GROWTH CONTROLS, REAL OPTIONS, AND LAND DEVELOPMENT

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Abstract—Many urban growth controls attempt to check sprawl by restricting allowable new housing densities. However, land may be undeveloped to preserve its real-option value. Real options in land markets arise from uncertainty as to the optimum use of a site. By limiting allowable development choices, growth controls can narrow real options and potentially accelerate investment. This paper examines the effect of price volatility, a generator of option value, on the timing of development after the imposition of an Urban Growth Boundary (UGB) around Seattle. While the net effect of the UGB is to lower the likelihood of new housing outside the boundary by between 28% and 39%, price volatility is no longer a deterrent to development.

I. Introduction

URBAN sprawl has become a major concern of local and national policymakers as the physical area of cities has increased by almost 50% from 1982 to 1997 (Glaeser & Kahn, 2001). State legislatures, concerned about loss of farmland, pollution, congestion, and inner-city decline, have responded with over 2,000 new planning bills between 1999 and 2001, and, as of 2002, one-third of all states were contemplating major planning reforms (Johnson et al., 2002). Most comprehensive plans, often referred to as "growth management," attempt to curb rural development and redirect it to existing urban areas by specifying the maximum allowable density that can be considered rural and the minimum allowable scale in areas deemed urban. This restricts the total number of units that can be built on a parcel, perhaps making agricultural uses of the land relatively more profitable, and thus forestalls development. However, planning laws that restrict density also reduce uncertainty about the profit-maximizing use of the land, reducing the option value of vacant land and making immediate development relatively more attractive.[1] This suggests that growth controls could have the unintended short-run effect of inducing construction. Thus, in the presence of house-price uncertainty, growth controls have a theoretically ambiguous effect on the likelihood of development.

Growth controls have been widely studied both theoretically and empirically.[2] At the same time, it is now widely accepted that the decision to develop a building site is ultimately a choice to exercise a real option. This paper explores growth controls (specifically new development density restrictions) in the presence of the real options and empirically tests a theoretical prediction that growth controls may affect the timing of land development differentially in the presence of uncertainty.

The analysis examines the impact of an Urban Growth Boundary (UGB) adopted in the early 1990s and drawn around the greater Seattle area (specifically King County, Washington). To examine the effect of the UGB on the timing of land development, it employs a rich data set of parcel and building descriptions, real property transaction files from the county assessor's office, and county GIS files of parcel location, zoning, and jurisdictional boundaries. When combined, these records yield a data set of over 500,000 home sales and 163,000 individual land parcels at risk of being developed from 1984 through 2001.

These data are used to estimate a proportional hazard model of the timing of new construction inside and outside the boundary before and after the implementation of the boundary, in which the hazard measures the duration of time until a structure is built upon a site. The specification includes time-invariant measures of site quality, time-varying measures of new housing demand, and time- and location-varying measures of expected future prices and price uncertainty.

The resulting estimates imply that the direct effect of the boundary is to lower the likelihood of land development by 28% to 39%. However, once the boundary is imposed, price volatility, a principal determinant of real-option value, no longer delays development. Allowing uncertainty to have a differential impact in the presence of the density restrictions reveals that in the absence of real-option considerations, the UGB would have been a stronger deterrent to development, lowering the likelihood of construction by 42% to 48%.

This paper makes contributions to the literatures on growth management and real options. First, it reveals the direct effects of a growth boundary on development. This is one of only a few papers to examine the impact of a growth control law before and after implementation.[3] Second, it

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[1] Like a financial call option, which gives one the right to own a security at a predetermined strike price, an owner of vacant land holds the right to own a building of given size for an exercise price equal to the costs of construction. If the value of these real options exceeds the value from building at the current expected price, a risk-neutral landowner will delay development and preserve the option. A critical determinant of real-option value is the ability to vary the intensity of investment, because, as prices rise, developers can substitute capital for land and build taller, denser structures.

[2] Empirical work on growth controls includes, among others, papers by Pollakowski and Wachter (1990), Mayer and Somerville (2000), and Brueckner (1998).

[3] Groves and Helland (2002) examined the change in house prices after the implementation of zoning for a single county in Texas. They found that zoning raised the value of homes that would remain residential but lowered the value of homes that could have been converted to commercial use. McMillen and McDonald (2002) examined changes in prices in Chicago, 1923, and found that, after zoning, land values grew faster in areas zoned residential than in areas zoned commercial. Glickfeld and

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identifies and tests a possibly unforeseen consequence of density restrictions. In addition, the paper is the first to explore and test the importance of variable investment intensity (in this case housing density) on option value. Finally, by testing the effect of binding zoning and uncertainty on development, it is one of only a few papers to explore the intersection of government regulation and real options in investment decisions.[4]

The paper is organized as follows. Section II provides a brief review of the theoretical and empirical research of growth boundaries. It then overviews the real-options literature and provides some intuition for how real options might alter landowners' development decisions and the implications for growth control efficacy. In particular, section II outlines key predictions of Capozza and Li's (1994) model for determining hurdle rents and the importance of a convex profit function with respect to price in creating option value. Section III reviews the legislative history of growth management in Washington State and King County. Section IV discusses the assembly of the data set, the measurement of house price uncertainty, and other explanatory variables. Section V tests the effect of the UGB on timing of development using a hazard model. There is a brief conclusion.

II. Theoretical Framework and Existing Research

A. Urban Growth Boundaries

Theoretical papers that attempt to model growth boundaries typically assume that prohibitions on development outside a growth boundary are complete and instead focus on the efficiency or efficacy of such laws. For example, Ding, Knaap, and Hopkins (1999) show that a boundary could be efficiency enhancing by coordinating the production of infrastructure and housing. Presuming a negative externality exists for metropolitan population growth, Brueckner (1990) finds that a growth boundary can be just as efficient as a development tax equal to the negative externality generated by population. However, Turnbull (2004) models developer behavior in a dynamic framework and finds that by immediately securing a positive externality (more open space), a growth boundary generates inefficiently fast development within the boundary relative to a development fee. Turnbull's model does not, however, incorporate uncertainty into developers' decision process, though in a footnote (page 217) he suggests that if housing demand is stochastic, a boundary is almost assuredly less efficient relative to a development tax because the optimum allocation of land to urban use (in part a market outcome) is contingent on unknown housing demand. While this is almost certainly true, growth boundaries are quite inflexible and unresponsive to unforeseen changes in the marketplace. This is not the central thrust of this paper. Instead, this paper suggests that parcels at the urban edge may be withheld from development, even if the discounted future rents from housing (less construction costs) exceed rents in agriculture, because of uncertainty as to the appropriate intensity of land use, which itself results from uncertainty as to the path of future housing rents; but that density restrictions imposed by the UGB, or, to be more precise, the foreknowledge of future density restrictions, may make immediate development outside the boundary relatively more attractive by removing uncertainty about available land use options when development choices are limited but not proscribed.

Empirical work on UGBs has largely focused on Portland, Oregon, which has utilized a growth boundary to curtail development since the early seventies. Knaap (1985), using cross-sectional variation in a hedonic regression, finds that nonurban land inside the UGB is more valuable than nonurban land outside the UGB. Others have debated the contribution of Portland's growth boundary to higher metropolitan house prices, either by inducing land scarcity or by generating an amenity such as protected open space. Research in this area includes Phillips and Goodstein (2000) and Downs (2002). The conclusion of these works is that the boundary around Portland could only have had a modest effect on housing prices and was largely in line with those in other western cities. Fischel (1997), however, counters that other western cities are not the appropriate "control" given the prevalence of local growth controls in California, and notes that relative to the other fast-growing areas like the South, Portland's price appreciation is considerable.

While this paper affords a chance to study the imposition of a growth boundary and thus to assess changes in development activity inside and outside the boundary, it does not attempt to assess the contribution of the boundary to overall Seattle-area house price appreciation, or for that matter, to decompose any such appreciation into demand effects, from the newly protected open space amenity, for example, or supply effects, from restricting new development. Also, it departs from the theoretical foundation of Brueckner (1990) and Turnbull (2004) by allowing for an alternate frontier development threshold incorporating real-option considerations first posited by Capozza and Helsley (1990) and acknowledging that UGB development restrictions are not absolute, placing this research design more in line with other tests of whether growth controls affect land markets.

