Irreversible Investment, Real Options, and Competition: Evidence from Real Estate Development

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This Version: November 26, 2002

*The authors wish to thank Andy Abel, John Donaldson, Larry Glosten, Joe Gyourko, Charlie Himmelberg, Glenn Hubbard, Ken Kuttner, Todd Sinai, Nick Souleles, Will Strange, and Tan Wang for helpful comments. Special thanks are due to Zhan Binghui for research assistance. The data are the result of assistance and cooperation from Stan Hamilton and the offices of the BC, Land Title Office, Registrar of Corporations, and Superintendent of Real Estate. Financial support for this research was received from the Social Science and Humanities Research Council of Canada, the Real Estate Foundation of British Columbia, and the Zell/Lurie Real Estate Center at Wharton. Previous versions of this paper circulated under the title, "Should I Build or Should I Wait Now? Idiosyncratic Risk, Competition and Real Options in Real Estate Investment." All errors are the responsibility of the authors.

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ABSTRACT

We examine 1,214 condominium developments in Vancouver, Canada between 1979-1998 to identify the extent to which uncertainty delays investment. We find that increases in both idiosyncratic and systematic risk lead developers to delay new real estate investments. Empirically, a one-standard deviation increase in the return volatility reduces the hazard rate of investment by 13 percent, equivalent to a 9 percent decline in real prices. Increases in the number of potential competitors located near a project negates the negative relationship between idiosyncratic risk and development. These results support the argument that competition erodes option values and provide clear evidence for the real options model of investment under uncertainty over alternatives such as simple risk aversion.

I. INTRODUCTION

Over the last two decades, the application of financial option theory to investment in real assets has altered the way researchers model investment. Under the real options approach, firms should apply a higher user cost to new investments in irreversible assets when returns are stochastic, reflecting the option to delay that is lost when investment occurs. Nonetheless, the existing empirical literature on irreversible investment and uncertainty has sometimes obtained mixed results when estimating the relationship between the two. Even for papers that find a negative relationship between uncertainty and investment, it is usually not possible to reject standard alternative interpretations to real options such as non-diversifiable risk or incomplete markets combined with risk averse investors.

Some theoretical models show that real options models can have limits on their power to predict investment behavior. A number of papers (see, for example, Grenadier 2002) argue that competition might mitigate the value of a real option through the threat of preemption. Caballero (1991) suggests that imperfect competition is vital to predicting a negative relationship between uncertainty and investment. Trigeorgis (1996) associates increased competition with a higher dividend yield from the underlying asset. When the dividend is high enough, it can induce early exercise by reducing the value of the option to wait.[1] Also, Abel, et. al. (1996) argue that the

[1] In contrast, Leahy (1993) and Dixit and Pindyck (1994) argue that the value of waiting, and thus the adverse effect of uncertainty on investment, is preserved even with perfect competition. Their findings require the endogeneity of prices in a competitive equilibrium model, a linear homogenous production function or the existence of firm or industry-specific risk. However, Kulatilaka and Perotti (1998) argue that firms with a strategic advantage (market power) are in a better position to gain greater growth opportunities when uncertainty is higher. This induces more investment in growth options for these type of firms while companies that do not have a strategic advantage will be discouraged from investing.

presence of dual options in many investments complicates the prediction of a negative relationship between irreversible investment and uncertainty. In the presence of demand and cost uncertainty, an investment in a real asset has a call option, the ability to delay investment, and a put option, the opportunity to disinvest and deploy that asset in an alternative use. Uncertainty raises the value of the call option, increasing the user cost and reducing investment, but it may also raise the value of the put option, increasing investment. Although the importance of each option depends on the degree of irreversibility in the investment, much of the empirical literature focuses on the call option.

We use data on 1,214 individual real estate projects (condominium or strata buildings) built in Vancouver, Canada between 1979 and 1998 to examine the relationship between competition, uncertainty, and irreversible investment. These data offer a number of appealing features for this type of analysis. First, we examine individual developments, which provide much more direct evidence about the investment-specific decision than can be observed from aggregate data. Second, we directly observe the level and volatility of individual investment returns in a specific market, rather than inferring the volatility of returns based on firm-level stock returns. Third, these condominium projects are typically quite difficult to convert to alternative uses.[2] This setting allows us to isolate the effect of the option to delay, the call option, from the put option to redeploy capital to alternative uses. We separate uncertainty into market risk, which is predicted to reduce investment in a variety of models including the CAPM, and idiosyncratic volatility, which has a negative impact on investment in the real options model.

[2]In fact, conversions are usually impossible if the developer has pre-sold any individual units to the public, as is common in this market.

In looking at real estate, we examine a sector that represents a large component of national investment and wealth that exhibits great cyclical volatility in investment.

Finally, we examine the theoretical prediction that competition may mitigate the incentive for firms to delay investment when facing greater uncertainty. The impact of competition on investment is important in its own right. Also, the findings regarding competition allow us to distinguish between two alternative interpretations of our results: real options and risk aversion. In the latter case, investors might simply shy away from risky investments in real estate simply because they cannot adequately diversify these risks. Evidence that competition diminishes the relationship between investment and uncertainty would support a real options interpretation because it is difficult to find a comparable prediction in a model of risk aversion that does not rely on real options behavior.

Our results support the premise that real options models help explain the behavior of real estate developers. In particular, we show that investment activity falls with increases in uncertainty. The probability of development occurring at a given site is negatively related to the volatility of returns. Upon decomposing volatility, we find that exposure to both idiosyncratic and market volatility delay investment to nearly the same extent. A one standard deviation increase in idiosyncratic volatility reduces the hazard rate of development by 13 percent, about the same predicted impact on new investment as a 9 percent decrease in real prices. A similar one standard deviation increase in market volatility is equivalent to a 7 percent fall in real prices.

We find that competition, measured by the number of potential competitors for a project, reduces the impact of volatility of prices on new investment. Empirically, competition has little direct effect on investment. Instead, competition only matters when interacted with volatility.

As predicted in Caballero, Trigeorgis and Grenadier, volatility has a smaller impact on option exercise for developments surrounded by a larger number of potential competitors. In fact, for the 5 percent of all units facing the greatest number of potential competitors, volatility has virtually no effect on the timing of investment. These findings provide unambiguous support for the existence of a call option in the ability to delay irreversible investment. Finally, we also find some empirical support for Grenadier's (1996) model of development cascades in declining market. In the data below, price declines can trigger a (short-run) increase in the likelihood of option exercise.

The importance of real options in real estate and the macroeconomy has substantive policy implications. Previous research notes the important connection between investment and business cycles (see Zarnowitz, 1999). In particular, Basu and Taylor (1999) suggest that the high volatility of investment relative to output, documented over long periods of time and across countries, is one of the great puzzles of macroeconomic cycles. The link between uncertainty, competition, and investment can help shed light on these issues. For instance, Abel and Eberly (1999) demonstrate that uncertainty and the irreversibility of investment can affect the capital stock. In the real options model, variation in the degree of competition over the cycle will also effect investment. Rotemberg and Saloner (1986) and Rotemberg and Woodford (1991, 1992) argue that tacit collusion is difficult to sustain in booms, relative to busts. Firms might optimally further delay investment in busts when product markets are less competitive, but undertake equivalent investments in booms when they face greater competition.

The remainder of the paper is structured as follows. Section II provides a review of relevant issues in the theoretical literature and a discussion of the empirical real options literature. In Section III, we present a summary of the basic theoretical model and discuss the impact of various assumptions in terms of the completeness of capital markets and the dynamic properties of real estate prices. We present a more detailed discussion of the data in Section IV. The empirical results are presented in Section V, and in Section VI we summarize with a brief conclusion.

II. PREVIOUS LITERATURE

There exists a well-developed theoretical literature that uses the real options methodology to examine the effect of uncertainty on irreversible investments.[3] The effects can be quite large. For example, Dixit and Pindyck (1994) use simulations to show that the optimal hurdle price triggering new irreversible investment can be 2 to 3 times as large as the trigger value when investments are reversible.

Empirically, real options theory has been applied to describe a broad range of investments.[4] Macroeconomic aggregate studies by Pindyck and Solimano (1993) and Caballero and Pindyck (1996) find a negative relationship between aggregate investment and uncertainty, using the variance in the maximum observed marginal revenue product of capital as the measure of uncertainty. Other recent papers (Holland, Ott, and Riddough 2000, Sivitanidou and

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[3]Reviews of the theoretical literature include Dixit and Pindyck (1994), Trigeorgis (1996), and Brennan and Trigeorgis (2000). Among the seminal papers in this areas are Abel (1983), Bernanke (1983), Brennan and Schwartz (1985), McDonald and Siegel (1986), Majd and Pindyck (1987), Pindyck (1988), Dixit (1989), and Abel, Dixit, Eberly, and Pindyck (1996).

[4]Applications include investments in natural resources extraction (Brennan and Schwartz 1985; Paddock, Siegel, and Smith 1988), patents and R&D (Pakes 1986), and real estate (Titman 1985, Williams 1991, Williams 1993 and Grenadier 1996). Lander and Pinches (1998) summarize the applied literature.

