the ratio of the marginal value of capital to marginal investment cost reaches a critical value that *exceeds* unity (in contrast to the "q" theory).

Given the challenges involved, modeling efforts focusing on *competitive* industries are noticeably fewer (Leahy 1993, Dixit and Pindyck 1994, Caballero and Pindyck 1996). Investment rules in these models also differ from the traditional ones *not* because of the option value to wait, which equals zero for any firm, but because, due to irreversibility, greater uncertainty reduces the value of investing relative to not investing at all. Thus greater uncertainty induces investors to require a higher current price relative to long run average cost before making irreversible investments.

Despite differences in scope, taken together, models accounting for irreversibility in light of uncertainty cast doubt on the investment rules advanced by traditional approaches and, by extension, on the completeness of empirical investment functions that are based on these rules.[5]

A Simple Model of Investment Decisions.[6] In what follows, the model of industry equilibrium presented by Dixit and Pindyck (1994) and Caballero and Pindyck (1996) is placed in the context of the market for office-commercial space. In such a market, investment can be viewed as a response of numerous small investment/ development firms to *stochastic* shifts in office space demand so that zero profit is achieved in equilibrium. Contemplating investments in discrete projects of unit size, such firms are competitive, risk-neutral, and have rational expectations regarding stochastic demand movements and the reaction of other firms to such movements.

Each firm, in particular, faces the downwardly sloping (inverse) space demand curve (1), where π is net rental income, S is the market's office stock, and is an office space demand shifter (e.g., office employment). The later is assumed to follow the geometric Brownian motion process in (2), where g denotes 's expected growth rate and σ denotes its standard deviation.

$$\pi = S^{-1}$$

(1)

$$d = g\ dt + \ dz \qquad (2)$$

Firm entry occurs and, therefore, S increases when π rises to a threshold π^*. Given the endogeneity of S, π will follow a stochastic process that is regulated by S through free entry so that at equilibrium, $\pi=\pi^*$. Thus free entry creates an asymmetry in the distribution of π because it limits the upside while leaving the downside unaffected.[7] At the free-entry equilibrium, the zero-profit condition requires that present value, V, of expected rental income flows, π, equal investment cost, F, which, once incurred, cannot be recovered. Assuming an appropriate (exogenous) discount rate ρ, this condition can be written as in (3).[8]

$V(\pi_t)= \quad {}_t\, \pi_{\,t}\, e^{-\rho\, t}dt = F$

(3)

When firm entry is *not* occurring, S is fixed, and, being proportional to , π evolves according to the stochastic process $d\pi = g\pi dt + \ \pi dz,$ but needs to remain at or below a fixed upper boundary, which in (industry) equilibrium should equal π^*. In determining π^*, Dixit and Pindyck (1994) show that $V(\pi_t)$ involves two components: the traditional asset price without the fear of entry, $P(\pi_t)$, and the reduction in this price, $P(\pi_t)(w-1)/w$ (where w is defined below) due to competitor entry. Given the exogeneity of the discount rate, the dynamic programming approach is used to derive the following solutions for π^* and $P(\pi^*)$ (see Dixit and Pindyck 1994):

$\pi^* = w(\rho - g)F; \; P(\pi^*) = wF$

where:

$$w = \beta/(\beta-1) > 1; \;\; \beta = ½ - (g/\ ^2) + \overline{((g/\ ^2) - |\ )^2 + 2\rho\ /\ ^2} \qquad (4)$$

Focusing on (4), it can be seen that it is optimal for investment to take place when P reaches some value threshold, $P(\pi^*)$, which *exceeds* investment cost, F by a factor $w=w(\rho, g, \sigma)>1$. The latter essentially reflects the opportunity cost of investing now and, from (4), it should obey $w_\rho < 0, \; w_g > 0, \; w_\sigma > 0$. Building on (4) and the aforementioned comparative effects, it is apparent that the smaller the discount rate, ρ, the higher the expected cash flow growth rate, g, and the greater the uncertainty, σ, regarding such a growth rate, the higher the opportunity cost of investing now and the higher the threshold value, $P(\pi^*)$, required before making the irreversible investment; hence, *smaller* investor entry would be required in order to restore the zero profit equilibrium.[9]

Accounting for Uncertainty in Models of Investment. Although focusing on the investment rule as opposed to the derivation of an explicit investment function, the model just summarized implicitly defines investment as the entry required to maintain the zero profit condition. As such, and at least in the *short-*

run, the above model, does suggest a greater role for uncertainty in influencing investment that the traditional models do (see Dixit and Pindyck 1994).[10] Deterministic models of (fully) irreversible investments, therefore, may need to be extended to account for the full opportunity cost of investment decisions.

Traditionally, empirical models of investment have been based on some variant of the "*q*" theory, and the question that arises is whether such theory extended to incorporate uncertainty can support the conclusions of the industry model of irreversible investments discussed above. Unlike the model presented above, the "*q*" theory assumes rising marginal cost curves due to either external or internal adjustment costs. Efforts to explore the effects of aggregate uncertainty in the presence of adjustment costs are rather incomplete but heuristic analyses suggest that uncertainty should induce effects similar to those discussed in the context of the industry-wide model without costs of adjustment. Romer (1996), for example, indicates that with asymmetric adjustment costs, it is more costly for firms to reduce their capital stock than to increase it. If the profit function shifts upwardly, the industry-wide capital stock will rise rapidly with entry, and the increase in profits will be short-lived. If, however, the profit function shifts downwardly, the stock will only fall slowly, and the decrease in profits will be long lasting. Uncertainty about the profit function will thus reduce expected profitability and, as such, must reduce investment.[11]

The conceptual correspondence between the theory of irreversible investments and the "*q*" theory has been discussed by Abel *et al*. (1996) with the aid of a simple two-period model of investment decisions at the firm, not industry level of analysis. Using such a model, the authors underscore the dependence of the negative relationship between uncertainty and investment on the full irreversibility assumption. With full irreversibility, firms have the option to invest later, a call option, the value of which increases in the degree of uncertainty, thus reducing the incentive to invest, as shown by previous work. Introducing (costly) reversibility, however, allows for disinvestment, a put option, whose value also increases in the degree of uncertainty, thus increasing the incentive to invest. The net effects of uncertainty on investment, therefore, depend on the interaction between the call and put options. Although such a clarification provides a valuable extension of the literature, empirical work on the relationship between investments and uncertainty strongly indicates that the call option effects do prevail (Leahy and Whited 1996). It remains to be seen whether such an effect is also prevalent in the case of office-commercial construction.

The Empirical Model

Building on the previous discussion of the stochastic model of irreversible investments and other (incomplete) modeling efforts, the empirical analysis in this study is intended to explore the response of construction activity to demand uncertainty, as postulated by the relevant theory, as well as other potential determinants of office-commercial construction. The analysis does not attempt to estimate structural relationships but rather summarize empirical regularities, if any, in these responses.