B. Real Options

Theoretical work by Dixit and Pindyck (1994) and McDonald and Siegel (1985, 1986), among others, suggests that if the future is uncertain and an investment is durable and illiquid, then the ability to pursue a different investment (or to not invest at all) in the future has economic value,

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Levine (1992) documented changes in growth controls in California in the 1970s and early 1980s.

[4] In a theory paper, Dixit (1991) showed that price ceilings that capped possible future price innovations increased the level of certainty necessary to justify new investment (market entry) and ultimately raised market prices. However, this is the first paper to empirically test the importance of flexible investment intensity (or lack thereof) on real-option decisions.

often referred to as a "real option." Pioneering theoretical work on investment and uncertainty includes Bertola (1988) and Pindyck (1988). These studies and others suggest that, in the presence of real options, the expected return necessary to justify an immediate investment can be two to three times the cost of the investment. However, only a limited number of papers have tested empirically for real options in investment decisions. Using aggregate industry measures at the two- and four-digit SIC code level, Caballero and Pindyck (1996) find that doubling uncertainty raises the necessary expected return on new capital investment by 20%. Paddock, Siegel, and Smith (1988) and Moel and Tufano (2002) examine real-option effects in natural resource extraction. The former utilize a contingent claims model to price bids for unexplored (and thus uncertain) offshore oil leases using microlevel data of oil leases, while the latter finds that gold price volatility delays both mine openings and closings consistent with real-option considerations.

A large share of the theoretical and empirical research on real options has focused on the real estate market where investments in buildings are highly durable and largely irreversible. In a theoretical model, Titman (1985) showed that the option to develop land in the future had value because uncertainty of future prices lead to uncertainty as to the optimum building height. In this environment, uncertainty raises the expected return necessary to justify an immediate investment, the so-called "hurdle rent." Work by Capozza and Li (1994, 2002) provides a formal model in which owners of rural land at the urban-rural frontier determine a hurdle rent that is sufficient for them to sacrifice their real options and develop. One of the comparative static predictions from their work is that price volatility raises the option premium and thus the hurdle rent necessary for development. Therefore, cities with higher price volatility will be physically smaller and have higher overall housing prices.

However, the value of the real option hinges not just on price uncertainty, but on the convexity in the underlying profit function with respect to price. As outlined by Titman (1985), the substitution of capital for land as rents rise yields a Jensen's inequality such that the expected future profit from building at the actual price is greater than or equal to the profit earned from building at the expected price. The greater the convexity of the profit function, the greater foregone earnings are when actual prices deviate from expected prices. Indeed, price uncertainty in the absence of flexible building technology does not yield option value.[5]

While previous empirical research has focused on uncertainty in prices, or production, this paper exploits the imposition of the UGB, which is effectively an intervention in the production technology, to test the importance of a convex profit function. By capping the ratio of units to land, the UGB makes the profit function (at desired densities above the cap) linear and collapses the inequality. Future rents may still be uncertain, but there is no expectation of foregone profit from an immediate investment. This is the first paper in the real-options literature to test the importance of the underlying production function in generating real-option value and the concurrent incentive to delay.

III. Growth Management in King County

Confronted by urban sprawl, traffic congestion, and deforestation, Washington State passed laws mandating that local planning and zoning statutes conform to the goals and requirements of the Growth Management Act. Growth management is distinct from growth controls (for example, those in California), because it not only attempts to limit development in rural areas, but also attempts to redirect growth to existing urban centers.[6] The most striking feature of growth management in Washington State is that it required select counties to draw a boundary that segregated areas intended for high-density urban use from low-density rural areas similar to that drawn around Oregon cities, most notably Portland.

The city of Seattle and much of its suburbs are located in King County, Washington. It is heavily settled in the west and bounded by high mountains in the east. However, the middle of the county consists of land in agriculture and forestry and an increasing number of subdivisions. King County's first attempt to direct unincorporated county land use began with the passage of the 1964 Comprehensive Plan. Wallace (1988) used data from the late 1970s and found that this early law affected the land market, resulting in the oversupply of agricultural and resource land and the undersupply of residential and industrial land. Development intensity in rural areas was further constrained by the Comprehensive Plan of 1985, which segregated unincorporated county land into five regions: urban areas that were to have fairly high levels of density; transitional areas with an intermediate density; rural areas that typically had a minimum allowable density of two and half acres per residence; and agricultural and forest lands with almost no development.

In 1990 and 1991, inspired in part by King County and suffering the effects of sprawl in other areas, Washington State passed laws creating the Growth Management Act (GMA).[7] The act tried to address fourteen different policy

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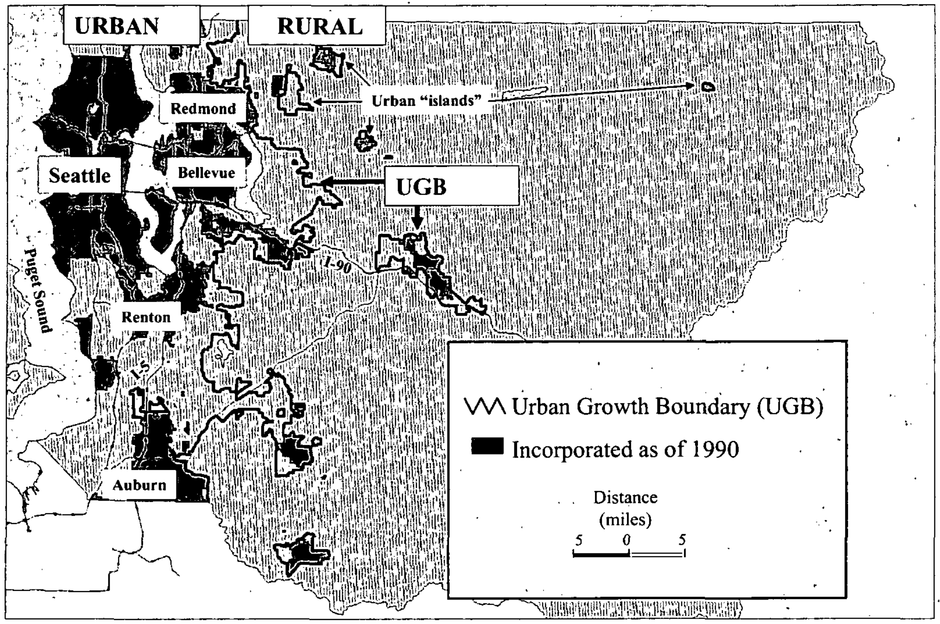
[5] The model by Capozza and Helsley (1990) does assume fixed-building technology; however, their model relies on uncertain housing rents relative to agricultural land rents to generate the nonlinear profit function and associated irreversibility premium.

[6] Brueckner (1998) utilized the data set of Glickfeld and Levine (1992) to test models of strategic interaction in the passage of growth control laws developed in Brueckner (1995) and Helsley and Strange (1995).

[7] For a careful discussion of the underlying causes of sprawl, see Brueckner and Fansler (1983) and Brueckner (2001). For a model of the taste for growth controls, see Brueckner (1999). Growth controls may also be efficiency enhancing in a world with lumpy public capital expenditures (Sasaki [1998]) or with local fiscal competition (Wassmer [2002]).

FIGURE 1.—THE 1994 URBAN GROWTH BOUNDARY



objectives, including the preservation of open space, agricultural land, and forests. It also encouraged higher-density development and development oriented toward mass transit. The principal mechanism for achieving these objectives was a mandate that counties engage in comprehensive planning. Compliance with the statewide GMA and with each locality's own plan is adjudicated by governor-appointed Growth Management Hearing Boards.[8]

The GMA led to the formation of King County's Growth Management Planning Council. The council's principal goal was to channel forecasted population growth in the Seattle area in such a way as to satisfy the objectives of the state law. The council's first task, as mandated by the GMA, was to segregate land for "urban" use from land that was to be kept "rural" or as "forest/resource." The maximum allowable density in the rural area was one residence per five acres, and in the forest/resource area it was one residence per eighty acres. The subsequent frontier between the designated urban and rural areas is sometimes referred to as the Urban Growth Boundary (UGB), a map of which is provided in figure 1.[9]

A review of the popular press from that time and interviews with people integral to the development of the legislation indicates that the public was well informed about the future location of the UGB long before it was actually imposed.[10] Thus, prior to the implementation of the UGB (in 1995), landowners beyond the (then future) boundary knew that they had the right to develop the land then, but would lose most of their development rights when the UGB went into effect.