Sivitanides 2000, and Sing and Patel 2001) examine the correlation between different types of uncertainty and aggregate real estate development. Although these papers use a number of different data sources, a negative relationship between uncertainty and development tends to be the common result, though not for all measures of uncertainty or development. Leahy and Whited (1996) and Bulan (2001) obtain mixed results when examining the effect of a firm's daily stock return volatility on the firm-level investment-capital stock ratio for a panel of manufacturing firms. However, real options models apply to individual investment projects and predict that trigger prices are non-linear, so aggregate investment studies may obscure these relationships.

Studies that use project level investment data have often found limited evidence of a link between investment and volatility, although recent work has tended to be more supportive of real options. Hurn and Wright (1994) find that the volatility of oil prices has a negative, but insignificant effect on the probability that a well site is appraised for development and production begun. Bell and Campa (1997) demonstrate that the volatility of exchange rates has a negative effect on new capacity investment in the international chemical industry, but that the volatility of input prices and demand have small and insignificant effects. In these studies, the weak results may be driven by the difficulty in properly measuring forward looking proxies for demand and price uncertainty and the selection bias in the investment decision. An exception is Quigg (1993). She develops a structural model of land valuation and compares sales prices with an estimated intrinsic value. In her results, the option to wait is worth about 6 percent of the value of undeveloped industrial land in Seattle. More recently, Downing and Wallace (2001) find a stronger negative link between volatility of prices and costs and the decisions of homeowners to improve their homes. Probably the most similar paper to our analysis is that of Moel and Tufano (2002) who examine the determinants of the decision to close or re-open a mine using a sample of 285 gold mines. They find that gold price volatility has a negative and statistically significant effect on these decisions, but that factors such as firm-specific managerial decisions also matter.

In using micro-data on real estate investments, this paper provides a number of enhancements to the existing literature. First, investments in real estate developments are essentially irreversible and are quite difficult to shift to alternative uses, so that the put option for disinvestment, which could otherwise obviate the negative relationship between uncertainty and investment, is not an important factor.[5] Second, we examine a relatively large data set of individual investments, rather than looking at aggregate or firm-level investment. Our strategy looks at the timing of development of each parcel measured from a fixed point in time, instead of linking the analysis with a potentially endogenous timing of a change in ownership. We can also directly measure the volatility of output (condominium) prices for these investments at the neighborhood level, rather than using imperfect proxies for investment-specific return uncertainty such as the volatility of firm-level stock market returns. Our approach also identifies the effect of volatility on investment timing rather than on investment levels. The former is a direct prediction of the real options model while the latter is only an implication. Third, we control for possible relationships between volatility and aggregate risk, by differentiating the impact of systematic and non-systematic risk. Both of these last factors help tie down a real options interpretation of the results beyond simply observing that uncertainty impacts

[5] For the option to disinvest to be a factor we need market dynamics to differ across different land uses and for buildings to be converted easily across uses. Conversions, such as between residential and office uses, are rare; when one sector in an area is down, others tend to be down as well.

development, a prediction that is not unique to real options models.[6] Finally, and perhaps most importantly, we provide a clearer test of the effect of uncertainty on irreversible investment by taking advantage of the real options prediction that the extent of competition can mitigate the negative relationship between uncertainty and investment.

III. EMPIRICAL SPECIFICATION

Most real options models solve for the price level that triggers new investment, P^*, so that when $P > P^*$, the owner will choose to make an irreversible investment. In the simple form of the model, the only source of uncertainty is the path of future asset prices. Here we assume that investments are completely irreversible, thus ignoring the put option to sell for an alternative use. The asset price is assumed to follow geometric Brownian motion:

$$dP/P = \alpha dt + \sigma\, dz \,, \tag{1}$$

where α and σ^2 are the drift (expected capital appreciation) and variance parameters, respectively, and dz is the increment of a Wiener process. The asset is also assumed to have a (constant) convenience (dividend) yield δ. A closed form solution can be found by dynamic programming or a contingent claims pricing solution that assumes complete markets, so that a short position can be taken in the asset.[7] As in Black-Scholes (1973), the trigger price is:

$$P^* = f(\mu^+,\ \delta^-,\ \sigma^+), \tag{2}$$

where f is a non-linear function, μ is the discount rate (equivalent to the expected rate of return

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[6] An unobserved investment-specific discount rate that is correlated with aggregate uncertainty will yield this result, but would be sufficient to prove real options behavior.

[7] See Dixit and Pindyck (1994) and Abel, et. al. (1996) for more detail on these competing approaches.

for the asset), and the superscript sign represents the expected sign of the effect (e.g., the usual results that the trigger price for new investment is increasing in the discount rate and volatility of returns and decreasing in the convenience yield).[8]

If investors are risk-neutral, the contingent claims solution is similar to that of the Black-Scholes options pricing problem and the discount rate is the risk-free rate of return, usually assumed to be the interest rate on a short-term government security. Alternatively, if investors are risk-averse, but markets are complete, the return on an asset can be derived from the capital asset pricing model (CAPM):

$$\mu = r_f + \phi \rho_{pm} \sigma. \tag{3}$$

Here r_f is the risk-free rate of return, ϕ is the market price of risk, σ is the standard deviation of the excess returns on the asset, and ρ_{pm} is the correlation between excess returns on the asset, in our case real estate, and excess returns for the broader market. Finally, if we assume that markets are in equilibrium but are incomplete and investors are risk averse, we can use a project specific discount rate μ, derived from the dynamic programming solution as the sum of expected capital appreciation and the convenience yield, as follows:

$$\mu \equiv \alpha + \delta. \tag{4}$$

In the empirical work, it is important to properly control for the discount rate, as volatility might reduce the likelihood of investment not because of real options behavior, but instead because investors are risk averse and volatility enters the discount rate directly. For example, in

[8]Ideally, we would be able to observe the exact determinants of all factors that determine P^*, including the cost of development and profitability at each site for each point in time, enabling structural estimation of f. Unfortunately, such variables are difficult to obtain.

the CAPM, systematic risk reduces the likelihood of investment, not due to any effect of irreversible investment, but instead because investors cannot fully hedge systematic or market risk. Below, we choose to include several alternative proxies for the (unobserved) discount rate, including estimates of the risk-free rate, the CAPM discount rate, and a project-specific discount rate derived from the relationship in equation (4). With incomplete markets for real estate assets and many individual investors who are likely risk averse, we would expect that risk factors will play a role. So, for example, the discount rate (μ) should depend, at least in part, on the covariance between the volatility of local real estate prices and aggregate risk, as in the CAPM.

The classic model of volatility and option exercise assumes that prices follow geometric Brownian motion with a constant drift and variance. However, existing empirical work strongly suggests that real estate prices exhibit short-run positive serial correlation and long-run mean reversion.[9] In addition, the volatility of asset returns have been shown to vary over time. Schwartz (1997) uses numerical methods to obtain comparative statics for a model with some of these characteristics. He has stochastic factors in mean reverting prices, mean reverting convenience–dividend-- yields and time-varying interest rates.[10] Schwartz shows that even in this more complicated world, the usual real options results hold except that option values become less sensitive to prices when there is mean-reversion in prices. Lo and Wang (1995) show that even with auto-correlation in returns, the option-pricing formula is unchanged.[11] Heston (1993)

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[9]See Case and Shiller (1989), Meese and Wallace (1993), and Quigley and Redfearn (1999)

[10]Miltersen (2000) solves for a closed form solution for the optimal development path when mean-reverting interest rates and the convenience yield are stochastic. He finds similar qualitative effects, but the option value is lower than in the standard Black-Scholes (1973) framework.

[11]They show that if the unconditional variance of returns is held constant, changes in the predictability of returns implies that the diffusion coefficient must also change over time.

on the other hand derives a closed-form solution for pricing options in a model with stochastic volatility. He finds that, similar to Black-Scholes, a higher variance still increases the price of an option.[12] These papers show that the basic qualitative results of the real options model hold even when the random walk assumption is relaxed and the volatility of returns is taken to be stochastic.

To provide a more accurate description of the evolution of real estate prices, we take advantage of time series changes in the volatility of real estate returns. This allows us to identify the impact of volatility on new construction, while using various controls for changes in expected returns over time. Under this specification, the predicted relationships between option prices and the underlying inputs (spot price, volatility, etc.) still remain, though the closed form solutions are difficult to obtain.

We estimate the hazard rate of investment *h(t)*, the conditional probability of development occurring at time t, as:

$$h(t) = \Pr(Pt \geq Pt^* | Px < Pt^* \forall x < t). \tag{4}$$

Given the current price level, the hazard rate is decreasing in the price trigger P^*. We can therefore estimate a reduced form hazard specification, where the hazard rate is a function of the determinants of P^*, holding the current price level fixed. The hazard has the following empirical specification:

$$h(t) = \exp(X_t{}'\beta)h_0(t) \tag{5}$$

where X_t is a vector of explanatory variables and β is the vector of coefficients to be estimated.

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[12]The stochastic volatility assumption affects the kurtosis and skewness in the distribution of spot returns.

The base model assumes a Weibull distribution for *t;* that is, the baseline hazard rate, h_0, is monotonically increasing or decreasing over time. We examine alternative distributions as well in the empirical results that follow.

IV. DATA DESCRIPTION

The data are 1,297 strata (or condominium) projects with at least four units per project built in the city of Vancouver, Canada between January, 1979 and February, 1998. Projects are identified according to the date that the government responds to the developer's filing of a strata plan to convert the single title for the lot into multiple strata (condominium) titles.[13] By law this can only occur near the completion of construction. We convert the granting of a strata title to the start of construction by introducing a one-year lag in the dependent variable.