Available cross-section time-series data reflect office-commercial completions rather than plans, orders or contract awards, thus necessitating the formulation of an empirical model that accounts for delivery patterns, as investment decisions may be realized into completions over several periods. A partial adjustment specification, summarized by (5)-(7), can account for such lags (Wheaton and Torto 1990).[12]

$$CC_{j\tau} = \psi \sum_{s=n}^{l=n+k} (1-\psi)^{s} C_{j,\tau-s} \qquad (5)$$

$$CC_{j\tau} - CC_{j,\tau-1} = \psi \, (C_t - CC_{j,\tau-1}) \qquad (6)$$

$$CC_{j\tau} = (1-\psi)\, CC_{j,\tau-1} + \psi \, C_{jt} \qquad (7)$$

As shown by (5), new office-commercial completions in market j at time τ, $CC_{j\tau}$, reflect the outcome of investment decisions or plans, $C_{j,\tau-s}$ at time $t=\tau-s$, where $s=n, n+1,...,n+k$, reflects the delivery or construction lag, n denotes an exogenous minimum delivery lag, and ψ denotes an adjustment rate. As shown by the autoregressive specification in (6)-(7), such an adjustment rate essentially reflects the constant fraction of outstanding planned investment that is completed each period.

In specifying a function for planned investment, C_{jt}, we extend the traditional "q" theory-based model, where new construction is expressed as a function of the difference between asset price, $P = \pi/\rho\text{-}g$, and development costs, F, to account for the full opportunity cost of investment. Discussed in the previous section, the latter includes not only the construction cost, F, but also the cost associated with the exercise of the option to invest, $w(\rho_t, g_{jt}, \sigma_{jt})$, which may be shaped by the discount rate, ρ, the demand growth rate, g, and its volatility, σ. Thus planned office-commercial construction in market j a time t, C_{jt}, can be expressed as in (8), where π, represents net rental income flows, which are driven by office space rents and the vacancy rate.

$$C_{jt}=f(P(\pi_{jt},\rho_t, g_{jt}), w(\rho_t, g_{jt}, \sigma_{jt})F_{jt}) \; (C_P>0;\ C_w<0;\ C_F<0;\ C_\pi >0;\ C_\rho<0?;\ C_g>0?,\ C_\sigma<0) \quad (8)$$

According to (8), new construction decisions respond positively to expected project value, P, negatively to direct investment cost, F, and negatively to w. To begin with, for a given threshold price, a greater current rental income flow, π, a lower ρ, and a higher g, all raise expected project value, thereby necessitating greater entry in order to restore equilibrium as described by the fundamental zero profit condition. Similarly, given P, a higher F or w--due to lower ρ, higher g, or greater σ-- would necessitate lower entry in order to restore the zero-profit condition. It should, therefore, be noted that both ρ and g affect investment decisions through opposing impacts on the fundamental value, P, and opportunity cost of current investment, as reflected in w. Although Dixit and Pindyck (1994), among others, suggest that the effects on fundamental value most likely prevail, in the absence of explicit functional forms in the context of a theoretical model, the direction of the net effect of ρ and g on investment is an empirical issue.

Building on (5)-(8), the empirical function can then be expressed as in (9), where $a_1=(1-\psi)$ reflects the fraction of investment plans that are outstanding due to delivery lags. Expectational lags are presumably captured by g and σ, which are discussed in the following section.

$$CC_{j\tau} = a_0 + a_1 CC_{j,\tau-1} + a_2\pi_{j\tau-n} + a_3 g_{j\tau-n} + a_4\sigma_{j\tau-n} + a_5\rho_{\tau-n} + a_6 F_{j\tau-n} + u_{j\tau-n} \quad (9)$$

Analyzing Office-Commercial Construction, 1982-1998

The empirical analysis utilizes annual data on the fifteen largest U.S. metropolitan office markets for the period of 1982 to 1998.[13] In what follows, the base model specification and empirical estimation results are discussed.

The Base Model, Data, and Variables

Building on equation (9), proxies for the determinants of office construction investment have been identified and incorporated into the base statistical model in (10), where *CC(1),* in accordance with (9), represents the lagged dependent variable. For the simplicity of exposition, the model in (10) omits location and time subscripts but, whenever applicable, includes the minimum lag indicator, n. The model's dependent and various explanatory variables are described in Tables 1 and 2, and, as such, are only briefly discussed below.

$$CC = a_0 + a_1 CC(1) + a_2 INCOME(n) + a_3 GROWTH(n) + a_4 VOLG(n) + a_5 RATE(n) + a_6 CCI(n) + a_7 SPATIAL + a_8 CLIMATE + u(n) \quad (10)$$

Normalized for size differentials across metropolitan markets, the dependent variable in (10) reflects metrowide office-commercial completions expressed as a fraction of the previous year's office stock.[14] Shown on Figure 1 for representative office markets in each of the nation's four main regions, the office-commercial construction series are based on detailed inventory surveys of all buildings located within metropolitan boundaries that are 20,000 square feet or larger in size. The survey-based *annual* data are compiled by CB Richard Ellis/Torto Wheaton Research.

Compiled by the authors from various sources, the explanatory variables in (10) represent variables proxying rental income flows, π ; the expected cash flow growth rate and its volatility, g and σ; an exogenous discount rate, ρ; and construction/development costs, F.

Rental income flows, π : Rental income flows, π, are proxied by *INCOME(n),* calculated as the product of each market's average inflation-adjusted office rent index and the metrowide occupancy rate.[15] In some alternative specifications, rental income flows are represented by their components, namely the rental rate, *RENT(n),* and the vacancy rate, *VACANCY(n).* The historic rent indices have been developed by CB Richard Ellis/Torto Wheaton Research through market-specific hedonic analyses of lease transaction data; for details, see Wheaton and Torto (1994). Provided by the same source, the vacancy rate histories are based on quarterly surveys of the majority of competitive office structures in each market.

Expected rental income growth, g, and uncertainty, σ : It should be emphasized that consistency with the theoretical framework of this paper, based on the premise that net income fluctuations are brought about by stochastic movements in *space* demand, requires that the expected rental income growth rate, g, and the uncertainty associated with it, σ, be defined in terms of *demand-oriented* empirical proxies. As it has been established in the relevant empirical literature (e.g., Wheaton 1987; Wheaton and Torto 1994), office employment represents by far the most important shifter of office space demand. The expected rental income growth rate, g, and the uncertainty associated with it, σ, are, therefore, proxied by the expected office (FIRE) employment growth rate, *GROWTH(FIN)(n)*, and its volatility, *VOLG(FIN)(n),* which can be viewed as a measure of industry-wide uncertainty.[16] Following a myopic expectations approach, *GROWTH(FIN)(n)* and *VOLG(FIN)(n)* are measured by the average office (FIRE) employment growth rate and its standard deviation over the preceding five years, respectively.[17]

Discount rate, ρ : Assuming that spanning is not possible, CAPM does not hold, and an exogenous discount rate must be used. Time variations in the real opportunity cost of capital are captured by *RATE(n)*, measured by the inflation-adjusted ten-year constant maturity Treasury rate, averaged over the previous ten periods. As already discussed, a negative sign is expected for *RATE(n)*.[18]

Construction/Development costs, F : Construction and development costs are proxied by *CCI(n), SPATIAL,* and *CLIMATE*. Representing an inflation-adjusted metropolitan-specific construction cost index, *CCI(n)* is intended to proxy the cost of construction materials and labor. Its effect is expected to be negative, as the higher the investment cost, the higher the project value required in order to justify new construction. *SPATIAL,* intended to proxy cross-section variations in land costs, represents metropolitan-specific average worker commutes. The underlying notion is that longer average commutes reflect larger average office-commercial districts that, all else equal, should command higher land rents (see Sivitanidou and Wheaton 1992). Therefore, *SPATIAL* is expected to exhibit a negative sign. Finally, *CLIMATE*, measuring average annual temperature, is intended to capture the opportunity cost associated with weather-related delays and productivity losses. A positive sign is expected for this variable, as warmer climates may help reduce such delays.