While the Growth Management Act is a very progressive law, Washington State retains some fairly strong property-rights provisions. The two most relevant for this paper are the homestead provision and permit vesting. The homestead provision states that landowners are allowed to build at least one house on their land, no matter what other regulations apply. Secondly, all permit applications, in this case subdivision and building permits, must be evaluated using the zoning and building codes at the time of application. Thus, property owners with land soon to be declared outside the UGB need only submit their permit before the boundary went into effect to avoid being constrained by the zoning provisions in the future. Once approved, a building permit could be extended for up to two years with little difficulty.

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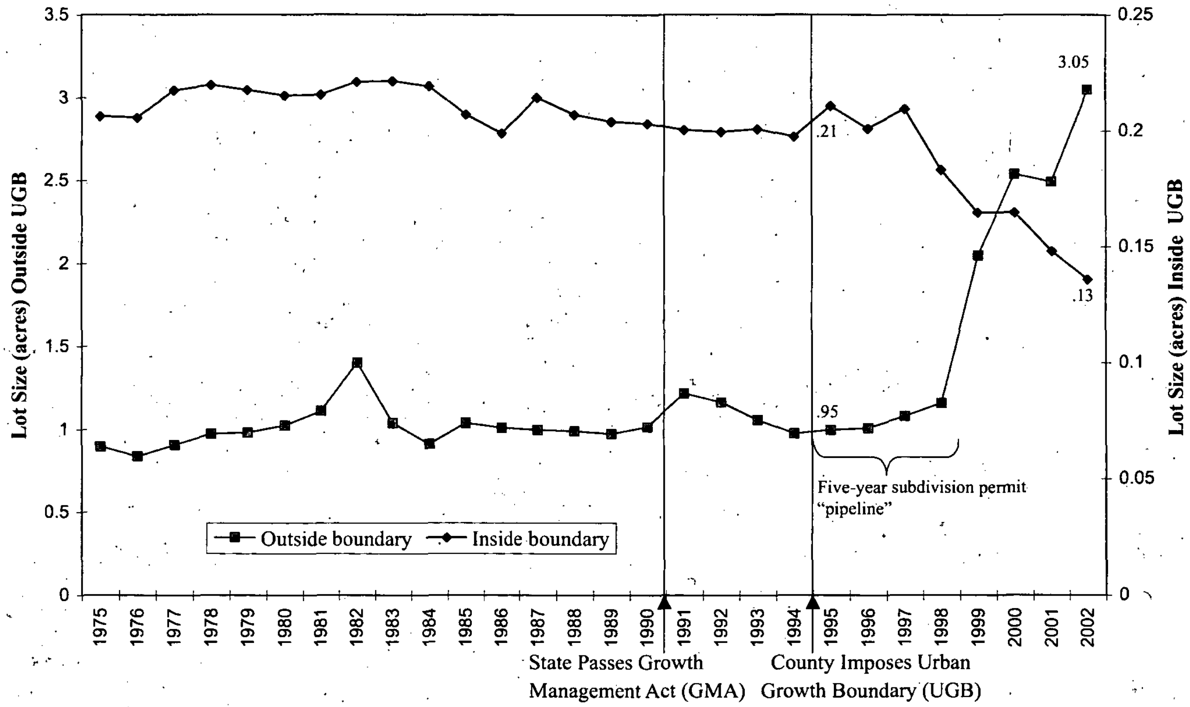
[8] One eastern Washington county's failure to draft a satisfactory plan culminated in the brief suspension of state transportation funds to the county. Another county's plan was rejected for having too large an "urban" area.

[9] Modifications to the boundary are allowed periodically for a limited set of reasons: if new "urban growth areas" are contiguous to the existing area and may be readily served by existing infrastructure; if the development in the new area contains a minimum density of four units per acre; and if the development dedicates four acres of open space for each additional acre of built land. To date, there has been almost no change in the location of the UGB since its implementation in 1995.

[10] There were numerous public meetings and considerable press coverage of what was a politically charged process.

FIGURE 2.—MEDIAN LOT SIZE OF NEW HOMES INSIDE AND OUTSIDE URBAN GROWTH BOUNDARY (WITHIN THREE MILES OF THE BOUNDARY)



Given the considerable literature on endogenous zoning, which demonstrates that many zoning laws simply codify free-market outcomes, at least at the time of their drafting (Siegan, 1970; Berry, 2001; McDonald & McMillen, 1998; McMillen & McDonald, 2002), it is worth briefly looking at whether the GMA reduced rural housing or raised urban density. Figure 2, which graphs the median lot size of newly constructed homes within three miles of the UGB, reveals a rather striking increase in the lot sizes of new homes outside the boundary.[11] Five years after the law went into effect, lot size outside the UGB increased dramatically, indicating that developers were constrained by the law. The timing of the lot-size increase corresponds roughly with the subdivision permitting "pipeline." At this time, because of a backlog of applications filed before the UGB went into effect, it was approximately four years before subdivision applications under the new rules were processed. By 1999, however, the lot sizes of new homes outside the UGB almost doubled in a year and continued to increase in size thereafter. At the same time, the lots of new homes inside the boundary shrank by 42%.

Additional evidence for the impact of the UGB on land markets comes from house and land prices. Figure 3 graphs the price difference between parcels inside and outside the UGB for developed and undeveloped properties.[12] The sample is for all parcels within three miles of either side the UGB. Figure 3 provides some evidence that the GMA affected land prices generally. Before the GMA was passed, undeveloped plots of land inside and outside the UGB traded at approximately the same price. After the GMA was passed, but before any zoning codes were changed, the price of vacant land inside the boundary began to rise relative to that of land outside the boundary. The phenomenon persists after the UGB was implemented, and, for a time in the late nineties, the value of vacant land inside the boundary exceeded the value of land with built homes.

The price of land with a house on it was approximately the same inside and outside of the boundary before and after the passage of the GMA. This finding discounts the possibility that land values were affected by unobserved changes in amenities such as school quality or city services. It also suggests that securing existing homes against neighboring development was not capitalized into a higher home price for buildings outside the UGB. Any change in amenities or dis-amenities should have raised the value of land with and without a house on it.

The decline of vacant land prices outside the boundary relative to inside the boundary after the law change but

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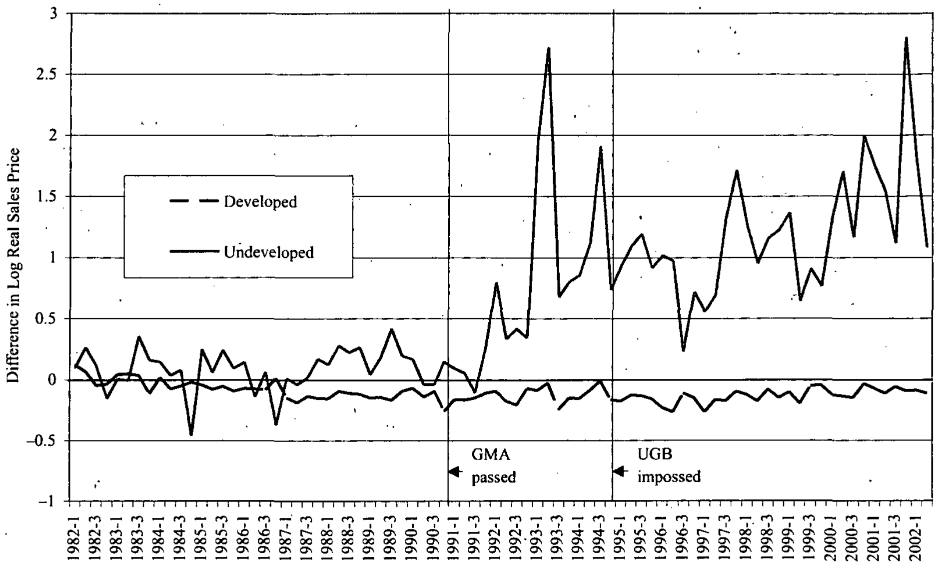
[11] These lot sizes were obtained from 2002 GIS parcel files, UGB location files, and building description files (which include year of construction). These data sets are described below.

[12] Prices were calculated from the county assessor's office transaction files, 2002 GIS files of parcel size, and the location of the UGB as described in section IV.