Over this period there are several bursts of development activity. Figure 1 shows four peaks in the number of strata real estate projects in 1982, 1986, 1991, and 1996. In addition, there has been a large secular increase in the average project size. The increase in condominium development activity over this time period was much greater than the growth in single family construction. Local commentators describe the mid-1980's as the point at which a broad, general acceptance of the strata form of ownership began, so that over this period the growth in strata project activity exceeded that of single family development.

Table 1 presents the descriptive statistics for the monthly data used in the paper, including

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[13] In British Columbia condominium units are those with a strata title to allocate ownership of the land among the units. Strata title legislation was first enacted in British Columbia in September 1966 and the first units under this legal form were built in 1968. While non-residential strata-titles exist, over 95 percent of strata projects are residential. For discussion of strata title legislation and the first years of strata development in British Columbia see Hamilton (1978).

citywide and neighborhood prices, the volatility of returns, expected price appreciation, the project specific discount rate, systematic risk, and the extent of competition across projects. The construction of these variables is described below. All data are presented in real terms.[14]

We compute a monthly repeat sales index of condominium prices using data obtained from the British Columbia Assessment Authority (BCAA) of all condominium transactions between 1979 to 1998. The repeat sales index has the advantage of controlling for changes in the quality of units sold over time.[15] The index is computed using the geometric repeat sales methodology outlined in Shiller (1991). Figure 2 presents the city-wide real price index for Vancouver condominiums. Our period of analysis covers three clear real estate price cycles. The first is a striking run-up between mid-1980 and mid-1981 followed by a sharp fall ending in mid-1982. The second is the 1988-1990 increase in prices that coincided with the post-Tiananmen Square wave of immigration from Hong Kong. The third is the much more moderate 1991-1994 period of increasing prices. Between 1994 and 1998, real condominium prices in Vancouver fell approximately 15 percent.

In addition, we create separate price indexes for seven sections of the city using BCAA neighborhood boundaries. Three neighborhoods are unique while the other four are amalgamations that are geographically contiguous, demographically similar, and have sufficient

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[14]We deflate with the moving average of the monthly inflation rate for the previous 6 months with declining weights by month.

[15]These condominium data are less susceptible to some of the flaws of repeat sales indexes. First, it is very hard to add to or substantially renovate these units, so unit quality and quantity are more likely to remain constant over time. Second, these units transact more frequently than do single family units, so we discard fewer transactions when requiring that units used for the repeat sales index must sell at least twice over the sample period. See Thibodeau (1997) for a summary of the issues associated with computing real estate price indexes.

transactions to create a monthly price index. We exclude 83 projects in neighborhoods that are difficult to combine into homogenous sub-markets, leaving a total sample of 1,214 units.

To measure uncertainty, we compute a time-varying measure of the volatility of monthly neighborhood returns using a GARCH (1,1) model to estimate the variance of residuals from an autoregressive model of returns on lagged returns. This GARCH specification incorporates the serial correlation in returns and time-varying volatility discussed in the previous section that is more appropriate to real estate prices than geometric Brownian motion. Using conditional maximum-likelihood, we obtain estimates of the conditional variance of returns given past prices, while controlling for the predictability in returns.[16] The structure imposed by GARCH will not change the qualitative predictions of the real options model. Bollerslev, Chou and Kroner (1992) maintain that the simple structure imposed by the GARCH model can be viewed as a reduced form of a more complicated dynamic process for volatility.[17]

We also consider two additional measures of uncertainty. The first is the simple variance in monthly returns over the previous two years. The second is a GARCH specification with a correction for the component of volatility caused by differences in the ratio of repeated sales of the same unit to the total transactions in a month. This latter GARCH measure adjusts for possible differences in the volatility observed by a developer who considers all transactions in the market compared with the volatility measured by a repeat sales index that only includes sales

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[16]This is consistent with Lo and Wang's (1995) assertion that the sample variance of asset returns is not the appropriate volatility input to the Black-Scholes formula. Instead, a volatility adjustment has to be made to account for predictability.

[17] Heston and Nandi (2000) show that a more general form of the GARCH (1,1) process approaches the stochastic volatility model of Heston (1993) in the continuous time limit.

of units that transact at least twice in the sample.[18] The three series of return volatilities are presented in Figures 3a and 3b for 1979-1998 and for the sub period 1986-1998, respectively. Return volatilities are substantially lower in the 1986-1998 period because we exclude the 1981 price spike. The main difference between these measures relates to the ex-post measurement of volatility versus the ex-ante estimation of expected volatility needed for decision-making.[19] We believe that the volatility forecasts from the transactions-adjusted GARCH model is the appropriate measure to use in the regressions that follow, although the same basic results hold for the other measures as well. First, unlike the lagged volatility measure, this measure describes uncertainty in predicting future returns, which is the uncertainty in real options behavior. Second, the adjusted GARCH corrects one of the shortcomings in the underlying repeat sales price index. In Figures 3a and 3b, it is clear that the transaction-adjusted GARCH measure is a lower bound to the two other volatility measures.

The appendix shows the results of the GARCH estimation using transactions-adjusted returns. The coefficients on lagged returns provide evidence of short horizon negative serial correlation, even though underlying real estate returns have positive long-run serial correlation.[20]

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[18] We correct for this potential bias by scaling mean returns to zero and then multiplying the calculated return for a given month by the square root of the ratio of repeat sales transactions to total transactions. The adjusted GARCH measure effectively smooths volatility as the share of sales in the repeat data base falls, offsetting a higher measured variance in months where we have relatively fewer repeat sales. We thank Bob Shiller for pointing out this issue and suggesting this correction.

[19] See Andersen, Bollerslev & Diebold (2002) for a survey of the different parametric and non-parametric volatility estimation techniques.

[20] The coefficients on lagged returns are negative in all neighborhoods. This finding is consistent with what often happens with a repeat sales index of real estate prices. The presence of an unusually high price in one period "biases" the index upward in the current period, resulting in a negative return next period. See Case and Shiller (1989) for a discussion of price indexes and serial correlation in real estate returns.

The repeat sales indexes have the characteristic that estimated volatility is higher, on average, during periods when the underlying index has fewer transactions. We believe that this pattern captures an important source of uncertainty faced by developers. In the typical search model, a thin market with relatively few transactions of heterogenous properties has greater underlying price uncertainty than a thick market with many transactions of relatively homogeneous properties. In a thinner market, developers will have more difficulty extracting signal from noise.

We compute expected price appreciation, α, from an auto-regressive process up to order three for each of the neighborhood return series. Expected price appreciation (the drift rate) is the one month ahead return forecast from this specification. The project specific discount rate is defined as the sum of expected price appreciation, α, and the dividend yield, δ, as in equation (4). The dividend yield is obtained from a quality-controlled rent series from neighborhood level CMHC (Canada Mortgage Housing Corporation) surveys. Unfortunately, we only observe neighborhood rents once or twice a year, not monthly like the rest of the data used in the analysis.

Finally, we measure exposure to market volatility, as in the CAPM, by multiplying monthly Toronto Stock Exchange (TSE) 300 stock market returns by a time varying measure of β, the covariance between excess returns in the Vancouver condo market and the TSE 300. To estimate a time varying measure in the CAPM beta we use Cleveland and Devlin's (1988) locally weighted regression methodology. This non-parametric specification estimates β using a weighted sub-sample of the time series, with heaviest weights on the closest time periods.[21]

[21]For each month, the excess neighborhood returns are regressed against excess TSE 300 returns using the nearest 60% of months as the sample. These observations are weighted using a tri-cubic function so that the weight for a month declines with distance in time from the month for which we are

V. EMPIRICAL RESULTS

As described above, our empirical hazard specification depends on the baseline hazard and a vector of explanatory variables *X*. From (5), the coefficient on a variable *X* is the proportional effect on the hazard rate of a unit change in *X*. A coefficient greater than one suggests that an increase in the variable has a positive impact on the baseline hazard--that is, a higher probability of development--while a coefficient less than unity implies the reverse effect.[22] Robust standard errors (Huber/White estimator of variance) are calculated that allow for the correlation across time in the hazard rate of individual projects.

One complication is that we do not observe the start of construction. By the time the developer has filed a strata plan, the building is mostly completed and ready for sale. However, the irreversible investment–option exercise–takes place months earlier when the developer begins physical construction of the project. To compensate, the date of our dependent variable is lagged by one year to reflect the time required for physical construction. Somerville (2001) shows that 59 percent of new multi-family projects are completed within one year of the start of construction. This built-in lag also reduces or eliminates any possible problems relating to simultaneity between prices and new construction. Reducing the lag length to six or nine months has little impact on the results. To control for differences in construction time, we include linear, quadratic and cubic terms for project size in the regressions.

The analysis below must also address possible censoring in projects that actually file a

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estimating the beta.