Empirical Model Estimation

A brief review of the functional form, the variable lags, and error-term structure of the estimated models is warranted. As already noted, the model's dependent variable reflects new completions, expressed as a percentage of each market's previous year's office stock. Embedded in the model depicted by (10) is a one-year lag (*n*=1), the outcome of considerable experimentation with alternative lag structures (*n*=0, 1, 2) of the model's right-hand-side variables. With few exceptions, the latter enter the model in logarithmic form in order to capture the nonlinearities embedded in the underlying theoretical specification (e.g., (4)).[19]

The base model in (10), as well as several of its variants, have been estimated using the GLS process embedded in LIMDEP 7.0's TSCS routine, an improved variant of Kmenta's (1986) time-series cross-section technique, introduced and described in detail by Greene (1993). Largely dictated by the model's error term structure, the estimation procedure we used assumes serially uncorrelated, groupwise heteroskedastic, and cross-sectionally correlated disturbances. The model's error structure was identified through appropriate tests for serial correlation, groupwise heteroskedasticity, and cross-sectional correlation. Serial correlation was tested for using the Durbin *h*-test, as opposed to the conventional Durbin Watson-test, due to the inclusion in the model of a lagged dependent variable (see Greene 1993).[20] The estimated *h*-statistic suggests that the null hypothesis of serially uncorrelated errors cannot be rejected, thus obviating the need to use instrumental variable techniques in model estimation.[21] Groupwise heteroskedasticity and cross-section correlation were tested for using appropriate Log-Likelihood Ratio (LR) statistics (see Greene 1993). The latter indicate that the error term is heteroskedastic, in spite of the use of completions *rates* as opposed to completions *levels* as the model's dependent variable. Such statistics also point to the presence of strong cross-section correlation, presumably arising from national shocks inducing effects that are correlated across metropolitan office-commercial markets.[22]

Empirical Estimation Results

Taken together, the estimation results shed light on the empirical relevance of the theory of irreversible investments, as reflected in the importance of demand volatility, while highlighting the role of other hypothesized determinants of office-commercial construction: net rental income flows, office employment growth, the discount rate, and construction costs.[23]

Presented in Table 3 and discussed below are the estimation results of two empirical model specifications: Model I, following the base model in (10), which utilizes net income flows as a proxy for

π; and Model II, which utilizes the components of π, that is, gross rental flows and the vacancy rate. Both model specifications also incorporate the regional dummies *SOUTH*, *WEST*, and *MIDWEST,* primarily intended to capture regional influences on office-commercial construction that are not being represented by the model's other regressors (e.g., regional economic forces, regulatory influences).[24] For each of the two model specifications, two variants are presented: Model I-1 and Model II-1, which employ the office employment growth rate and its volatility, *GROWTH(1)* and *VOLG(1)*, respectively, and Model I-2 and II-2 which utilize the FIRE employment growth rate and its volatility, *GROWTHFIN(1)* and *VOLGFIN(1)*, instead.[25]

Office-Commercial Construction Lags. To begin with, the empirical results indicate that the time lag associated with new office-commercial investments during 1982-1998 is appreciably long. This is evident in the coefficient of lagged office-commercial construction, *CC(1)*, which ranges from 0.51 to 0.54 across model specifications. These results suggest that once decisions are made, 80% of investments are realized in 3.4-3.6 years, which represents a reasonable range for the delivery lag involved in new nonresidential investments.[26]

But Does Volatility Matter? Focusing now on the central issue of this paper, demand volatility does matter in a manner that is fully consistent with the underlying theory. The empirical results of Models I-1 and I-2 and Models II-1 and II-2 are consistent with the proposition that greater demand volatility raises the opportunity cost of investing, thereby discouraging office-commercial construction. More specifically, *VOLG(1)* and *VOLGFIN(1)*, reflecting the volatility of office and FIRE employment, respectively, exhibit a consistently negative sign and are statistically significant at the 95% level of confidence across model specifications. Notably, the effect of both volatility proxies remains robust in several other model variants not presented in Table 3. In the absence of the regional dummies, for example, both *VOLG(1)* and *VOLGFIN(1)* maintain their statistically significant negative effects. In model variants incorporating both *VOLG(1)* and *VOLGFIN(1)*, however, given that the two proxies move together to a significant degree, only *VOLGFIN(1)* exhibits a statistically significant (negative) effect.[27]

Other New Construction Determinants. Equally important is the fact that all of the models' explanatory variables not only exhibit the expected signs but are also statistically significant in most model variants. Represented by *INCOME(1)* in Models I-1 and II-1, rental income flows exhibit the expected sign and are highly statistically significant across all specifications, thus suggesting that higher levels of property income raise expected project values thereby encouraging investment in office-commercial construction. Models I-2 and II-2 test explicitly for the statistical significance of each of the two major determinants of *INCOME(1)*, that is, *RENT(1)* and *VACANCY(1)*. As indicated by the estimation results, both variables have the expected sign and are statistically significant at the 95% level of confidence across all relevant model variants. The positive sign of *RENT(1)* and the negative sign of *VACANCY(1)* are consistent with the proposition that higher rental levels and lower vacancy rates raise project cash flows and project value, thereby stimulating office construction.

The consistently positive sign of *GROWTH(1)* indicates that its hypothesized positive effect on expected project values, which would encourage investment, prevails over its hypothesized positive effect on the opportunity cost of investment, which would discourage office-commercial construction. Note that both growth in office employment, proxied by *GROWTH(1),* and growth in FIRE employment, proxied by *GROWTHFIN(1)*, perform very well.

The real estate discount rate proxy, *RATE(1)*, exhibits the expected negative sign indicating that higher discount rates discourage office construction. Given the dual effect of the discount rate on investment decisions, this result suggests that its negative effect on expected project value, which would discourage construction, is greater than its negative effect on the opportunity cost of investing, which would encourage office-commercial construction.

Construction and development costs, proxied by *CCI(1)*, *SPATIAL*, and *CLIMATE,* also seemingly exert statistically significant influences on office-commercial construction. *CCI(1)* exhibits the expected negative sign and is statistically significant in two of the model variants, while *SPATIAL* and *CLIMATE* display the expected signs and are statistically significant across all model variants. Such effects are again consistent with the proposition that high investment costs weaken the incentive to invest in office-commercial development.