FIGURE 3.—DIFFERENCE IN AVERAGE PRICE OF DEVELOPED AND VACANT LAND INSIDE THE URBAN GROWTH BOUNDARY MINUS OUTSIDE



before the implementation of the UGB could have been a result of landowners capitalizing the value of future public services such as sewer and road capacity that were signaled by being within the UGB. It also may simply indicate a substitution effect caused by restricting the supply of available land. Another explanation for the separation of the price series prior to implementation is that vacant land outside the UGB was stripped of much of its real-option premium by the passage of the legislation. In 1993, two years before the UGB was imposed, both parcels inside and outside the UGB could be developed as intensely as before the law. However, land inside the UGB had its future development rights secured by the GMA, while land outside the UGB lost its future development rights.

This evidence is, of course, only suggestive. Figures 3 and 4 do not control for any other parcel characteristics or market factors that may have changed among parcels sold after 1990. To identify the impact of the boundary on the real option and the timing of development, the balance of the paper utilizes multivariate analysis. The data set of parcels at risk of development used in this analysis is discussed in the next section.

IV. Data

The data come principally from detailed records of parcel and building description files maintained by the county assessor's office for the year 2002. The parcel-description file includes seventy indicator variables for property characteristics that might affect a site's value. Similarly, the building-description file contains over thirty measures of building size, quality of construction, condition, and additional features. These records are maintained for all parcels and buildings in the county, independent of whether the land or the house was ever sold. The county also maintains records of all real property transactions from 1982 through the present. These records include sales price, type of property sold, and over fifty indicators for unusual features of the transaction. Finally, GIS files of parcel location and shape are used to measure distance to downtown Seattle and parcel size. GIS software also is used to assign parcels to school districts and to determine zoning status before the GMA.

A. *Timing of Development*

To understand the effects of the growth boundary and price uncertainty on the timing of development, the duration of time, in years, is calculated from when a parcel first enters the sample in 1984 (the earliest year I can construct a measure of uncertainty) until a structure is built upon it. By 2002, there were a total of 531,000 land parcels in the county, with and without buildings on them. To determine when a parcel ceases to be vacant, I use the "year built" variable from the King County Assessor's residential building file (427,000 observations) and the commercial building file (39,300 observations) from 2002.

A parcel's duration as undeveloped land ends when the construction of a home or building starts. Construction is assumed to start in the year preceding the recorded year of completion in the building-description files.[13] Note that this method of inferring exposure to development pools vacant land with land that once contained dilapidated structures.[14] Parcels with homes completed before 1985 are excluded from the analysis. Measured this way, a total of 163,120 parcels were eligible for development in the sample period, of which 95,805 had structures built upon them by 2002, while 67,315 land parcels remained undeveloped.

B. *Forecasted Prices and Price Uncertainty*

To measure quality-adjusted housing prices, I use single-family-home sales from the King County real property transaction file. A total of 474,594 home sales took place without any unusual conditions of sale.[15] These transactions are then matched to parcel, house, and GIS records using the lot's identification number. Some sales do not have a corresponding lot, building, or GIS record in 2002, yielding a total of 463,152 home sales.[16] Unlike for the timing-of-development data set discussed above, I am able to determine the actual date of sale.

Working with these sales, I divide the county into fifteen regions based on school district. To ensure a sufficient number of transactions in each region to estimate time-varying house prices, I consolidate five sparsely populated eastern districts into two larger regions and also attach two smaller urban districts to larger neighboring school districts. Finally, I exclude Vashon Island, which had insufficient trades to assemble a consistent time series and could not be readily merged with a neighboring district.

I run separate regressions for each school district and each quarter of sale between the first quarter of 1982 and the second quarter of 2002. Thus, I run a total of 1,230 separate house price regressions (82 quarters × 15 school districts) with the following specification of log real price on an intercept and two vectors of covariates:

$$\ln(p_{ijt}) = \delta_{jt} + H'_{it}\phi_{jt} + L'_{i}\chi_{jt} + \varepsilon_{ijt}. \qquad (1)$$

The variables H_{it} and L_i denote vectors of house and lot characteristics, respectively. The subscript i indicates house-specific variables, j denotes school district, and t the quarter of sale. By running separate regressions, the intercept δ_{jt} and the hedonic contributions of house and lot characteristics, ϕ_{jt} and χ_{jt}, are allowed to vary with time and region, respectively.

I use the resulting time- and district-varying parameter estimates to predict the value of a constant-quality home in that quarter and school district. The specification for the quality-adjusted price series, $p^{\bar{q}}_{j}$, is

$$p^{\bar{q}}_{jt} = \hat{\delta}_{jt} + \bar{H}'\hat{\phi}_{jt} + \bar{L}'\hat{\chi}_{jt}, \qquad (2)$$

where $\bar{H}$ and $\bar{L}$ are vectors of the average house and lot characteristics in King County over the entire sample period.

To estimate house-price uncertainty, σ, I begin by estimating the one-year-ahead quality-adjusted price of housing, $P^{\bar{q}}_{jt+4}$, as a function of an intercept and the current quality-adjusted price, $P^{\bar{q}}_{jt}$:

$$P^{\bar{q}}_{jt} = \alpha_{0j} + \alpha_{1j}P^{\bar{q}}_{jt-4} + e_{jt}, \qquad (3)$$

where t is the quarter of sale and j denotes the school district. The parameter estimates for the regressions are presented in table 1. While the ability to predict future prices is at odds with efficient-market theory, there is evidence that quality-adjusted housing prices can be forecasted in the near term (for example, Case & Shiller, 1989). Four quarters is the shortest time horizon a developer might consider, given that it is the approximate construction time for a new house in this area.

I estimate price uncertainty, $\hat{\sigma}^2_{jt}$, by calculating the four-quarter moving variance of residuals from equation (3):

$$\hat{\sigma}^2_{jt} = \mathrm{var}(\hat{e}_{jt-1}\cdots\hat{e}_{jt-4}). \qquad (4)$$

This specification assumes that a would-be developer's confidence in the one-year-ahead price forecast depends on how accurate price forecasts were in the recent past.[17] Other measures of uncertainty, including the simple moving variance of prices and the sum of squared errors, were examined and tested in Cunningham (2006) and were found to yield parameter estimates largely consistent with the variance of residuals. However, I consider the variance of residuals to be an intuitively appealing and arguably more conservative measure in terms of what information the developer uses to forecast prices. For example, it is possible that the residuals from the forecasting model in equation (4) display positive serial correlation, to which developers adapt their forecasts. Alternatively, developers may simply know more about what is driving market price than researchers are able to discern. Note, however, that equation (4) can be rewritten as

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[13] The lag between the initiation of construction and the year of completion was confirmed using a subset of buildings that could be matched to county building-permit records, which have the date of permit application and date of building completion. Building permits from 1992–2003 were obtained for parcels in unincorporated King County from the Division of Development and Environmental Services.

[14] Not knowing what predates a structure may be problematic, because the hurdle rent for an existing built-upon site that is generating rents may be higher relative to that of a vacant plot, whose owner must forego all housing services until time of construction. Demolition and permitting costs also may be higher, but conversion costs are probably lower.

[15] Over 400,000 transactions do not have a price. Typically, these transactions include transfer of property rights associated with a divorce, inheritance, foreclosure, and so on.

[16] Sales that occurred before the recorded year of construction are excluded because they presumably were dilapidated structures that were subsequently torn down and replaced with the unit observed in 2002. Similarly, sales that occurred before the year of renovation are excluded.

[17] This is similar to ARCH, in which residuals from a forecasting equation are used to measure volatility. The method above weights each lagged residual equally; ARCH methods solve for the likelihood-maximizing weights that predict e_t.