[22]In the regressions below, a one unit change in X leads to a *(β-1)* percent change in the hazard rate.

strata plan. For example, a developer may start and subsequently abandon a project prior to filing a strata plan. Extensive discussion with market participants suggests that once construction begins, such a scenario is relatively uncommon in this market.[23] Abandonment is rare, in part, because it involves extinguishing a valuable put option on the completed project. Most new developments use relatively high leverage. Once a project has been granted financing, loan agreements typically make future draws on the construction loan contingent on reaching certain (engineering) stages in the construction process. Given that the developer has put his own money into the project up front, if the developer stops prior to completion, he will likely lose all of his equity. If the developer continues with the project, there is always a chance that the market will improve. In this case there is a nearly costless put option that is extinguished by abandoning prior to completion. Even so, we address the possible impact of actual censoring by artificially censoring the data on our own. As described below, our results are unchanged under these circumstances.

A. Base Specification

The first three columns of Table 2 present maximum likelihood estimates for our base specification with the alternative measures of the project discount rate, μ. All regressions use neighborhood level prices and volatilities and also include building type and neighborhood fixed effects and controls for project size. The regression coefficients are generally of the expected sign for the real options model and are almost uniformly statistically different from one. Not

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[23] Somerville (2001) finds that new information on market conditions and demand shocks have no effect on the rate at which units under construction are completed, conditional on the number of units started. It is more common that developers start preliminary work on zoning and permitting issues and then abandon before permits are even issued.

surprisingly, developers choose to develop a parcel more quickly when neighborhood prices are higher. Price coefficients are greater than one in six of the seven neighborhoods and statistically significant in five of those neighborhoods. Even controlling for prices, however, the coefficient on the volatility of condo returns is less than one and statistically significant at the 95 percent confidence level in all specifications, suggesting that developers wait longer to develop when the volatility of returns is higher. The coefficients on volatility suggest economically important effects. In column (1), a one standard deviation increase in the condo return volatility (35 percent) decreases the monthly hazard rate of development by 13 percent. Evaluated with the average neighborhood price coefficient of 1.014, this increase in volatility is equivalent to a 9 percent decrease in prices.[24]

We choose not to include the convenience yield δ in these regressions, instead substituting with the expected price appreciation α, as in equation (4). We do so because our measure of the convenience yield--quality controlled rents on a neighborhood basis--varies only once or twice a year. As well, the presence of a changing rent control regime also makes it difficult to identify the correct δ. We find that the drift rate α, has little impact on the probability of development. Finally, the risk-free interest rate, measured as the real short-term Canadian T-Bill rate, has a large impact on construction. A one percentage point increase in the risk-free rate leads to a 52 percent decline in the monthly hazard rate.

In column (2) we include a separate control for systematic risk based on the CAPM,

[24] Papers on housing supply such as DiPasquale and Wheaton (1994) and Mayer and Somerville (2000) find that controlling for house prices, starts or permits consistently fall in non-price measures of demand such as expected time to sale. We also run the model including the level and volatility of two other measures of demand, existing single family home sales and the ratio of units listed for sale to actual sales. We find that increases in the volatility of sales or the ratio of listings to sales also leads to a statistically significant decline in the hazard rate.

where ρ is measured as the risk-free interest rate plus a control for the risk premium that equals time-varying β multiplied by the volatility of the TSE 300 index. As expected, adding market volatility decreases the effect of idiosyncratic volatility somewhat–the coefficient on idiosyncratic volatility moves closer to one, from 0.9961 to 0.9968, but it remains statistically different from one and economically important. The coefficient on market volatility is 0.8371 and is statistically different from one with 90 percent confidence. In this case, a one standard deviation increase in the average market volatility across the neighborhoods leads to an 8 percent decline in the hazard rate, while an equivalent one standard deviation increase in idiosyncratic volatility leads to a 11 percent decrease in the hazard rate.

Our measure of the project specific discount rate does not do as well as the other proxies for the actual discount rate. The third column measures the project specific discount rate as the sum of the dividend yield and expected short-term appreciation. The former, as explained above, is measured from a quality-controlled rents series and the latter variable is estimated from an AR regression on past real estate condo returns. There are a number of possibilities why the project specific discount rate does not perform very well. First, this measure of ρ does not exhibit much time series variation in the dividend flow, so it is strongly correlated with α. In addition, as noted above, the model that uses this measure of the project specific discount rate makes the questionable assumption that the real estate market is in perpetual equilibrium. Previous research (Case and Shiller 1989 and Meese and Wallace 1993) suggests that real estate markets exhibit important periods where prices are inefficiently determined over the real estate cycle. As a result, the remaining regressions use the second measure of the discount rate (column 2) based on the CAPM, so that the project discount rate is equivalent to the risk free rate plus an adjustment for market risk.

An insignificant coefficient on α, the expected price appreciation parameter, is consistent with the standard real options model in which the hurdle rate is independent of the drift rate. However, one might be concerned that volatility is picking up factors related to periods of rapidly increasing or decreasing prices that might have an independent effect on investment. For example, given the positive short-run serial correlation in prices that has been documented in many markets, a developer might choose to delay construction in anticipation of further short-run price increases. Alternatively, rising prices can provide capital gains that allow developers to overcome liquidity constraints, enabling them to pursue a larger number projects. Thus future expected price increases might lead to a greater hazard rate of new construction.

More interestingly, Grenadier (1996) raises the possibility that falling prices could also trigger a cascade of development. In a game theoretic model with two owners of competing parcels, Grenadier demonstrates the existence of a "panic" equilibrium where developers each race to build before prices fall too far. As in the prisoner's dilemma, both developers choose to build rather than be preempted. In the Grenadier framework, holding the price level constant, both expected price increases and decreases can spur development activity.

In column (4) we differentiate between positive and negative expected price appreciation. These variables are calculated by multiplying α by a dummy variable that equals one if α is positive (negative) and zero otherwise. In fact, the inclusion of these terms does not affect the coefficient on volatility. However, the coefficient on positive expected price appreciation is above one while the coefficient on negative expected price appreciation is less than one, with both coefficients significant at the 5 % level. These results suggest that holding price constant, development is more likely when prices are rising faster *and* when prices are falling faster. For the latter, the coefficient interacts with negative price changes to produce the positive effect on the hazard. This result supports Grenadier's strategic behavior analysis of the "price equilibrium" as well as arguments for increased development during periods of rapid price changes.

In Table 3 we test for robustness, running these regressions over different time periods and for different hazard distributions. Over a three year period (1981-83) real prices in Vancouver rose by 100% and then fell to their original level. Elevated volatility over this period could dominate the data and drive the relationship between volatility and new construction. In column (1) we run the model using data from 1986-98 only. The statistical significance of prices drops considerably in this later time period, but the coefficient on the volatility of condo returns remains below one and is statistically significant at the 10 percent level. The coefficients on the risk free rate and overall market volatility are also below one and are highly significant. In the second column, we truncate the sample in 1994, by including all projects developed after 1994 as artificially censored projects; to test for any censoring bias that may be due to the abandonment of projects that we do not observe. Again, although the statistical significance of prices is slightly reduced, the findings for volatility remain unchanged. The coefficient on the risk free rate, however, is now significant only at the 10 percent level, while the coefficient on systematic risk is not significant at all.

In column (3) we rerun the base specification using an exponential distribution for the underlying hazard, which assumes a constant baseline hazard rate. In column (4) we use the lognormal distribution, which allows the baseline hazard rate to be single-peaked. The latter is estimated in accelerated failure time and coefficients are reported in exponentiated form, so positive coefficients lead to increases in survival time (decrease in the hazard rate) and negative coefficients indicate a decrease in survival time. In both specifications the coefficients on systematic and idiosyncratic volatility are statistically significant, so increases in volatility lead to decreases (increases) in the hazard (survival) rate. The real risk free rate also has the expected sign and is statistically significant. The data suggest that the Weibull is the preferred specification. The log likelihood in both specifications increases in absolute value from the Weibull specification. In all Table 2 specifications, the log-likelihood test strongly rejects the hypothesis that the estimated Weibull parameter is equal to unity, supporting the assumption of an increasing baseline hazard. We use the Weibull specification in the remaining regressions.

B. Competition

We now examine the impact of competition on real option exercise. This allows us to test the theoretical predictions that increases in competition reduce the value of the option to wait. In the regressions above we control for a variety of factors that might be part of the project specific user cost, but are unrelated to the option to develop. Nonetheless, it remains possible that idiosyncratic volatility impacts investment through risk-averse investors, rather than through a higher hurdle rate on the call option to make an irreversible investment. In this case, our measure of idiosyncratic risk would capture the effects of excluded components of this user cost, suggesting that risky projects demand a higher risk premium in the calculation of the investment's present value. The effect of competition on option exercise offers a test of this hypothesis because the correlation between uncertainty and unobserved portions of the user costs should not be related to the degree of competition faced by a project. If anything, competition might even increase the expected volatility of future cash flows given uncertainty about the behavior of each of those competitors, making investment appear more sensitive to volatility. To test these models, we examine the coefficients on the interaction between competition and uncertainty.

We measure competition by the number of competing projects within a given distance of each development site. At each point in time that project *i* in our sample has not yet been developed, we count the number of other potential, but as of yet unbuilt, projects within a one or two kilometer radius from project *i*. This measure is the actual number of all future developments that will be built around the development site *i*. To address the problem that our measure of competition naturally leads to a reduction in the number of competitors as time moves closer to the end of the sample, we include all projects in the sample up to 1998, but run the regressions only up to 1994. Furthermore, we compare the results using alternative measures of the relevant time horizon, counting all the projects that will be built in the future in our data and only those to be built in the next 4 years.