Demand Volatility vs Other New Construction Determinants. But how important is employment growth volatility relative to other construction determinants? In order to explore differences in the strength of such effects, the β*eta* coefficients for Models I-1's and I-2's explanatory variables were calculated and portrayed in Figure 2.

Focusing on Model I-1 (I-2), and in spite of the statistically significant effects already discussed, demand volatility appears to exert weak standardized effects on office-commercial construction rates. This is evident in the β*eta* coefficient of -0.02 (-0.03) for the uncertainty proxy, *VOLG(FIN)(1),* which is substantially lower than the β*eta*s for all other construction determinants considered. Notably, rental income flows and the discount rate have, on average, the greatest influence on office-commercial construction rates. In particular, one standard deviation increase in *INCOME(1)* induces a 0.17 (0.21) standard deviation increase in office-commercial completion rates, while one standard deviation increase in *RATE(1)* induces a 0.15 (0.15) standard deviation decrease in construction activity. The office (FIRE) employment growth rate, *GROWTH(FIN)(1)*, with a β*eta* of 0.14 (0.09), the land cost proxy, *SPATIAL,* with a β*eta* of -0.12 (-0.13), and the climate proxy, *CLIMATE*, with a β*eta* of 0.07 (0.07) also appear to exert stronger influences than demand volatility on office-commercial construction.

Are the Nineties Different from the Eighties?

The empirical results just discussed are consistent with the proposition that demand volatility does exert statistically significant effects on office-commercial construction, yet these results also indicate that such effects are weaker than the ones exerted by other construction determinants. But is the supply model expanded to account for the effects of demand volatility equally robust during the pre- and post recession periods in the last seventeen years? Are the relative effects of demand volatility and other construction determinants substantially different during these sub-periods in the recent history of the U.S. office market?

Motivating the questions just posed are arguments pointing to a more "restrained" behavior on the part of key real estate players following the most recent market crash which, as Caplin and Leahy (1994) note, may have signalled the end of "business as usual" and the onset of "wisdom after the fact."[28] Motivated by the loss of pre-crash informational capital, the end of "business as usual" may have been exemplified by waiting for more information until the longer run status of the national economy and the investors' own fortunes could be better known. Bernanke (1983) presented, perhaps, the first attempt to explain changing patterns of *irreversible* investments at the onset of such crashes. Following his line of argument, investors at the onset of the most recent recession were being faced with "unusual drawings" or a state of the office market environment that was considerably different from the past. This may have made them less sure about the distribution generating project returns. Thus the opportunity cost of investing may have increased along with increases in the downside risk brought about by the unfavorable market changes. As a result, investors may have become more cautious in responding to market conditions compared to the pre-recession period.

Notably, Bernanke's model assumes that more information is associated with decreased levels of uncertainty, while Dixit and Pindyck's (1994) model assumes that the future is always uncertain. Incorporating an "unusual" event in such a model involves the use of a mixed Brownian motion/jump process (in place of the simple Brownian motion described by (2)), where the probability for a sudden (or continued) downward jump in project values can be accommodated. As shown by Dixit and Pindyck (1994) and earlier by Merton (1976), in the simplified case where the "event" is expected to involve a *total* collapse of asset values, the effects of such a probability can easily be traced by assuming a higher effective discount rate, say, $\rho'=\rho+\lambda$ in place of ρ in all relationships defining the model summarized in the second section of this paper. Among the relationships that have been modified in this fashion are (4) and (8), which are hereafter referred to as (4)' and (8)'.

In exploring the second-order effects of λ, it can be assumed, for simplicity, that such probability was ignored in the pre-recession period and that investors got alerted to it at the onset of the most recent recession. In light of some (discrete) increase in λ (from 0 to some positive value), it can be shown in a straightforward manner that a more reserved behavior in terms of several of the model's regressors stems from such an "event." More specifically, assuming, as usual, that the fundamental value component, $P(\pi,\rho+\lambda-g)$, and the full investment cost component, wF, enter the investment function in an additive manner, the following effects can be detected:[29]

Employment Growth Volatility, σ : Demand volatility may exert a *more* pronounced *negative* influence on office-commercial construction. Simply, in light of a greater probability for a collapse of asset values, the opportunity cost of investing now, w, increases faster with uncertainty (as, from (4)', $w_{\sigma}>0$ and $w_{\sigma\lambda}>0$). As a result, the threshold value required for making the irreversible investment rises faster as well, further suggesting that an even smaller entry would be required to restore the zero profit condition. Alternatively, from (8)', $C_{\sigma\lambda}=C_w w_{\sigma\lambda}<0$ (as $C_w<0$ and $w_{\sigma\lambda}>0$).

Current cash flows, π : Current case flows, π, however, may be less influential. In light of a greater λ, the positive effect of π on the fundamental asset value, $P=\pi/(\rho+\lambda-g)$, decreases, thereby reducing investor response. Alternatively, from (8)', $C_{\pi\lambda} = C_{\pi\lambda} = P_{\lambda}/\pi<0$.

Expected employment growth, g : The influence of office or FIRE employment growth may be stronger or weaker in light of a greater λ, because of conflicting dual effects. On the one hand, in light of a greater λ, the positive effect of π on the fundamental asset value decreases, thereby reducing investor response. Alternatively, from (8)', $P_g>0$ and $P_{g\lambda}<0$, suggesting a greater incentive not to invest. On the other hand, with a greater λ, the positive effect of g on the opportunity cost of investing now decreases (as from (4)', $w_g>0$ and $w_{g\lambda}<0$), thereby strengthening the incentive to invest. In summary, from (8)', the sign of $C_{g\lambda}=P_{g\lambda}-Fw_{g\lambda}$ cannot be determined a priori.

Discount rate, ρ : Similarly, the discount rate may have a more or a less pronounced negative effect on current investments, as, from (8)', the sign of $C_{\rho\lambda}=P_{\rho\lambda}-Fw_{\rho\lambda}$ is uncertain. On the one hand, a greater λ lessens the negative effect of the discount rate on the opportunity cost of investment, as, from (4)', $w_{\rho}<0$ and $w_{\rho\lambda}>0$, suggesting a lower propensity to engage in current investments. On the other hand, a greater λ lessens the negative effect of the discount rate on the fundamental asset value, $P=\pi(0)/(\rho+\lambda-g)$, as $P_{\rho}<0$ and $P_{\rho\lambda}>0$, which helps promote current investment.

Construction costs, F : Construction cost effects may be weaker, that is, *F* may exert a less pronounced negative effect on new construction. Simply, the effect of construction costs on the price threshold and investment depends on the opportunity cost of investing now, *w* (as from (4)', $P(\pi^*)=wF$ and from (8)',$C_F=-w$). With a greater λ, the opportunity cost decreases (as from (4)', $w_{\lambda}<0$), thus weakening the negative effect of construction cost on investment. Alternatively, $C_{F\lambda}=-w_{\lambda}>0$.