TABLE 1.—PRICE FORECASTING PARAMETER ESTIMATES BY REGION[1]

	Intercept		Lagged Quality-Adjusted Price (four quarters)	
Region	Parameter Estimate	Standard Errors	Parameter Estimate	Standard Errors
1	−0.129	(0.397)	1.015	(0.035)
2	1.322	(0.798)	0.886	(0.070)
3	0.819	(0.638)	0.932	(0.055)
4	0.633	(0.580)	0.948	(0.050)
5	0.916	(0.583)	0.924	(0.050)
6	2.223	(0.823)	0.818	(0.069)
7	1.235	(0.678)	0.897	(0.058)
8	1.540	(0.695)	0.868	(0.061)
9	8.483	(1.027)	0.247	(0.091)
10	2.047	(0.804)	0.823	(0.070)
11	0.471	(0.562)	0.960	(0.050)
12	0.296	(0.633)	0.976	(0.056)
13	1.701	(0.787)	0.850	(0.070)
14	1.538	(0.831)	0.864	(0.074)
15	0.454	(0.589)	0.962	(0.052)

[1] $P^q_{jt} = \alpha_{0j} + \alpha_{1j} P^q_{jt-4} + e_{jt}$, quality-adjusted prices four quarter ago predicts current price. Quarterly, quality-adjusted price, P^q_{jt} is constructed by predicting the price of a synthetic home with mean house and lot characteristics (for that school district) using time and district varying hedonic coefficient estimates derived from 1,230 (82 quarters × 15 districts) individual regressions of log sales price on parcel and lot characteristics drawn from 554,906 home sales.

$$\hat{\sigma}^2_{jt} = \sum_{k=1}^{4} (\hat{e}_{jt-k} - \bar{\hat{e}}_{jt})^2/4, \tag{5}$$

where

$$\bar{\hat{e}}_{jt} = \frac{\sum_{l=1}^{4} \hat{e}_{jt-l}}{4}. \tag{6}$$

The measure, $\hat{\sigma}^2_{jt}$, as shown in equations (5) and (6), accommodates these concerns by imposing the assumption that developers know $\bar{\hat{e}}_{jt}$ over the coming year. Using this method, which locally de-means the error term, ensures that the measure of price uncertainty only increases when a price forecast for a particular quarter deviates from the three other closest forecasts. There is considerable variation in price uncertainty over time and across districts.[18] Graphs of the uncertainty measure can be found in Cunningham (2006). Finally, I take the annual average of the uncertainty term to create the mean level of uncertainty by year and school district.

C. Other Explanatory Variables

To test the effect of the UGB on hurdle rents and the timing of development, I must include additional controls for the fact that land may generate rents in its current (preconversion) state. In the basic model, development occurs at the urban-rural frontier when land rents from supplying housing services exceed agricultural rents (less the cost of conversion). If, however, binding zoning sets allowable density below the profit-maximizing density, such that land is more profitable if kept in its current state, then growth controls will deter new development.

To account for housing price levels in determining the timing of development, I include the one-year-ahead forecasted school-district-level house price as a determinant of demand for housing in a given location. The forecasted price is used because it takes approximately one year to build a new home in this area and, as such, represents the price the developer might expect to receive at the time of sale. The value is taken from equation (3). I also calculate the one-year growth rate in prices as the natural log of current house prices over prices in the previous year. The timing-of-development data set also contains the real risk-free interest rate, measured as the interest on a ten-year U.S. Treasury bond.

The intrinsic value of the option is also affected by the fixed costs of converting vacant land to housing. I do not have a measure for per-unit construction cost, which would, in any event, only vary with time, but I do control for conversion costs associated with developing particular sites. I include dummy variables for whether the parcel was at risk of erosion, flooding, a landslide, or an earthquake. Dummy variables for whether a site had difficult topography, water problems, or a restrictive shape for development are included as well.

In addition to school-district-level prices, some sites may be more attractive for development because of their location or a proximate amenity. The data set contains the assessor's rank of the quality of the scenic view (from 0–4), which I treat as a cardinal variable. The effect of this localized amenity on the prospective house price for a home on a

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[18] By measuring price uncertainty as the variance of residuals from a forecasting model, I sacrifice the first two years at risk of development. This occurs because the forecasting model does not yield a residual until the first quarter of 1983. Taking the variance of the past four-quarter residuals means that the first measure of price uncertainty is obtained in the first quarter of 1984.

TABLE 2.—SUMMARY STATISTICS FOR VARIABLES USED TO TEST DETERMINANTS OF LAND DEVELOPMENT

Variable	Mean	Median	Standard Deviation
Dummy if site developed in that year	0.050		
Dummy if site is outside UGB	0.240		
Anticipated one-year-ahead quality-adjusted house price[1] (in logs)	11.444	11.422	0.247
Price uncertainty[2]	0.006	0.002	0.007
Interest rates (ten-year U.S. Treasury %)	7.979	7.670	1.920
Population (100,000)	15.197	15.073	1.316
Distance to CBD (miles)	15.148	14.466	8.313
Scenic view (rank 0–4)	0.342	0	0.932
High erosion danger	0.008		
High flood danger	0.009		
High seismic danger	0.008		
High risk of landslide	0.007		
Difficult topography	0.095		
Water problems	0.052		
Oddly shaped lot	0.083		
Subcounty zoning			
Incorporated	33.44		
Urban	41.89		
Transitional	6.63		
Rural	11.36		
Agricultural/Forest	6.68		
Parcels	163,120		
Parcels developed	95,805		
Observations	1,956,547		

[1] Log predicted quality-adjusted house price four quarters ahead from model $P_{jt}^{a} = \alpha_{0j} + \alpha_{1j}P_{jt-4}^{a} + e_{jt}$.
[2] Moving variance of residuals, var($\hat{e}_{jt-1} \ldots \hat{e}_{jt-4}$), from forecasting model above.

particular lot is not captured in the school-district-wide, quality-adjusted house prices. This value is determined by taking the best numeric score (assigned by the assessor) for views of two mountain ranges, two volcanic mountains, the downtown Seattle skyline, and several different bodies of water.

Commuting distance to the central business district is a principal determinant of lot value. At the same time, cities tend to expand outward over time. To control for these possible determinants of development timing, a lot's distance from downtown Seattle is calculated in miles using the GIS parcel file. To control for existing zoning statutes that might affect the timing of development, I digitized a historic map of King County's 1985 Comprehensive Plan discussed in section III and included dummy variables for the subcounty land-use designations (urban, transitional, rural, and agricultural/forest).

Finally, parcels outside the boundary are identified by a dummy variable, $D_i^{outside}$, which was determined using GIS files of parcel and UGB location. As I discussed in section III, the ultimate location of the UGB was well anticipated by most property owners. Yet, it is the ability to respond to higher prices in the future that creates real option value. Note that because of the homestead provisions and permit vesting, landowners still could develop the profit-maximizing structure before 1995, but they lost the ability to develop land more intensively in the future, should prices rise. Thus, I create a second dummy, D_t^{after}, to identify parcel-years-at-risk of development after the passage of the GMA (in 1990). The summary statistics, along with the mean number of new homes built, are presented in table 2.

V. The UGB and the Timing of Land Development

To examine the determinants of the timing of development, I estimate a hazard model in which a site "dies" when a new home is built on it. Utilizing the timing-of-development data set described in section IV, I specify the following hazard:

$$h(t) = h_0(t)\exp(X'\beta), \tag{7}$$

where the baseline hazard, $h_0(t)$, is shifted by changes in a vector of covariates X.

In a hazard model, it is necessary to specify a start time in order to measure the duration of time until failure. However, in land development, it is unclear when a parcel is first "at risk" of being built upon: when the first settlers arrived, or, perhaps, when the first car was sold? Given that I am only able to observe price uncertainty starting in 1984, I set this as the start year for all parcel spells. This assumption may be problematic. By setting a start time arbitrarily, I may be mismeasuring spell length and assuming that some parcels were at risk for more or less time than they actually were. This may bias the parameter estimates. In addition, because all parcels have the same start year, I cannot distinguish between pure calendar-time effects and spell-time effects without placing parametric restrictions on the distribution of the baseline hazard. For example, if I were to use a flexible estimator, such as the nonparametric hazard of Prentice and Gloeckler (1978) and Meyer (1990), all purely intertemporal variation in the likelihood of development would be captured in the baseline hazard estimate, limiting identification to parameters associated with explanatory variables that vary both intertemporally and cross-sectionally. This would preclude the identification of the impact of interest rates and hinder the identification of variables like price uncertainty.

In light of these concerns, I rely on the somewhat restrictive exponential distribution for the parameterization of the baseline hazard. While the exponential distribution implies a constant hazard over time, it is appealing because it is unaffected by misspecification of the start time (if this is, in fact, the correct distribution) and allows for temporal variation in the explanatory variables. Cunningham (2006) used the Prentice-Gloeckler-Meyer nonparametric estimator, and it yielded similar parameter estimates as those resulting from an exponentially distributed hazard. Cunningham (2006) also showed that these results were robust to analysis on subsamples of parcels that likely shared similar start times.

A. *Hazard Estimates for the Deterministic Case*

First, I examine the effect of the law change on the timing of development without consideration of price uncertainty. From the basic urban model, we know that construction will only occur when land rents from housing exceed rents in the current use (less conversion cost). If development density is restricted, the land rents generated after conversion may not exceed rents in the current use. For example, land outside the UGB may have been profitably developed at a density of four homes per acre had the boundary not been implemented, but after the law, only can be developed at a density of one home per five acres. At that allowable density, the land may continue to yield greater rents if it is kept in its current use, for example, agriculture.