Table 4 presents regressions that include the various measures of competition, a variable for volatility, plus an interaction term for competition and condo return volatility. The results are consistent with theoretical prediction that competition reduces the value of the option to wait. In all four columns, the coefficient on volatility is below one and significant, while the coefficient on the interaction between competition and condo return volatility is greater than one and significant at the 10% level or better suggesting that volatility has a smaller impact on option exercise in locations that face greater potential competition. Consider the estimates in column (2), where competition is measured as the number of projects four years into the future within a one kilometer radius. At the mean number of potential projects, a one standard deviation increase in volatility leads to a 12.6 percent decline in new construction, which is slightly bigger than our earlier estimates. However, if the number of competitors increases by 50 percent, the same one standard deviation increase in volatility only leads to a 7.1 percent decrease in the hazard rate. Thus as a project is surrounded by more competitors, its hazard rate of construction becomes less sensitive to volatility. Competition appears to operate only by reducing the impact of volatility. In all cases, the coefficient on competition itself is never close to statistical significance at conventional levels. Other coefficients are of the expected signs and are similar to the base regressions in Table 2.

As an alternative, Table 5 measures competition as the number of condominium units in each potential project, and not just the number of potential projects. In this sense we differentiate between large and small projects, and also account for the increase in project size over time. Nonetheless, the impact of competition on volatility remains unchanged. In all columns, the interaction between the number of competitors and volatility is above one and significant at the 8 percent level or better and the coefficient on volatility is below one and highly significant as well. The coefficients on prices and other coefficients are all similar to the previous table's results.

VI. CONCLUSION

The results in this paper support many of the conclusions from the burgeoning theoretical literature on the importance of real options in explaining irreversible investment. We use data on 1,214 condominium projects with more than four units built in seven neighborhoods of Vancouver, Canada between 1979 and 1998, along with relatively precise measures of output prices, to estimate a hazard rate of development. Our empirical estimates suggest that builders delay development during times of greater idiosyncratic uncertainty in real estate returns and when the exposure to market risk is higher. These findings hold across different time periods. The impact of volatility in our sample is economically significant. A one standard deviation increase in condominium return volatility leads to a 13 percent decline in the hazard rate of investment, the same effect as a 9 percent decline in prices. Similarly, our estimates suggest that the hazard rate falls 8 percent when exposure to systematic risk increases by one standard deviation.

We also show that competition significantly reduces the sensitivity of option exercise to volatility. Increases in competition appreciably decrease the coefficient on volatility in our hazard rate specification. In fact, volatility has no estimated effect on option exercise for the 5 percent of the project-months in our sample with the largest number of potential competitors. This finding is fully consistent with Caballero (1991), Trigeorgis (1996) and Grenadier (2002) who argue that competition diminishes the value of waiting to invest. The erosion in value of the investment opportunity due to one's competitors creates incentives to invest earlier. Hence competitive firms are not able to capture the full benefits to waiting that a monopolist has. This result supports the real options model because the link between competition and volatility should not affect the user cost of a reversible investment. In this way we provide clearer evidence in favor of the real options model.

From a policy perspective, these results have important implications for understanding real estate cycles. An often-repeated claim in the real estate industry is that overbuilding in the real estate industry is due to irrational developers. Grenadier (1996) has suggested a rational basis for the bursts of construction that sometimes occur just as market prices begin to fall–strategic behavior by competing developers in imperfectly competitive markets. We find some evidence in favor of the Grenadier model; holding the level of prices constant, builders appear more likely to build when prices begin to fall.

More important, however, is the observation that the volatility of returns, exposure to market risk, and competition play important roles in the timing of investment. Builders are especially susceptible to business cycle shocks, as developer bankruptcies rise considerably in recessions. If competition is less pronounced in recessions, real options behavior may lead developers to delay irreversible investments in structures longer than they would in booms when markets are more competitive. Given that changes in investment are an important component in the business cycle, these results suggest that uncertainty and competition may play a role in understanding cyclical movements in investment in real estate and the macro economy.

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Table 1 - Descriptive Statistics: 1979-98

Variable	Location	Mean	Std	Min	Max
Real Condo Price (p)	Citywide	99.0	16.3	75.6	152.9
Real Condo Price (p)	Neigh. 1 (2)	107.0	19.6	76.9	165.5
Real Condo Price (p)	Neigh. 2 (7)	96.8	15.7	67.1	164.1
Real Condo Price (p)	Neigh. 3 (13)	94.3	19.5	63.9	157.9
Real Condo Price (p)	Neigh. 4 (40)	109.1	16.1	76.4	156.5
Real Condo Price (p)	Neigh. 5 (50)	93.1	17.8	56.4	158.5
Real Condo Price (p)	Neigh. 6 (51)	93.0	17.3	59.2	149.9
Real Condo Price (p)	Neigh. 7 (61)	105.7	17.9	70.6	163.8
expected price appreciation (alpha)	Citywide	-0.04	1.61	-4.87	8.96
expected price appreciation (alpha)	Neigh. 1 (2)	0.05	1.10	-2.76	8.99
expected price appreciation (alpha)	Neigh. 2 (7)	-0.05	2.36	-8.08	8.99
expected price appreciation (alpha)	Neigh. 3 (13)	0.05	1.88	-6.30	6.89
expected price appreciation (alpha)	Neigh. 4 (40)	-0.04	3.81	-11.51	12.95
expected price appreciation (alpha)	Neigh. 5 (50)	0.15	1.88	-6.19	6.71
expected price appreciation (alpha)	Neigh. 6 (51)	0.18	2.97	-6.19	6.71
expected price appreciation (alpha)	Neigh. 7 (61)	-0.07	3.83	-13.56	10.93
project specific discount rate (rho)	Citywide	0.31	1.61	-4.35	9.48
project specific discount rate (rho)	Neigh. 1 (2)	0.33	1.10	-2.44	4.39
project specific discount rate (rho)	Neigh. 2 (7)	0.28	2.37	-7.71	9.44
project specific discount rate (rho)	Neigh. 3 (13)	0.46	1.89	-5.65	7.51
project specific discount rate (rho)	Neigh. 4 (40)	0.34	3.81	-11.22	13.40
project specific discount rate (rho)	Neigh. 5 (50)	0.46	1.89	-5.82	7.17
project specific discount rate (rho)	Neigh. 6 (51)	0.49	2.97	-13.06	11.20
project specific discount rate (rho)	Neigh. 7 (61)	0.19	3.83	-19.99	22.17
systematic risk = market volatility * beta	Citywide	0.65	0.39	0.10	2.25
systematic risk = market volatility * neigh. beta	Neigh. 1 (2)	0.42	0.47	-0.54	1.44
systematic risk = market volatility * neigh. beta	Neigh. 2 (7)	0.65	0.45	-0.18	2.56
systematic risk = market volatility * neigh. beta	Neigh. 3 (13)	0.39	0.18	0.02	1.44
systematic risk = market volatility * neigh. beta	Neigh. 4 (40)	0.91	0.45	0.09	2.85
systematic risk = market volatility * neigh. beta	Neigh. 5 (50)	1.10	0.50	0.44	3.01
systematic risk = market volatility * neigh. beta	Neigh. 6 (51)	0.74	0.33	0.20	2.26
systematic risk = market volatility * neigh. beta	Neigh. 7 (61)	0.66	0.79	-0.60	3.95
Garch - Condo Return Variance	Citywide	8.90	8.52	1.09	37.2
Garch - Condo Return Variance	Neigh. 1 (2)	21.3	16.9	6.05	96.2
Garch - Condo Return Variance	Neigh. 2 (7)	30.3	37.0	3.42	184.5
Garch - Condo Return Variance	Neigh. 3 (13)	29.4	24.4	9.30	146.0
Garch - Condo Return Variance	Neigh. 4 (40)	43.1	49.1	14.4	466.5
Garch - Condo Return Variance	Neigh. 5 (50)	32.6	28.3	2.56	106.3
Garch - Condo Return Variance	Neigh. 6 (51)	26.3	27.2	4.29	129.6
Garch - Condo Return Variance	Neigh. 7 (61)	43.8	59.6	3.98	356.1
# of Projects, 2 km radius, remaining time period	Citywide	170	131	0	578
# of Projects, 2 km radius, 5 years forward	Citywide	72	53	0	211
# of Projects, 1 km radius, remaining time period	Citywide	62	49	0	220
# of Projects, 1 km radius, 5 years forward	Citywide	27	22	0	95
# of Units, 2 km radius, remaining time period	Citywide	7,137	5,846	0	23,319
# of Units, 2 km radius, 5 years forward	Citywide	2,248	2,079	0	12,771
# of Units, 1 km radius, remaining time period	Citywide	2,437	2,423	0	12,944
# of Units, 1 km radius, 5 years forward	Citywide	809	933	0	8,382

Table 2 -- Hazard Specification: Time to Develop a New Site

Hazard is estimated using a Weibull distribution

(Z-statistics in parentheses, except where noted)