Taken together, the effects just discussed point to a more pronounced response to uncertainty and *potentially* more reserved responses to all other factors influencing office-commercial construction during the post-recession years.

Empirical Estimation Results

Against the discussion above, the study tests for changes in the strength of various influences on office-commercial construction following the onset of the most recent recession. To this end, Models III and IV were formulated. Such models represent the dummy-variable counterparts of Models I-1 and I-2, which have been expanded to include relevant interactive terms between the basic regressors--*CC(1), INCOME(1)*, *GROWTH(FIN)(1), VOLG(FIN)(1),* and *CCI(1)*-- and *BREAK{1,0}*.[30] Representing a dummy that takes the value of 1 during the post-recession period and the value of 0 otherwise, the latter assumes two alternative specifications. Embedded in Models III-1 and III-2, the first involves a *common* "break" separating the pre- from the post-recession era. Signifying the period *following* the first substantial drop (by more than 50%) in the office/FIRE employment growth rate in *most* markets, *BREAK{1,0}* takes the value of one during 1991-1998 and the value of zero otherwise. Embedded in Models IV-1 and IV-2 and signifying the period that similarly follows the first substantial drop in the office/FIRE employment growth rate in *each* market, the second specification involves *market-specific* breaks (see Figure 1).[31,32]

The empirical results of Models III and IV are presented in Table 4. Taken together, the estimation results of these extended formulations indicate that the effects of demand volatility and other construction determinants differ during the two sub-periods in the recent history of the U.S. office market. More specifically, the results are consistent with a more reserved approach to investment during the post-recession period. Seemingly, during the pre-recession period, office-commercial investment did react in a predictable manner to, among other factors, cash-flow levels, *INCOME(1)*, the expected office (FIRE) employment growth rate, *GROWTH(FIN)(1)*, the discount rate, *RATE(1)*, and construction costs, *CCI(1)*, but did *not* respond to employment growth volatility, *VOLG(FIN)(1)*. During the post-recession period, as shown by the signs and statistical significance of the relevant interactive terms, office-commercial construction became *less* responsive to cash flow levels, *INCOME(1),* the office (FIRE) employment growth rate, *GROWTH(FIN)(1)*, and construction costs, *CCI(1)*, and, most importantly, responded *negatively* to the uncertainty associated with office or FIRE employment growth. All these results are consistent with the theory of irreversible investments and the potential crash-induced effects discussed previously in this section, suggesting that more reserved investment outcomes follow market crashes.[33]

Also consistent with the conclusions above are the smaller delivery lags during the post-recession years, as smaller and, perhaps, better managed projects may have been favored during this period.[34,35] As the (negative) coefficient of *BREAK*CC(1)* suggests, 80% of investments during the post-recession period are realized in 2.0-2.2 years, a delivery lag appreciably shorter (by about a year) than the one observed in the pre-recession period.

Relative Effects. Figure 3 presents the standardized effects of the factors just discussed during the pre-recession and post-recession periods. The figure exemplifies the dominance of the rental income flow, *INCOME(1)*, and expected cash flow growth proxies, *GROWTH(FIN)(1)* in the pre-recession years and their substantially decreasing influence following the market crash. It furthermore illustrates the increasing influence of *VOLG(FIN)(1)* in the post-recession era, while accentuating, at the same time, the fact that such a factor remains less influential than the model's other explanatory variables. Overall, the shifts in the relative importance of all regressors are consistent with a more restrained approach to office-commercial investment following the onset of the most recent recession. It remains to be seen whether such a restrained behavior will continue into the coming years.

Alternative Explanations

It is important to note at this point that although the empirical results just discussed may be consistent with the theory of irreversible investments in uncertain environments, other factors, including constraints to external and internal finance, may have also contributed to the particular investment outcomes. Focusing on external capital availability, it is well known that real estate capital providers started experiencing significant capital losses in 1989 that led to a credit or capital crunch for various real estate loans (see Browne and Rosengren 1992). Facing stringent regulatory controls and the increased risks of declining asset values, they may have, therefore, become far more cautious in providing debt capital for both construction/ development and permanent real estate loans (see Fergus and Goodman 1994). Such cautiousness on the part of capital providers may have well been reflected into the reserved investment responses indicated by the empirical results.

Although, perhaps, more difficult to document, limited internal capital may have also played a role. Real estate development/investment firms may have become more cautious after the most recent recession because of the drain on their liquid assets and internal resources brought about by the collapse in real estate prices (see Tinsley and Krieger 1997). More specifically, during the pre-recession period, real estate investment firms have been experiencing large accumulations of retained earnings and, as such, may have been facing a low probability of exhausting such internal capital and liquid asset reserves. As a result, they may have been placing little weight on the risk exposure associated with cash flow and asset price variations. In contrast, after the dramatic decrease in asset prices brought about by the recession, "self-financing" protection may have been eroded by drains on liquid asset buffer stocks, thus raising greater concerns about the uncertainty of projected cash flows that may have, again, motivated investors to scale back construction.[36]

Conclusion

Focusing on the nation's major metropolitan markets, this study explores empirically movements in office-commercial construction during 1982-1998. The empirical results convey two major conclusions:

First, the theory of irreversible investments in uncertain environments seems to be relevant in shedding light on movements in office-commercial construction, a conclusion that is consistent with the findings of the general empirical literature on irreversible investments, discussed by Leahy and Whited (1996), as well as those of Holland, Ott, and Riddiough (forthcoming). More specifically, our results indicate that volatility in office or FIRE employment growth, exemplifying the opportunity cost of exercising the option to invest, exerts statistically significant *negative* influences on office-commercial construction. Yet, we also find that such a factor is overshadowed in terms of relative importance by all other factors considered, including (but not limited to) rental income flows, office employment growth rates, and the risk-free rate, all seen to exert substantial impacts on office commercial activity.

Second, the nineties do appear to be different than the eighties in terms of investment behavior. By and large, the empirical results are consistent with the proposition that the investment and development community has followed a more reserved approach to office-commercial investment following the most recent real estate market crash. The latter is signified by the negative influence of the office employment growth volatility (compared to its lack of influence in the pre-recession years), as well as the weaker investment responses to (among other factors) rental income flows and office/FIRE employment growth.

Further research is needed along several dimensions. From the theoretical perspective, the formidable task of developing an integrated "q" model of industry equilibrium with *aggregate* uncertainty, along the lines of Abel *et al*. (1996) and Romer (1996), needs to be undertaken. Such a model would provide the theoretical basis for empirical models that intend to shed light on long-run structural relationships between uncertainty and investment. From the empirical perspective, further research could focus on office construction movements in individual office markets, as (due to data limitations) this study has only focused on average investment behavior (across metropolitan markets). Given the widely accepted segmentation of real estate markets along metropolitan boundaries, it is very likely that investment responses vary across markets (see Pollakowski, Wachter, and Lynford 1992). The existence of such differential behavior needs to be empirically examined.

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Endnotes

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[1] In a much earlier study, Quigg (1993) examined the relevance of the real options model in commercial land valuation.