The vector of covariates that shift the baseline hazard contains determinants of land development:

$$\begin{aligned} X'\beta = {} & \varphi_1 E[P^{\bar{q}}_{jt+1}] + \varphi_2 g_{jt} + \varphi_3 r_t + \varphi_4 u_i + \varphi_5 v_i \\ & + C_i'\Psi_i + Z_{FE_i} + \theta_1 D_i^{outside} + \theta_2 D_t^{after} \\ & + \theta_3 (D_t^{after} \times D_i^{outside}). \end{aligned} \tag{8}$$

Note that expected school district housing prices and house-price growth rates vary by year t and by school district j, while interest rates only vary by year t. In the presence of real options, interest rates have an ambiguous effect on the timing of development. A higher interest rate raises the cost of capital to a firm and, thus, pushes up the threshold return necessary to justify an immediate investment. At the same time, however, higher interest rates lower the discounted present value of future profits, making short-run profits relatively more valuable than any forgone future rents from a suboptimal development. This latter effect lowers the hurdle price necessary to justify an immediate investment.[19]

Parcels that were excluded from the UGB may be different in unobserved ways that lead to their exclusion from the urban area. To control for this, $D_i^{outside}$ identifies all parcels that were outside the ultimate UGB. The parameter for $D_i^{outside}$ is θ_1. The dummy variable, D_t^{after}, controls for any unobservable change in the likelihood of development that is constant across all land parcels. Thus, if there was a change in an unobserved determinant of development that affected all parcels in the county (for example, a change in unit construction costs or regional income), then the associated parameter, θ_2, will capture this effect. To capture the change in the likelihood of development from the imposition of the boundary after the law, I interact the dummy variable $D_i^{outside}$ with the dummy variable D_t^{after}. The null hypothesis is that the UGB restrictions are not binding on the optimum development scale and, thus, do not affect the likelihood of development, $H_0 : \theta_3 = 0$. The alternative hypothesis is that the UGB reduced the likelihood of development outside of the boundary, $H_a : \theta_3 < 0$.

Column 1 of table 3 presents the results from a simple specification without accounting for the UGB.[20] Note that parameter estimates conform to theory reasonably well. Higher house prices are associated with an increased likelihood of development, as are parcels with a scenic view. A higher growth rate in housing prices reduces the likelihood of development. Parcels that may require additional expense to build on, such as those with water problems or a restrictive lot shape, are slower to develop.

Column 2 incorporates the UGB by including the dummy variables for location and whether the parcel is at risk after the GMA passed in 1990. The parameter estimate on the dummy variable for whether a parcel was outside the UGB, $\hat{\theta}_1$, is significantly less than 0, indicating that parcels outside the boundary were less likely to develop even before the UGB was established. The parameter estimate $\hat{\theta}_2$ measures the proportional shift in the likelihood of development after 1990.[21] It is negative, but small, suggesting that parcels inside the boundary were slightly less likely to be developed after the law. The parameter estimate on the interaction $D_i^{outside} \times D_t^{after}$, $\hat{\theta}_3$, captures the effect on parcels of being outside the boundary after the law change. It is statistically less than 0 for all standard significance levels, leading to the rejection of the null hypothesis that the UGB did not affect

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[19] Capozza and Li (2001, 2002) construct and test a model in which higher interest rates can speed the timing of development. They found that 25% to 50% of their sample of Californian metropolitan statistical areas was in the appropriate range for this to occur.

[20] Bootstrapped standard errors are listed in parentheses.

[21] I also examine the change in development timing after the UGB was *enacted in 1995. The full sample parameter estimates for* $\hat{\theta}_1$, $\hat{\theta}_2$, *and* $\hat{\theta}_3$ are −0.141, 0.268, and −0.500 respectively. All three values are significantly different from 0 at standard p-values, though $\hat{\theta}_1$ becomes insignificant when the analysis is restricted to subsamples around the UGB.

TABLE 3.—LAND DEVELOPMENT AND THE UGB HAZARD MODEL OF DEVELOPMENT (BOOTSTRAPPED STANDARD ERRORS IN PARENTHESES)[1]

Explanatory Variable	(1) No Controls for UGB	(2) Include Controls for UGB	(3) Restricted to within Three Miles of UGB	(4) Restricted to within One Mile of UGB	(5) Pseudo-UGB (one mile inside actual UGB)[4]
Anticipated one-year-ahead (φ_1) quality-adjusted house price[2]	0.750	0.854	0.413	0.304	0.223
	(0.015)	(0.017)	(0.029)	(0.029)	(0.028)
House-price growth rate (φ_2)	−0.441	−4.555	−0.656	1.260	3.743
	(0.448)	(0.638)	(0.732)	(0.948)	(0.922)
Real interest rate (φ_3)	−0.035	−0.049	−0.067	−0.090	−0.070
	(0.002)	(0.002)	(0.003)	(0.004)	(0.004)
Distance to CBD (φ_4) (in log miles)	0.298	0.315	−0.038	−0.104	−0.143
	(0.007)	(0.005)	(0.016)	(0.025)	(0.017)
Scenic view (φ_5)	0.048	0.046	0.016	−0.003	−0.010
	(0.003)	(0.003)	(0.004)	(0.006)	(0.006)
Dummy Variables for UGB[3]					
Outside UGB (θ_1)		−0.132	−0.027	−0.027	−0.088
		(0.015)	(0.017)	(0.017)	(0.014)
After 1990 (θ_2)		−0.057	0.105	0.218	−0.018
		(0.009)	(0.013)	(0.012)	(0.021)
After 1990 × outside UGB (θ_3)		−0.325	−0.390	−0.492	0.303
		(0.016)	(0.019)	(0.027)	(0.021)
Additional Conversion Costs					
High erosion danger (Ψ_1)	−0.095	−0.027	−0.123	−0.330	−1.716
	(0.052)	(0.047)	(0.052)	(0.082)	(3.141)
High flood danger (Ψ_2)	−0.058	−0.024	−0.048	−0.117	−0.057
	(0.050)	(0.053)	(0.060)	(0.055)	(0.086)
High seismic danger (Ψ_3)	0.117	0.082	0.135	0.246	0.127
	(0.051)	(0.046)	(0.038)	(0.054)	(0.058)
High risk of landslide (Ψ_4)	−0.070	−0.019	−0.008	−0.176	−0.846
	(0.057)	(0.056)	(0.054)	(0.093)	(0.185)
Difficult topography (Ψ_5)	−0.731	−0.712	−0.546	−0.489	−0.596
	(0.016)	(0.015)	(0.018)	(0.034)	(0.028)
Water problems (Ψ_6)	−1.401	−1.367	−1.268	−1.278	−1.534
	(0.028)	(0.023)	(0.028)	(0.053)	(0.045)
Oddly shaped lot (Ψ_7)	−1.740	−1.737	−1.712	−1.879	−1.682
	(0.023)	(0.026)	(0.036)	(0.056)	(0.044)
Constant	−12.012	−13.134	7.130	−5.584	−4.623
	(0.174)	(0.199)	(0.358)	(0.373)	(0.335)
Subcounty zoning fixed effects	Yes	Yes	Yes	Yes	Yes
Log likelihood	−190,361	−189,921	−126,223	−69,403	−80,051
Parcel years at risk	1,990,255	1,990,255	1,220,551	674,047	717,066

[1] Exponential distribution.

[2] Average of school district quarterly predicted quality-adjusted house prices in the next calendar year, from regression model: $P^{\hat{q}}_{jt} = \alpha_{0j} + \alpha_{1j} P^{\hat{q}}_{jt-4} + e_{jt}$.

[3] Dummy variables for whether a parcel is ever outside the UGB; whether the spell-year at risk is after 1994 (the year of UGB implementation); and for spell-years at risk of development for parcels outside the UGB.

[4] Sample consists of parcels within one mile of simulated boundary. Thus, column 5 is analogous to column 4.

the likelihood of development in favor of the alternative that the UGB reduced development activity outside the boundary. The parameter estimate of −0.325 indicates that the undeveloped parcels outside the boundary were 28% less likely to develop after the law change and that the UGB was successful in reducing rural development.[22] This decline in the likelihood of development is equivalent to a 6.7 point increase in long-term real interest rates. This finding is qualitatively consistent with the finding of Mayer and Somerville (2000) that greater land-use regulation delays new construction.