Variable	Reg. (1)	Reg. (2)	Reg. (3)	Reg. (4)
Real condo price - neighbor 2	0.9997	1.0021	1.0007	1.0020
	-(0.10)	(0.61)	(0.17)	(0.60)
Real condo price - neighbor 7	1.0075	1.0067	1.0083	1.0066
	(1.84)	(1.66)	(1.72)	(1.64)
Real condo price - neighbor 13	1.0225	1.0223	1.0233	1.0239
	(5.79)	(6.00)	(4.74)	(6.24)
Real condo price - neighbor 40	1.0057	1.0062	1.0065	1.0060
	(1.10)	(1.22)	(1.12)	(1.21)
Real condo price - neighbor 50	1.0266	1.0263	1.0271	1.0269
	(8.85)	(8.92)	(7.37)	(8.98)
Real condo price - neighbor 51	1.0202	1.0198	1.0209	1.0197
	(4.03)	(3.98)	(3.65)	(4.07)
Real condo price - neighbor 61	1.0167	1.0182	1.0168	1.0185
	(4.98)	(5.19)	(4.30)	(5.15)
Garch condo return variance	0.9961	0.9968	0.9963	0.9944
	-(2.61)	-(2.08)	(2.47)	-(3.21)
Risk free rate	0.4824	0.4685		0.463
	-(4.67)	-(4.80)		-(4.94)
Expected Price Appreciation	0.9934	0.9941	0.685	
	-(0.52)	-(0.47)	-(0.42)	
Positive Expected Price Appreciation				1.057
				(2.39)
Negative Expected Price Appreciation				0.9386
				-(2.59)
Systematic risk		0.8371		0.8437
		-(1.86)		-(1.78)
Project specific discount rate			1.4482	
			(0.41)	
Weibull parameter	1.90	1.84	1.87	1.82
(standard error)	(0.07)	(0.07)	(0.07)	(0.07)
No. of Subjects	1214	1214	1214	1214
Log Likelihood	-1112	-1110	-1121	-1106

Notes

1) All regressions include building type and neighborhood fixed effects and linear, quadratic and cubic variables measuring project size.
2) All price variables are in real dollars.

Table 3 -- Robustness Tests - Different Years & Different Distributions
Hazard is estimated using a Weibull distribution

(Z-statistics in parentheses, except where noted)

Variable	Reg. (1)	Reg. (2)	Reg. (3)	Reg. (4)
Real condo price - neighbor 2	0.9986	0.9948	1.0101	0.0033
	-(0.17)	-(1.30)	(3.68)	(1.32)
Real condo price - neighbor 7	0.9594	1.0039	1.0069	0.0029
	-(3.45)	(0.93)	(1.82)	(1.16)
Real condo price - neighbor 13	1.0104	1.0188	1.0255	-0.0121
	(1.34)	(4.55)	(7.77)	-(4.94)
Real condo price - neighbor 40	0.9888	1.0006	1.0143	0.0008
	-(1.06)	(0.10)	(3.66)	(0.21)
Real condo price - neighbor 50	0.9994	1.0231	1.0283	-0.0135
	-(0.07)	(7.55)	(10.79)	-(6.15)
Real condo price - neighbor 51	0.9993	1.0166	1.0271	-0.0075
	-(0.06)	(3.07)	(6.06)	-(1.70)
Real condo price - neighbor 61	1.0194	1.0151	1.0286	-0.0061
	(2.52)	(4.17)	(8.11)	-(2.25)
Garch condo return variance	0.9911	0.9964	0.9863	0.0024
	-(1.67)	-(2.34)	-(7.58)	(2.81)
Risk free rate	0.5960	0.7346	0.6390	0.7765
	-(2.79)	-(1.69)	-(2.73)	(3.60)
Expected Price Appreciation	1.0135	0.9845	1.0049	0.0060
	(0.62)	-(1.21)	(0.34)	(0.72)
Systematic risk	0.3405	0.9235	0.4890	0.2955
	-(5.80)	-(0.85)	-(7.49)	(3.60)
Hazard Specification	Weibull	Weibull	Exponential	Lognormal
Weibull parameter	1.91	1.65		
(standard error)	(0.16)	(0.07)		
No. of Subjects	760	1214	1214	1214
Log Likelihood	-727	-1281	-1199	-1328
Years of Analysis	1986-1998	1979-1994*	1979-1998	1979-1998

Notes

1) All regressions include building type and neighborhood fixed effects and linear, quadratic and cubic variables measuring project size.
2) All price variables are in real dollars.
3) *Sample is artificially censored in 1994.
4) Coefficients for the Lognormal Distribution are reported in Accelerated Failure Time Form

Table 4 -- Hazard Specification with Competition Measured by Number of Projects
Time to Develop a New Site
Hazard is estimated using the Weibull distribution
1979-94

(Z-statistics in parentheses, except where noted)

Variable	**Reg. (1)**	**Reg. (2)**	**Reg. (3)**	**Reg. (4)**
Competition Measure	**Number of Projects**			
	Infinite Horizon 2 km. Radius	4 Year Horizon 2 km. Radius	Infinite Horizon 1 km. Radius	4 Year Horizon 1 km. Radius
Real condo price - neighbor 2	0.9938	0.9945	0.9941	0.9948
	-(1.51)	-(1.36)	-(1.45)	-(1.31)
Real condo price - neighbor 7	1.0011	1.0018	1.0013	1.0019
	(0.27)	(0.44)	(0.33)	(0.45)
Real condo price - neighbor 13	1.0182	1.0189	1.0188	1.0198
	(4.41)	(4.55)	(4.50)	(4.66)
Real condo price - neighbor 40	1.0016	1.0020	1.0018	1.0025
	(0.27)	(0.33)	(0.31)	(0.43)
Real condo price - neighbor 50	1.0246	1.0245	1.0247	1.0246
	(7.43)	(7.42)	(7.42)	(7.37)
Real condo price - neighbor 51	1.0178	1.0177	1.0175	1.0179
	(3.07)	(3.11)	(3.04)	(3.16)
Real condo price - neighbor 61	1.0143	1.0153	1.0142	1.0152
	(3.96)	(4.18)	(3.98)	(4.15)
Garch condo return variance	0.9913	0.9932	0.9918	0.9933
	-(3.25)	-(2.63)	-(3.00)	-(2.55)
No. of Competitors*Garch condo return variance	1.00002	1.00005	1.00006	1.00012
	(2.89)	(1.84)	(2.44)	(1.75)
Number of Competitors	0.9996	0.9998	0.9998	1.0032
	-(0.63)	-(0.09)	-(0.09)	(0.84)
Risk free rate	0.7669	0.7463	0.7583	0.7425
	-(1.44)	-(1.59)	-(1.50)	-(1.61)
Expected Price Appreciation	0.9825	0.9824	0.9828	0.9822
	-(1.33)	-(1.34)	-(1.31)	-(1.35)
Systematic risk	0.9568	0.9225	0.9395	0.9160
	-(0.47)	-(0.85)	-(0.66)	-(0.92)
Weibull parameter	1.68	1.66	1.71	1.67
(standard error)	(0.08)	(0.07)	(0.08)	(0.07)
No. of Subjects	1214	1214	1214	1214
Log Likelihood	-1273	-1276	-1274	-1273

Notes

1) All regressions include building type and neighborhood fixed effects and linear, quadratic and cubic variables measuring project size.
2) All price variables are in real dollars.
3) The full sample is artificially censored in 1994.

Table 5 -- Hazard Specification with Competition Measured by Number of Units
Time to Develop a New Site
Hazard is estimated using the Weibull distribution
1979-94

(Z-statistics in parentheses, except where noted)

Variable	**Reg. (1)**	**Reg. (2)**	**Reg. (3)**	**Reg. (4)**
Competition Measure	**Number of Units**			
	Infinite Horizon 2 km. Radius	4 Year Horizon 2 km. Radius	Infinite Horizon 1 km. Radius	4 Year Horizon 1 km. Radius
Real condo price - neighbor 2	0.9949	0.9943	0.9952	0.9942
	-(1.27)	-(1.42)	-(1.19)	-(1.43)
Real condo price - neighbor 7	1.0024	1.0016	1.0034	1.0023
	(0.58)	(0.38)	(0.82)	(0.57)
Real condo price - neighbor 13	1.0193	1.0181	1.0197	1.0192
	(4.63)	(4.17)	(4.69)	(4.44)
Real condo price - neighbor 40	1.0024	1.0019	1.0020	1.0021
	(0.40)	(0.32)	(0.35)	(0.35)
Real condo price - neighbor 50	1.0250	1.0237	1.0243	1.0236
	(7.45)	(7.29)	(7.53)	(7.33)
Real condo price - neighbor 51	1.0182	1.0174	1.0175	1.0174
	(3.17)	(3.10)	(3.12)	(3.15)
Real condo price - neighbor 61	1.0135	1.0122	1.0142	1.0120
	(3.88)	(3.19)	(4.09)	(3.10)
Garch condo return variance	0.9911	0.9939	0.9937	0.9945
	-(3.35)	-(2.65)	-(3.00)	-(2.55)
No. of Competitors*Garch condo return variance	1.000001	1.000002	1.000001	1.000003
	(2.86)	(1.93)	(2.16)	(1.77)
Number of Competitors	0.99998	1.000039	1.00000	1.00012
	-(1.06)	(1.53)	(0.01)	(2.45)
Risk free rate	0.7497	0.7893	0.7334	0.7836
	-(1.58)	-(1.29)	-(1.70)	-(1.33)
Expected Price Appreciation	0.9842	0.9839	0.9850	0.9836
	-(1.24)	-(1.26)	-(1.19)	-(1.28)
Systematic risk	0.9168	0.9219	0.9016	0.9297
	-(0.93)	-(0.86)	-(1.09)	-(0.76)
Weibull parameter	1.62	1.61	1.65	1.62
(standard error)	(0.07)	(0.07)	(0.07)	(0.07)
No. of Subjects	1214	1214	1214	1214
Log Likelihood	-1274	-1273	-1276	-1271

Notes

1) All regressions include building type and neighborhood fixed effects and linear, quadratic and cubic variables measuring project size.
2) All price variables are in real dollars.
3) The full sample is artificially censored in 1994.