[2] The assumption of exogenous output is required to render the desired capital stock determinate, while the stock adjustment process is necessary to determine the rate of investment. The exogenously determined output, Hayashi (1982) argues, is inconsistent with perfect competition, while the often-used (distributed) lag structure of (net) investment is a-theoretic, as it is not derived as an optimal response to adjustment or installation costs that would provide the rationale for such a structure.

[3] Bischoff (1970) and Hambor and Morgan (1971a, 1971b) use such a stock adjustment model to explain nonresidential construction. In a more recent paper, Eppli and Shilling (1995) also apply a stock adjustment framework to the analysis of intertemporal adjustments in nonresidential real estate stock.

[4] Hayashi (1982) presents an application of the "*q*" theory to the U.S. corporate sector, while Abel and Blanchard (1986) apply the (marginal) "*q*" theory to manufacturing investments. In a recent paper, Gyourko and Voith (1993) present simulations examining real estate development processes based on such a theory, while Wheaton, Torto, and Evans (1997) draw on the "*q*" model to explore construction movements in the London office market.

[5] Dixit and Pindyck (1994), for example, note that several empirical models, regardless of how well they translate theoretical notions into empirical measures, fail to explain investment using traditional rules. The low explanatory power of such models may lie in the omission of factors brought into effect by investment irreversibility.

[6] Investment lags are not explicitly modeled; as noted by Bar-Ilan and Strange (1996), the modeling results remain unaltered when such lags are taken into account. Furthermore, the model described here does not account for other intricate characteristics of office-commercial real estate assets. For details, see Grenadier (1995).

[7] Unfavorable demand shocks, for example, lead to decreases in prices *along* the firms' supply curve; in contrast, favorable demand shocks leading to price increases induce entry, thus *shifting* the supply curve, and limiting the potential for upside price movements. Hence, any stochastic shifts in demand will result in less than proportionate increases in π. Said differently, π^* is a *concave* function of the stochastic demand shifter.

[8] The arbitrage theory cannot be used as a framework for specifying a discount rate, as real estate cannot be traded instantaneously due to its lumpiness, heterogeneity, high transaction costs, and related market imperfections. Alternatively, an equilibrium specification of the discount rate in accordance with the capital asset pricing model (CAPM) could be used. In such a case, the risk-adjusted discount rate can be determined as $\rho = r + \phi\sigma\rho_{pm}$, where r is the risk-free rate, ϕ the market price of risk, and ρ_{pm} the correlation coefficient between real estate and the whole market portfolio. Notably, such an approach requires that stochastic fluctuations in real estate markets be "spanned" by financial markets, implying that a traded asset perfectly correlated with real estate exists. However, such spanning assumption may not hold in the case of real estate, as the latter represents a highly illiquid and unique asset. In light of the problems just discussed, an exogenous discount rate can be assumed. Under assumptions of risk neutrality, this can be proxied by the riskless rate. Alternatively, r can be assumed to incorporate risk premia reflecting investor perceptions regarding non-diversifiable market risks. Interpretation of such a measure is problematic, as it does not reflect capital market equilibrium and as investor preferences cannot be measured in an objective manner. Unfortunately, however, no perfect solution to this problem exists.

[9] Leahy (1993) showed that the price threshold required for entry by a competitive firm is essentially the same as the price threshold required by a firm with a monopoly right to invest. The reason is that the monopolistic firm has a

positive option value of waiting which exactly equals the competitive firms' reduction in asset value due to the ceiling free entry imposes on rental income flows. This suggests that a competitive firm can make the correct choice by acting myopically, as if it were the last firm to invest. The competitive equilibrium problem, therefore, can be cast in terms of a single firms' choice.

[10] Tracing the long-term effects of uncertainty on investment requires the development of explicit structural models of long-run equilibrium levels of investment that would preferably incorporate adjustment costs. We attempted to construct such a model, but our efforts proved unproductive. As indicated by Dixit and Pindyck (1994) and, more recently, Abel and Eberly (1997), this represents a difficult task, which explains (perhaps) why such a model is not yet available.

[11] Stochastic models employing rising marginal cost functions have also been presented by Abel and Eberly (1997). Using the case of a competitive firm with constant returns to scale production function and convex adjustment costs, these authors derive the following closed form solution:

$$I = f(q(\pi, \rho, g, \sigma) - F) \qquad (I_{\pi}>0;\ I_{\rho}<0;\ I_{g}>0;\ I_{\sigma}>0)$$

where q is the present value of the expected marginal revenue product of capital. The associated comparative statics are the same as in (8) with the exception of uncertainty, which is shown to have a positive, as opposed to a negative, effect on investment. The latter is the result of q being a convex, as opposed to a concave, function of σ^2. In contrast to Dixit and Pindyck (1994), however, these authors consider neither the effects of *aggregate* uncertainty nor the equilibrium effects of firm entry on the investment decision calculus of firms. As noted by Pindyck (1993), the negative effect of aggregate uncertainty on industry investment largely stems from an investor's consideration of the possibility of entry by competing investors. Such an outcome, he notes, also applies to firms that are constrained to some size (say, through adjustment costs), or firms with decreasing returns to scale.

[12] A geometric lag structure, inducing serially correlated errors (Gujarati 1995), was originally adopted but later abandoned as appropriate tests indicated that the error term of the estimated models was not serially correlated (see the discussion on empirical model estimation).

[13] These office markets include: Atlanta, GA; Boston, MA; Chicago, IL; Dallas, TX; Denver, CO; Houston, TX; Los Angeles, CA; Minneapolis, MN; New York, NY; Philadelphia, PA; Phoenix, AZ; San Diego, CA; San Francisco, CA; Seattle, WA; and Washington, D.C.

[14] The models discussed in this and the following sections have *also* been estimated using levels as opposed to rates of new construction. The results are available upon request.

[15] Net income flows enter the model in a lagged form as they refer to the time of investment decision. Thus from a time series point of view, endogeneity is not an issue. From the cross sectional perspective, lagged income, *INCOME(n)* acts as an instrument of *INCOME*, thereby mitigating endogeneity concerns; a Hausman test did indicate that, indeed, endogeneity is not an issue.

[16] In light of the widely established segmentation of the real estate industry along metropolitan boundaries (see discussions of the segmentation of the office-commercial sector in Pollakowski, Wachter, and Lynford,1992; Wheaton and Torto, 1994; Sivitanidou and Sivitanides, 1999), each metropolitan area can be viewed as an independently operating market reaching its own industry equilibrium. In this sense, our metro-wide uncertainty proxies are consistent with the definition of industry-wide uncertainty. The estimation procedure is consistent with this view as well; the TSCS model treats each metropolitan area as a separate unit and controls for any common influences from the national economy through the cross-section correlation correction.