In an attempt to control for unobservable characteristics of land markets, such as when a parcel first became eligible for conversion or the installation of unobserved localized amenities, I restrict the sample to parcels that are within three miles (on either side) of the UGB. Limiting the analysis to parcels in the vicinity of a jurisdictional boundary was used successfully by Holmes (1998) to control for economic geography in assessing the effect of state right-to-work laws on the location of manufacturing activity and by Black (1999) to control for unobserved neighborhood quality in assessing homebuyers' valuation of elementary school quality. Holmes examined counties within 25 miles of a right-to-work/no right-to-work state frontier, while Black used homes within 0.35, 0.2, and 0.15 miles of elementary school catchments boundaries.[23] A map of the buffer used to create the three-mile sample is presented in figure 4; the parameter estimates from the regression on this subsample are provided in column 3.

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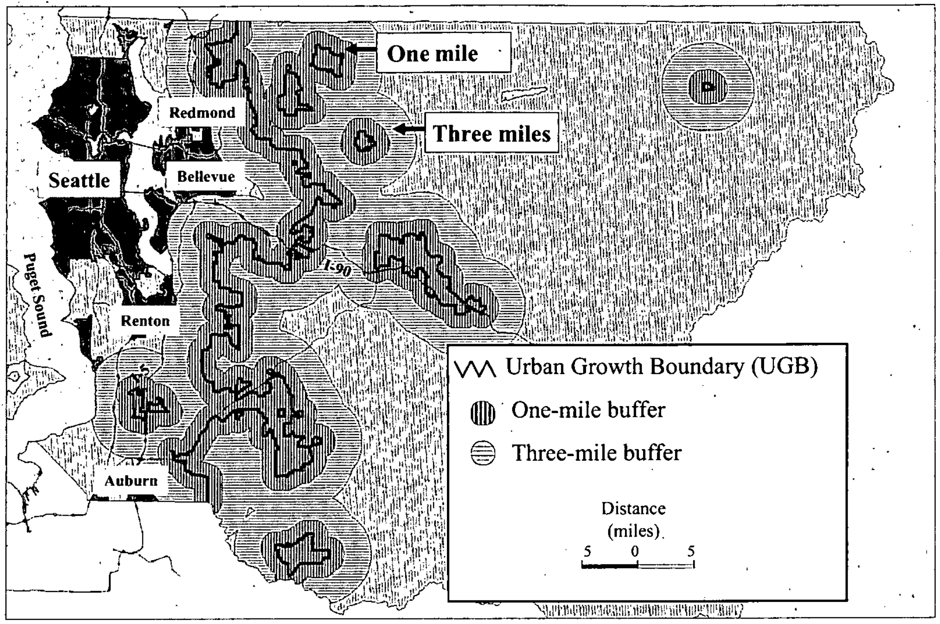
[22] The marginal effect was calculated as the following: $-0.28 = \exp(-0.325) - 1$.

[23] To my knowledge, this is the first paper to utilize a spatial discontinuity feature within a difference and difference framework.

FIGURE 4.—PARCEL SAMPLES AROUND UGB



Note that the parameter estimate $\hat{\theta}_3 = -0.390$ indicates that parcels outside the boundary after the law change were significantly less likely to develop even in this restricted sample. The parameter estimate is of a similar magnitude to the estimate using the whole sample. In addition, when the analysis is restricted to parcels within three miles of the UGB, the parameter estimate $\hat{\theta}_1$ is only modestly statistically different from 0 (p-value = 0.118). This finding indicates that before the UGB was imposed, parcels outside, but near, the boundary were not much less likely to develop than parcels within the boundary. However, on this subsample of parcels near the boundary, the parameter estimate $\hat{\theta}_2$ becomes positively significant, suggesting that there may have been some increase in the likelihood of development just inside the boundary, after the law change. As a further robustness check, I limit the sample to parcels within one mile (on either side) of the UGB. The parameter estimates from the hazard regression on this sample are largely unchanged, with the exception of further lowering the likelihood of development outside the UGB after the law change. Within one mile of the UGB, parcels outside the boundary are 39% less likely to develop.

It may be the case that the likelihood of development outside the UGB is declining over time for reasons unrelated to the boundary. For example, rising traffic congestion during the sample period may have raised the cost of commuting, reducing the price families would be willing to pay for parcels far from the central business district and therefore lowering the likelihood of development. If this were truly the case, a post-GMA drop in the likelihood of development simply may have resulted from a continuous decline in development over time and space. As a robustness check against this possibility, I construct a pseudo-UGB one mile inside the actual boundary. If the likelihood of development is declining over time with distance, then we should observe a similar set of parameter estimates around the pseudo-boundary. This robustness check is restricted to parcels two miles inside of the actual UGB or, alternatively, one mile on either side of the pseudo-boundary and is, thus, analogous to column 4 of table 3. The coefficient estimates are presented in column 5. Land outside the pseudo-UGB was actually more likely to be developed after the law change than land inside the pseudo-UGB. This finding suggests that the UGB parameter estimates presented in columns 2–4 are the result of boundary-specific effects, not of unobserved changes in the urban economy.

B. *Hazard Estimates for the Stochastic Case*

A central prediction of this paper is that density restrictions make developers less sensitive to real-option considerations, making uncertainty in the marketplace less of a deterrent to development. To test this prediction, I interact the price uncertainty term, $\hat{\sigma}^2_{jt}$, which I created in section IV, with the dummy variables for UGB presented above. The econometric specification of the covariates that shift the baseline hazard is

TABLE 4.—LAND DEVELOPMENT, UGB, AND UNCERTAINTY HAZARD MODEL OF DEVELOPMENT
(BOOTSTRAPPED STANDARD ERRORS IN PARENTHESES)[1]

Explanatory Variable (parameter)	(1) No Controls for UGB	(2) Include Controls for UGB	(3) Restricted to within Three Miles of UGB	(4) Restricted to within One Mile of UGB	(5) Pseudo-UGB (one mile inside actual UGB)[5]
Anticipated one-year-ahead (φ_1) quality-adjusted house price[2]	0.777	0.998	0.567	0.497	0.378
	(0.015)	(0.015)	(0.023)	0.034	(0.034)
House-price growth rate (φ_2)	0.543	−8.315	−5.171	−4.504	0.123
	(0.522)	(0.627)	(0.890)	(0.973)	(0.975)
Interest rates (φ_3)	−0.018	−0.046	−0.065	−0.090	−0.067
	(0.002)	(0.002)	(0.002)	(0.004)	(0.004)
Distance to CBD (φ_4) (in log miles)	0.337	0.372	0.094	0.097	−0.016
	(0.006)	(0.007)	(0.014)	(0.027)	(0.023)
Scenic view (φ_5)	0.054	0.052	0.024	0.005	−0.005
	(0.003)	(0.003)	(0.004)	(0.006)	(0.006)
Dummy Variables for UGB[3]					
Outside UGB (θ_1)		−0.029	0.068	0.151	−0.060
		(0.020)	(0.027)	(0.019)	(0.022)
After 1990 (θ_2)		−0.185	−0.026	0.019	−0.086
		(0.010)	(0.015)	(0.019)	(0.026)
After 1990 × outside UGB (θ_3)		−0.537	−0.595	−0.654	0.200
		(0.029)	(0.026)	(0.040)	(0.026)
Price uncertainty ($\hat{\sigma}^2$) (γ_1)	−20.477	−27.744	−21.848	−21.252	−27.005
	(0.746)	(0.858)	(1.078)	(1.093)	(3.169)
Dummy Variables for UGB × Price Uncertainty[4]					
Outside UGB × $\hat{\sigma}^2$ (γ_2)		−0.882	2.969	−15.530	6.314
		(1.550)	(1.748)	(2.762)	(3.452)
After 1990 × $\hat{\sigma}^2$ (γ_3)		6.643	−4.309	9.980	−5.540
		(1.327)	(1.967)	(1.804)	(4.050)
After 1990 × outside UGB × $\hat{\sigma}^2$ (γ_4)		17.491	26.680	22.969	13.897
		(4.140)	(3.986)	(6.465)	(4.679)
Constant		−14.734	−9.065	−8.121	−6.578
		(0.180)	(0.290)	(0.438)	(0.426)
Additional conversion costs (Ψ_i)	Yes	Yes	Yes	Yes	Yes
Subcounty zoning fixed effects	Yes	Yes	Yes	Yes	Yes
Log likelihood	−189,687	−188,931	−125,712	−69,062	−79,777
Parcel years at risk	1,990,255	1,990,255	1,220,551	674,047	717,066

[1] Exponential distribution.