APPENDIX

Table A1 -- GARCH Estimation Results for the Volatility of Adjusted Condo Returns: 1975-1998

(z-statistics in parentheses, except where noted)

Variable	**Reg. (1)**	**Reg. (2)**	**Reg. (3)**	**Reg. (4)**
Return Equation	Neighborhood 2	Neighborhood 7	Neighborhood 13	Neighborhood 40
AR(1)	-0.2952	-0.3377	-0.4197	-0.5334
	-(5.01)	-(5.24)	-(5.55)	-(7.12)
AR(2)		-0.1286		
		-(1.83)		
AR(3)		-0.2005		
		-(2.65)		
Variance Equation				
ARCH(1)	0.1309	0.1450	0.1702	0.6052
	(4.18)	(3.26)	(2.57)	(5.53)
GARCH(1)	0.8540	0.8450	0.7948	0.2890
	(27.27)	(23.83)	(9.84)	(4.06)
Number of Observations	271	273	237	264
Wald Statistic	25.05	31.57	30.76	50.66
(p-value)	(0.00)	(0.00)	(0.00)	(0.00)

(z-statistics in parentheses, except where noted)

Variable	**Reg. (5)**	**Reg. (6)**	**Reg. (7)**
Return Equation	Neighborhood 50	Neighborhood 51	Neighborhood 61
AR(1)	-0.4364	-0.4718	-0.4892
	-(5.95)	-(6.79)	-(8.54)
AR(2)	-0.1329	-0.1413	-0.2730
	-(2.20)	-(1.95)	-(3.76)
Variance Equation			
ARCH(1)	0.0626	0.0870	0.2379
	(3.06)	(3.04)	(3.49)
GARCH(1)	0.9266	0.8943	0.7584
	(52.06)	(25.49)	(13.95)
Number of Observations	236	230	267
Wald Statistic	36.11	47.42	73.05
P-value	(0.00)	(0.00)	(0.00)

Notes

1) Adjusted returns are calculated by multiplying the monthly condo return by the square root of the ratio of repeat sales to total sales in a given month .

2) A constant term is included in both equations for returns and conditional variances.

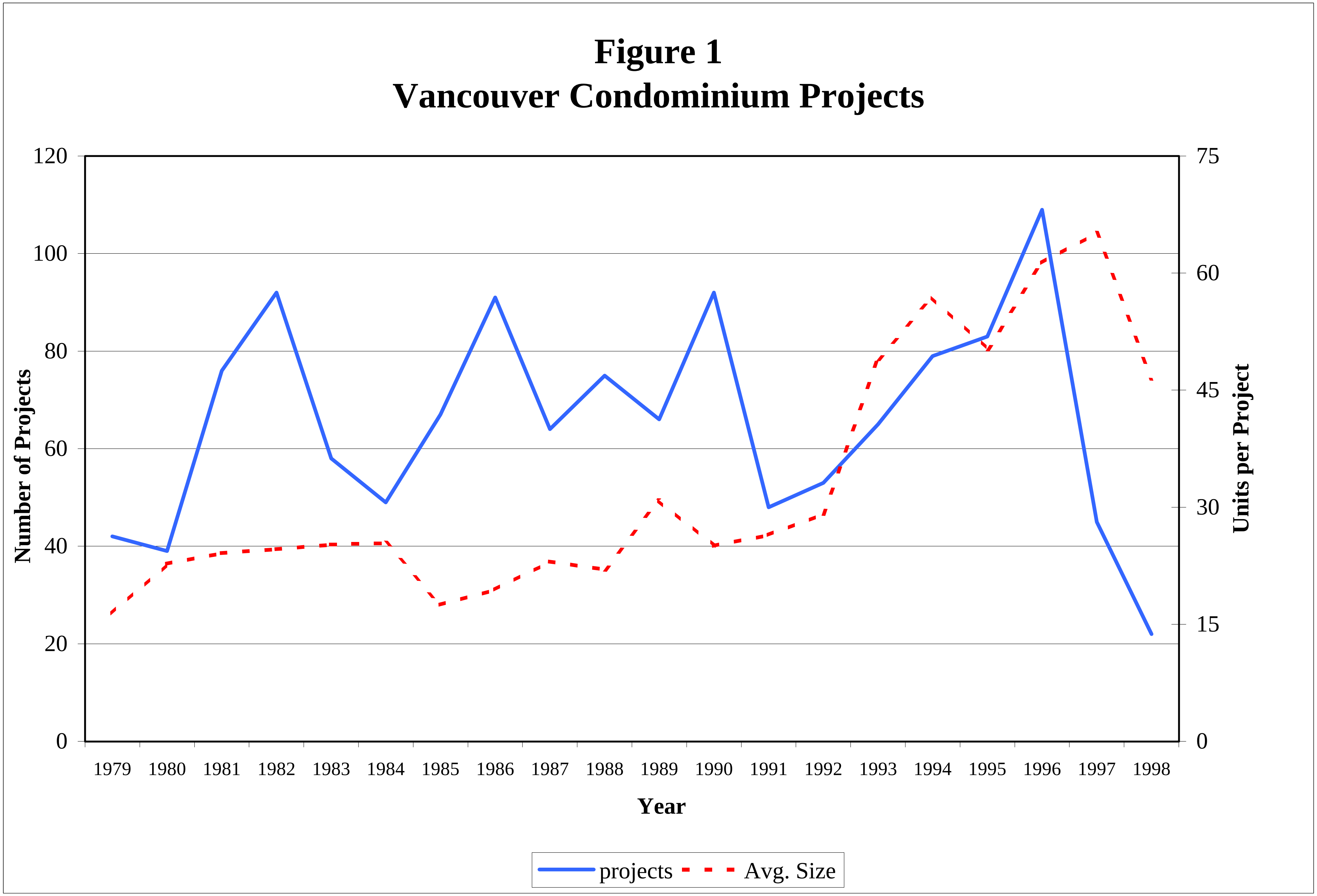
Figure 1
Vancouver Condominium Projects
120
100
80
60
40
20
0
75
60
45
30
15
0
Number of Projects
Units per Project
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
Year
projects
Avg. Size

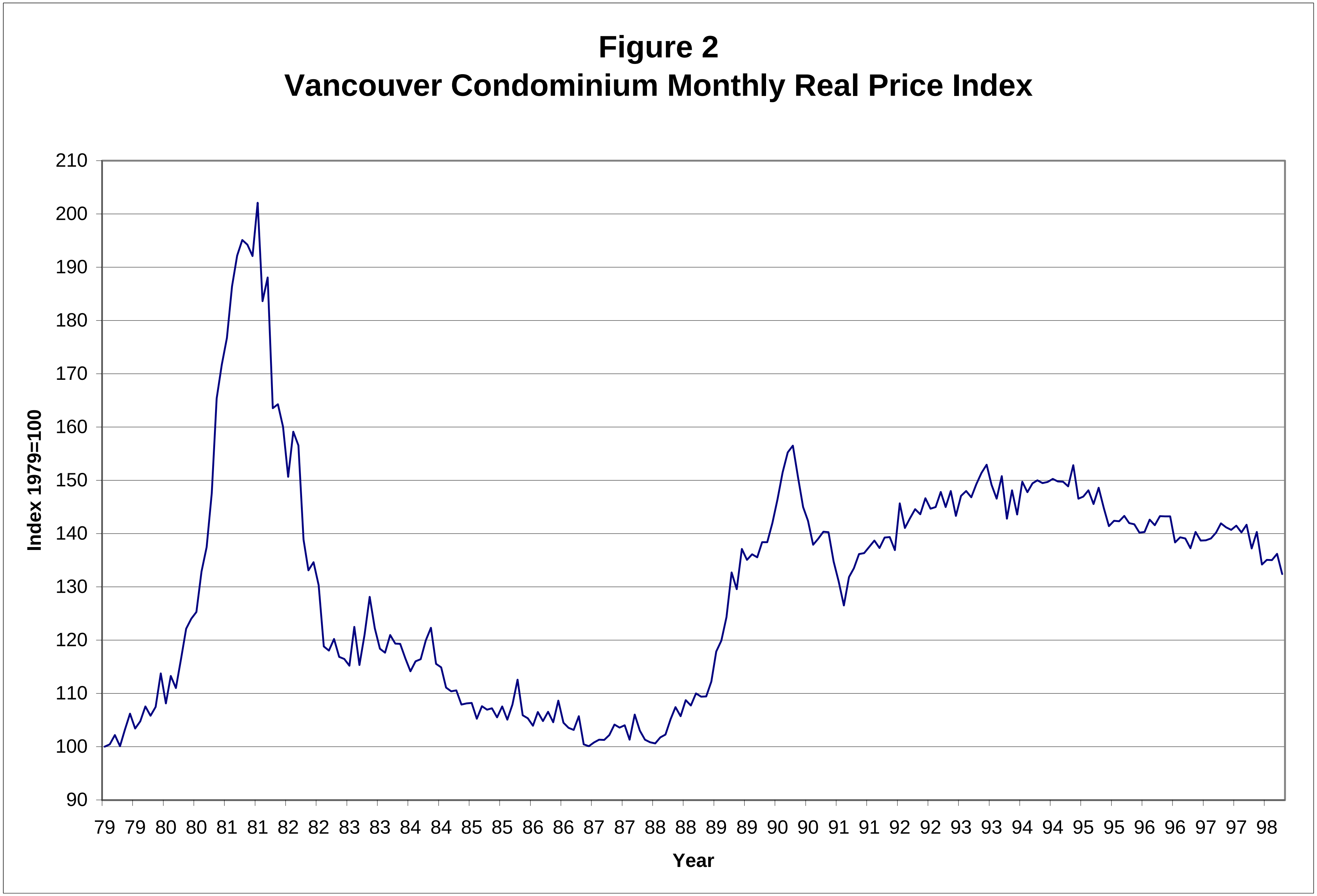
Figure 2
Vancouver Condominium Monthly Real Price Index
Index 1979=100
210
200
190
180
170
160
150
140
130
120
110
100
90
79 79 80 80 81 81 82 82 83 83 84 84 85 85 86 86 87 87 88 88 89 89 90 90 91 91 92 92 93 93 94 94 95 95 96 96 97 97 98
Year