[17] Two points need to be made here. First, the uncertainty proxy, as defined here, is time-varying, which deviates from the constant-volatility assumption in the model outlined in the second section of this paper. As, however,

Hassler (1996) has shown, the negative impact of uncertainty on investment is not typically influenced by such a specification. Second, it should be noted that in a previous version of this paper using semi-annualized data, alternative proxies for *GROWTH(FIN)(n)* and *VOLG(FIN)(n)* were developed based on an adaptive expectations approach. In particular, *GROWTH(FIN)(n)* was calculated separately for each metropolitan area as the three-semester forward forecast of an ARIMA specification using the historic office employment growth rate as the input series. *VOLG* was proxied by the standard error of that forecast. Depending on the degree of differencing required to transform the historic office employment growth series of each metropolitan area into a stationary variable, two alternative ARIMA specifications were estimated: ARIMA(1,0,1) with first order seasonal autoregressive and moving average terms for metropolitan areas for which first order differencing was not required; and ARIMA(0,1,1) without any seasonal terms for metropolitan areas for which differencing was required. The degree of differencing needed to transform the office employment change into a stationary variable was determined through Dickey-Fuller tests. Preliminary model estimation indicated that the myopic proxies performed far better.

[18] As indicated in note 8, our theoretical framework does not rely on CAPM and, as such, uses an exogenous discount rate. For the reasons also cited in the same note, a riskless rate is hypothesized. It should be noted, however, that if a non-risk-free discount rate, that is influenced by industry-wide uncertainty, were used, we wouldn't be able to separate the direct effects of uncertainty on construction from its potential indirect influences through the discount rate and prices. Separating these effects following the Holland, Ott, and Riddiough (forthcoming) modeling approach would not be feasible since it would require office property price series for each metropolitan market included in our sample. Simply such price series are not available.

[19] These exceptions include, of course, all dummy variables, as well as *GROWTH(FIN)(1)*, which takes negative values in some years and, as such, cannot be expressed in logarithmic form.

[20] Given the inclusion of a stochastic regressor in the right-hand-side of the model, serial correlation has been a major concern, as in the presence of autocorrelated disturbances least squares would lead to biased and inconsistent estimates, thus necessitating the use of instrumental variable techniques (see, for example, Hatanaka 1974) in order to salvage the property of consistency.

[21] Reported in Table 3, which is discussed in the following subsection, the Durbin *h*-statistic is approximately normally distributed with a unit variance. Given that the reported estimates are smaller in absolute value than the critical value of the normal distribution at the 1% level of significance, the null hypothesis of no serial correlation cannot be rejected.

[22] The test statistics for groupwise heteroskedasticity and cross section correlation are also reported in Table 3. The LR statistic for heteroskedasticity follows a chi-squared distribution with $N-1$ degrees of freedom, $\chi^2(N-1)$, where N=15 denotes the number of cross-section units; its critical value at the 1% level of significance is 29.14, suggesting that the null hypothesis of homoskedastic errors be rejected. The LR statistic for cross-section correlation follows a chi-squared distribution with $N(N-1)/2$ degrees of freedom, $\chi^2(N(N-1)/2)$; its critical value at the 1% level of significance is 140.84, again suggesting that the null hypothesis of no cross-section correlation be rejected.

[23] The reader is spared the details of the many regression models that were estimated, but it's worth noting that the empirical results were also robust across model variants using nominal rental flows and nominal construction costs together with inflation-adjusted discount rate proxies.

[24] Given that the model's dependent variable controls for size differences across markets and that nearly all regressors are market-specific, the inclusion of metropolitan location dummies was not deemed necessary.

[25] *J* tests (see Kmenta 1986) used to compare Model I-1 to Model I-2 (and Model II-1 to Model II-2) indicate that it is unclear whether one model variant is "superior" to the other at the 5% level of significance. At the 1% level of significance, however, Model I-1 (Model II-1) seems stronger than Model I-2 (Model II-2).

[26] This time span, or delivery time, was estimated as $d=n+[ln(1-x)/lna_1]$, where n is the minimum delivery lag, x is the fraction of investments delivered and a_1 is the coefficient of lagged completions.

[27] The estimation results of model variants not shown on Table 3 are available upon request.

[28] The general empirical literature on business cycle asymmetries includes (among others) Burns and Mitchell (1946), DeLong and Summers (1986), and Sichel (1993).

[29] The simple derivations associated with the comparative statics discussed below are available upon request.

[30] In an effort to reduce collinearities introduced by interactive terms, such terms were avoided for the time-invariant *CLIMATE* and *SPATIAL*.

[31] More time series observations would certainly be desirable for such tests. However, the use of a relatively large cross-section time-series sample helps mitigate efficiency concerns.

[32] With the exception of *BREAK*GROWTH(1)*, which appears with a negative sign and exhibits a statistically insignificant effect, and *BREAK*GROWTHFIN(1),* which exhibits a statistically significant positive effect, all other results remain unaltered (in qualitative terms), when *BREAK{1,0}* is added as a separate regressor in Models III-1 and III-2. In contrast, *all* empirical results remain unaltered (in qualitative terms) when *BREAK{1,0}* is added as a separate regressor in Models IV-1 and IV-2. In all models, *BREAK{1,0}* exhibits a statistically significant negative sign.

[33] Although not shown in Table 3, estimation results using *only* the post-recession observations convey the same conclusions.

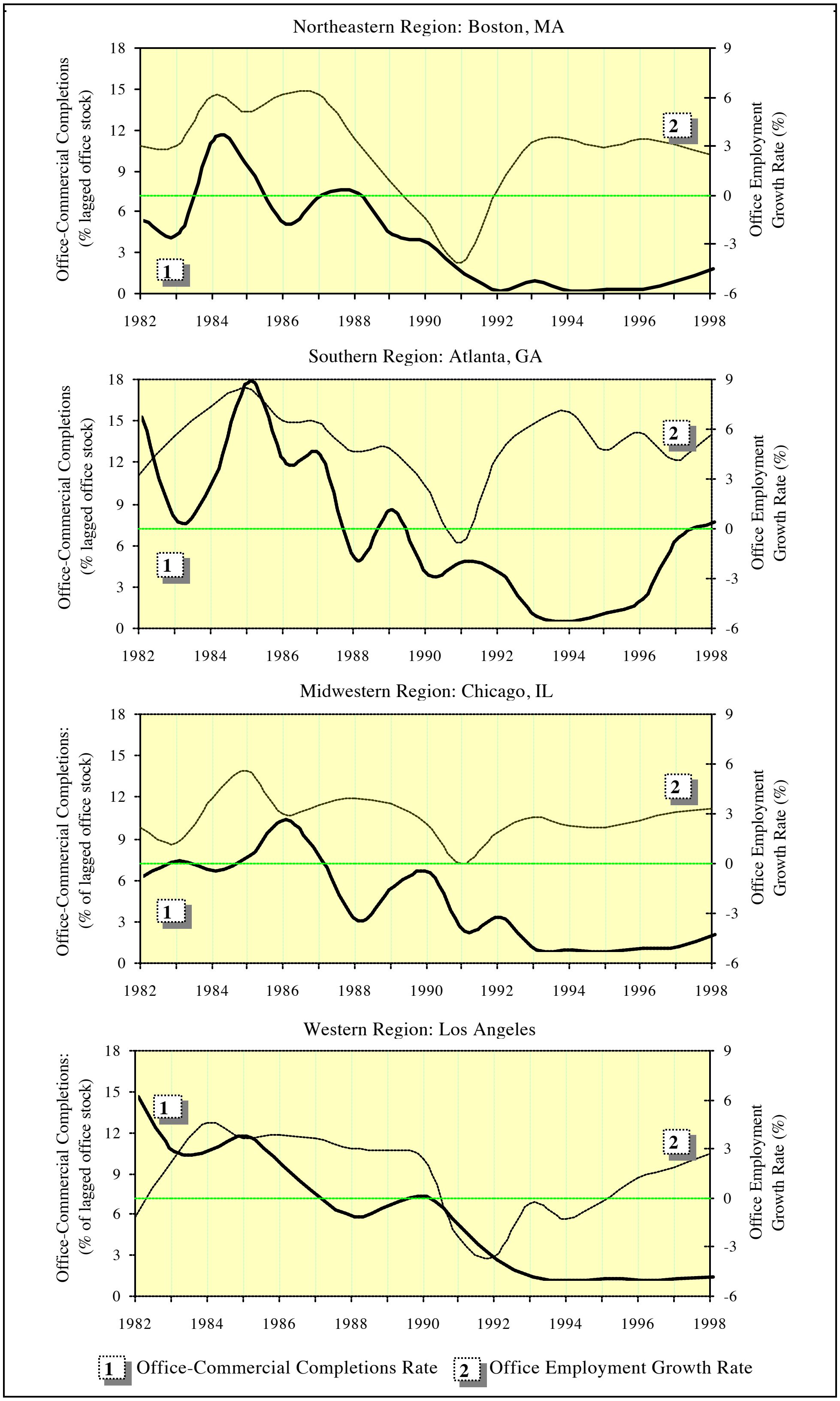
[34] CB Richard Ellis/Torto Wheaton data for 1991-1998 do indicate a shift in the size distribution of new construction in favor of smaller projects.