Figure 3a
Estimated Time Varying Volatility of Returns on Real Condo Prices
1979-98

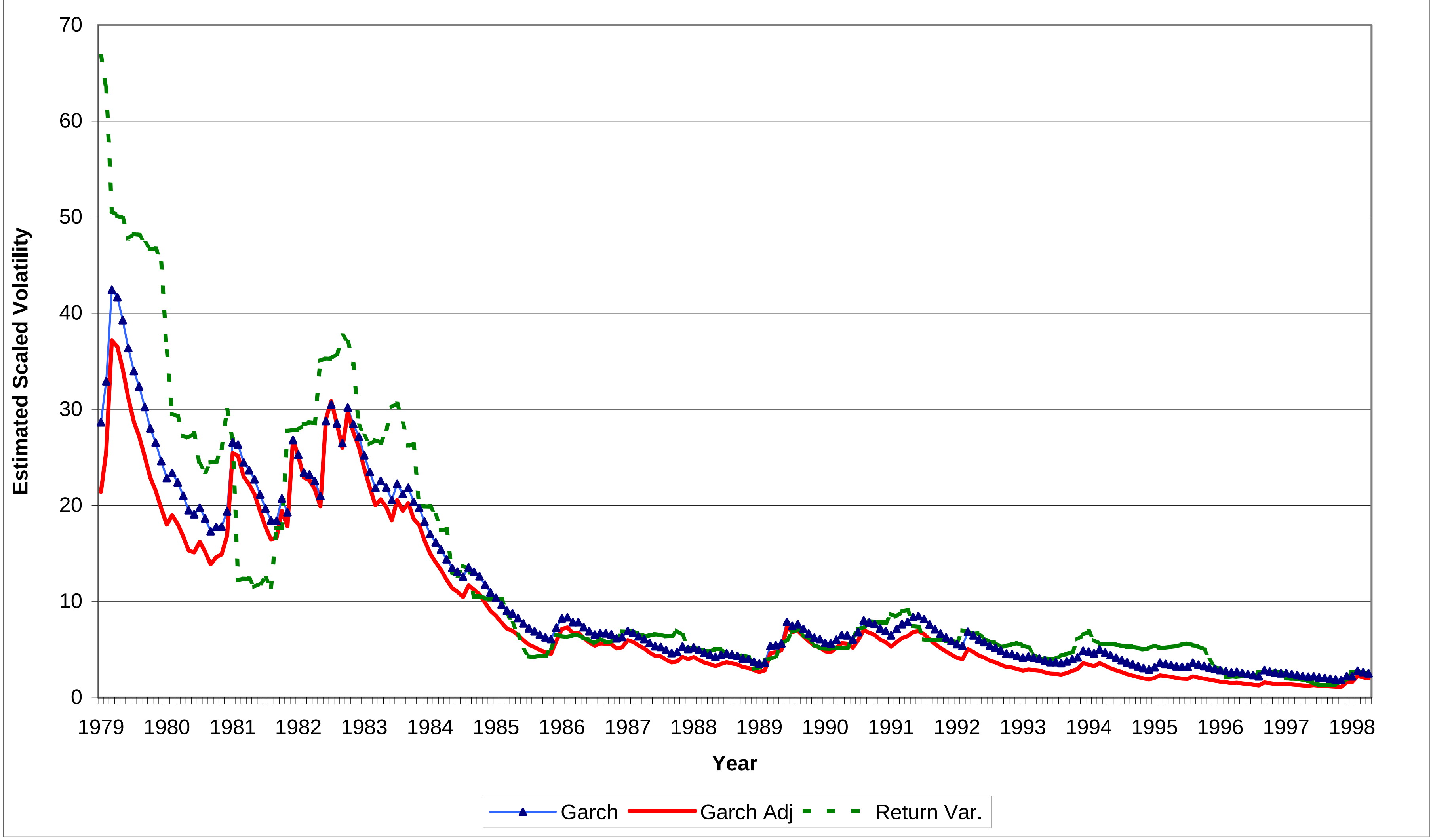

Figure 3b
Estimated Time Varying Volatility of Returns on Real Condo Prices
1986-98

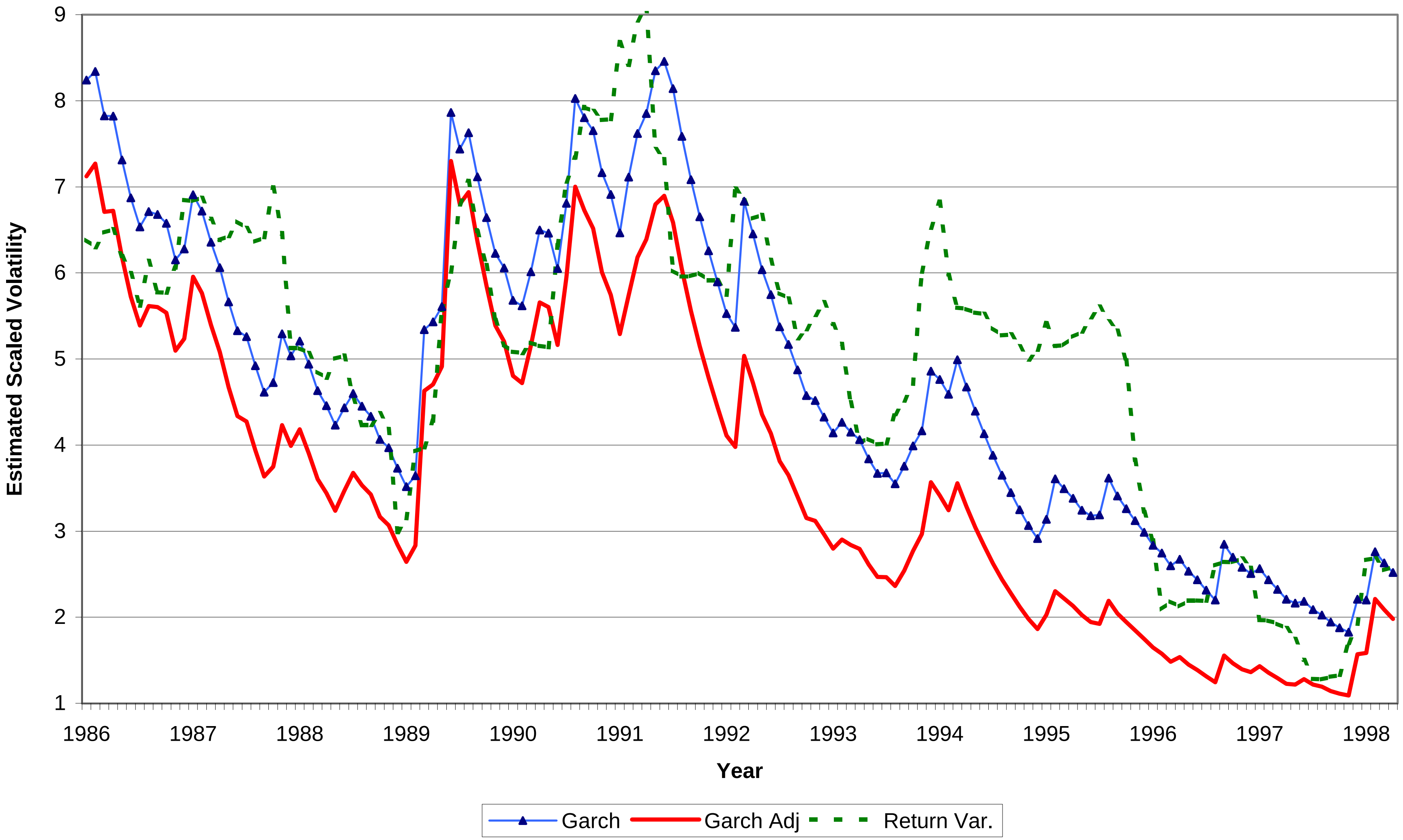

Figure 4 - Non-Parametric Beta
Vancouver Condos vs. TSE300