[35] Montgomery (1995) attributes shorter production periods to better technology or smaller projects.

[36] Originated in the work of Fazzari, Hubbard, and Petersen (1988), a growing volume of economic literature predicts that the relationship between cash flows and investment should be stronger in the case of companies facing greater barriers to external finance; by extension, greater barriers to external finance in the post-recession period may have led to increased reliance on internal financing, likely to be reflected in an increased sensitivity to cash flow variables. However, as Kaplan and Zingales (1997) suggest, the relationship need not be monotonic, and decreased sensitivities to cash flow variables may also be a reasonable outcome in the face of external financing constraints. The relevance of such theories to the case of real estate investments needs to be examined from both the theoretical and empirical perspectives.

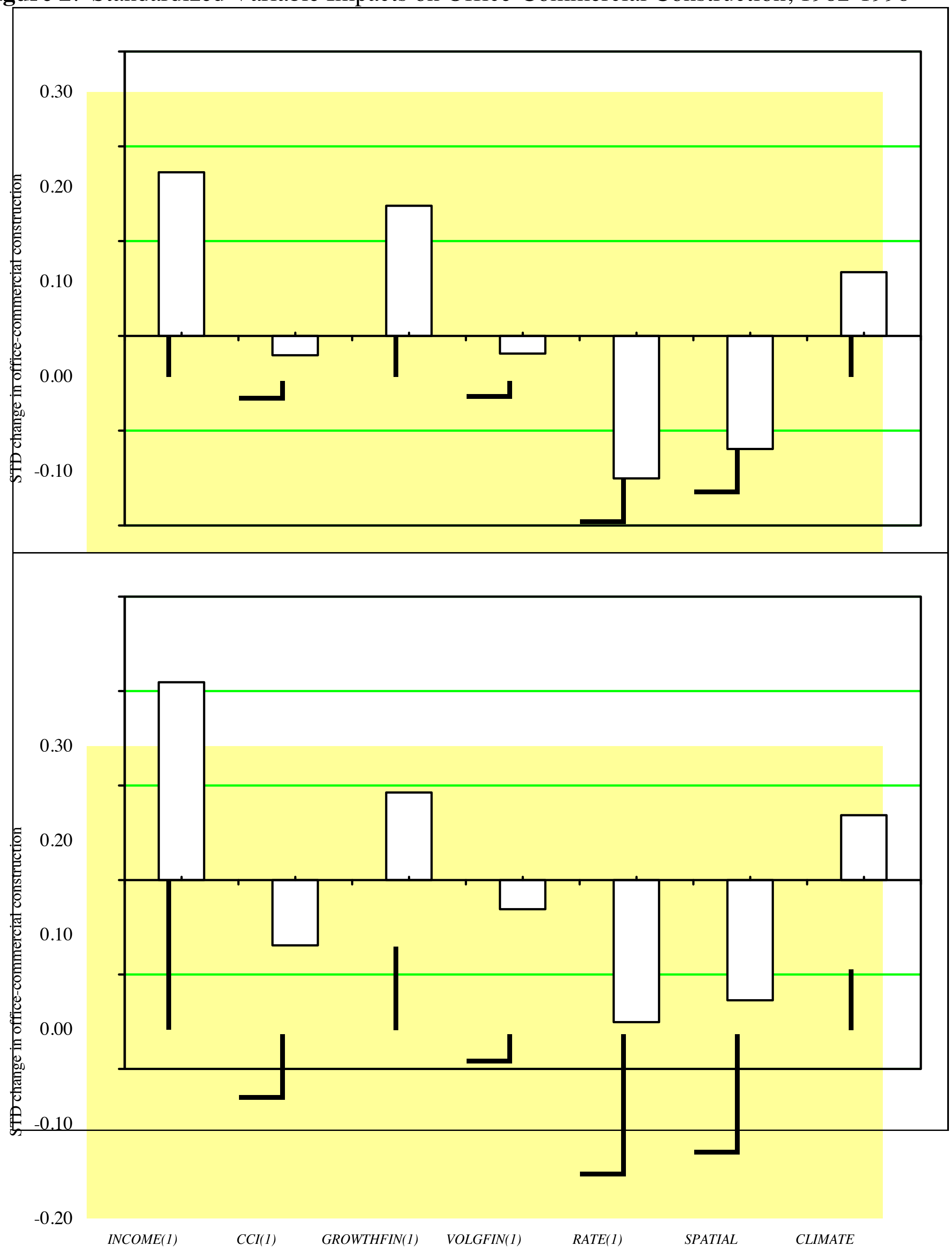
Figures and Tables

Figure 1. Office-Commercial Construction in Selected Metropolitan Markets



This figure presents office-commercial construction rates and juxtaposes them to office employment growth rates. The source of the data is CB Richard Ellis/Torto Wheaton Research.

Figure 2. Standardized Variable Impacts on Office-Commercial Construction, 1982-1998



Panel (b)

The effects presented in the figure above represent standard deviation changes in construction rates, stemming from one standard deviation change in each explanatory variable. The effects presented in panel (a) are based on Model I-1's estimates, while the effects in panel (b) are based on Model I-2's estimates.