[2] Average of school district quarterly predicted quality-adjusted house prices in the next calendar year, from regression model: $P^{\bar{q}}_{jt} = \alpha_{0j} + \alpha_{1j}P^{\bar{q}}_{jt-4} + e_{jt}$.

[3] Dummy variables for whether a parcel is ever outside the UGB; whether the spell-year at risk is after 1994 (the year of UGB implementation); and for spell-years at risk of development for parcels outside the UGB.

[4] Allow the effect of price uncertainty on the hazard of development to vary by UGB status.

[5] Sample consists of parcels on either side of a simulated boundary one mile inside the actual boundary.

$$
\begin{aligned}
X'\beta = {} & \varphi_1 E[P^{\bar{q}}_{jt+1}] + \varphi_2 g_{jt} + \varphi_3 r_t + \varphi_4 u_i + \varphi_5 v_i + C_i' \Psi_i \\
& + Z_{FE_i} + \theta_1 D_i^{outside} + \theta_2 D_t^{after} + \theta_3 D_t^{after} \\
& \times D_i^{outside} + \gamma_1 \hat{\sigma}^2_{jt} + \gamma_2(\hat{\sigma}^2_{jt} \times D_i^{outside}) \\
& + \gamma_3(\hat{\sigma}^2_{jt} \times D_t^{after}) + \gamma_4(\hat{\sigma}^2_{jt} \times D_i^{outside} \times D_t^{after}).
\end{aligned} \tag{9}
$$

In addition to the variables from the hazard without uncertainty (equation [8]), I include the measure of price uncertainty directly in the model, with the associated parameter, γ_1. Next, I interact the dummy variable for whether a parcel was outside the UGB $D_i^{outside}$ with the price uncertainty term, $\hat{\sigma}^2_{jt}$. The parameter on this interaction is γ_2. This interaction allows the timing of development to be more or less responsive to uncertainty outside the boundary. Then, to allow the effect of uncertainty on development timing to be different after the GMA for the entire county, I interact $\hat{\sigma}^2_{jt}$ with the dummy variable, D_t^{after}. The parameter on this interacted term is γ_3. Finally, I interact price uncertainty, $\hat{\sigma}^2_{jt}$, with the dummies D_t^{after} and $D_i^{outside}$. The parameter γ_4 captures the marginal effect of price uncertainty on the likelihood of development outside the boundary after the law was passed. If the real option to convert is reduced by the density restrictions, then development decisions for parcels outside the boundary after the law changes should be relatively less responsive to price uncertainty than before the GMA. Formally, I test the null hypothesis, $H_0 : \gamma_4 = 0$, against the alternative hypothesis: $H_a : \gamma_4 > 0$.

Column 1 of table 4 provides the parameter estimates when a measure of house-price uncertainty is included, but controls for the UGB are omitted. Note that, when measured for the entire county and for the entire sample period, greater price uncertainty delays the construction of new housing, a finding consistent with the presence of real options in land markets generally. Column 2 provides the parameter estimates when the model includes the dummy variables for the UGB and the dummy variables are interacted with the measure of price uncertainty, as presented in equation (9). First note that that parameter estimate $\hat{\theta}_3$ is negative and significant and suggests a larger deterrent to development than the equivalent estimate in column 2 of table 3 (42% decline in the likelihood of development relative to a 28% decline). The parameter estimates for interaction of uncertainty with the dummy variable for a parcel being outside the boundary before the law, $\hat{\gamma}_2$, is not statistically different from 0 at any of the standard significance levels. Furthermore, uncertainty after the passage of the GMA, as indicated by the coefficient estimate on the interaction term $\hat{\gamma}_3$, is relatively modest, which suggests that price uncertainty did not differentially impact parcels outside the boundary before the GMA or parcels inside the boundary after the law change.

The parameter estimate of principal interest, $\hat{\gamma}_4$, is positive and significantly different from 0. A positive coefficient indicates that parcels outside the boundary after the law change were relatively less deterred from developing at a given level of uncertainty. The parameter estimate for $\hat{\gamma}_4$ is a positive 17.491. This finding is consistent with the hypothesis that restrictions on the intensity of development may reduce the value of the real option to convert land to a higher-intensity use and thus accelerate development. In fact, summing the parameter estimates for uncertainty, $\hat{\gamma}_1 + \hat{\gamma}_2 + \hat{\gamma}_3 + \hat{\gamma}_4$, yields a value of −4.492, suggesting that greater uncertainty is much less of a deterrent to development outside the boundary after the GMA. Applying a Wald test to the hypothesis H_0: $\gamma_1 + \gamma_2 + \gamma_3 + \gamma_4 = 0$ indicates that one cannot reject the null in favor of the alternative H_a: $\gamma_1 + \gamma_2 + \gamma_3 + \gamma_4 \neq 0$ (p-value equals 0.366) that price uncertainty does not delay development outside the boundary after the law change.

Following the convention of table 3, I restrict the sample to parcels within three miles of the UGB. The results from estimating the hazard on this subsample are presented in column 3. Within three miles of the UGB, the effect of price uncertainty appears to play even less of a role in deterring development outside the boundary after the law. The coefficient estimate $\hat{\gamma}_4$ is statistically greater than 0 at standard cutoffs and is associated with a 17% increase in the likelihood of development. Restricting the sample to parcels within one mile of the UGB (column [4]) does not appreciably affect the magnitude of the coefficient estimate, $\hat{\gamma}_4$, or its statistical significance. Examining the effect of price uncertainty on parcels outside the pseudo-UGB (column [5]) after the law change, I find that price uncertainty remains a significant (though smaller) deterrent to development. The null hypothesis that uncertainty does not affect development is rejected at all significance levels, with an χ^2 value of 40.1. The finding that uncertainty remains a deterrent outside the simulated UGB, but not the actual UGB, is further evidence that the restrictive zoning of the GMA was responsible for eroding option value.

Table 4 reveals that uncertainty is a principal deterrent of development in the market generally; however, it is much less of a deterrent (if any) once parcels are subject to the GMA. This finding, perhaps obviously, suggests that landowners weigh their real options only when they in fact have options. Removing legal development rights from the land appears to desensitize its owners to volatility in the marketplace. Furthermore, failure to consider the deterrent effect of uncertainty (equation [8], table 3) would lead to the underestimation of the direct effect of the UGB on the timing of development.

VI. Conclusion

This paper presents compelling evidence that the enactment of a growth boundary reduced development in designated rural areas and increased construction in urban areas, which suggests that the Growth Management Act is achieving its intended effect of concentrating housing growth. It also finds that variable investment intensity is an essential factor in the real option to delay. By restricting future development intensity, binding growth controls remove a principal deterrent to investment: uncertainty about optimum future use. This suggests that in the absence of real-option considerations, the growth boundary would have reduced development by 42% to 48%, but by severing the link between future price uncertainty and future use uncertainty, the net effect of the GMA was to reduce the likelihood of development by only 28% to 39%.

This analysis, in the end, reflects the experience of only a single city. It may be problematic to extrapolate how other cities may respond to similar legislation. A growth boundary around another city might have a greater impact on housing construction, given that unincorporated King County already had some planning laws and because school finance equalization mitigates some of the fiscal incentives to sprawl that exist in other states. At the same time, the Seattle area has enjoyed strong employment and earnings growth, yielding considerable upward pressure on house prices and thus development.

On the other hand, one can reasonably posit that the growth controls themselves have contributed to rising house prices by curtailing the supply of land. Indeed, the contribution of growth controls and growth management to rising house prices and the ultimate welfare effects of such appreciation is a central theoretical and empirical debate with regards to growth boundaries, growth controls, and zoning generally. Recently, Glaeser and Gyourko (2003) and Glaeser, Gyourko, and Saks (2005) have argued that the myriad of planning, zoning, and permitting regulations governing development is largely responsible for the dramatic rise in house prices in a select number of cities. By making it more difficult to subdivide land by capping building heights, designating historic districts, imposing impact fees, and generally raising bureaucratic hurdles, local and state governments have made building supply less elastic, causing demand shocks for housing in a city to result in higher housing prices instead of new housing construction. This paper supports their underlying findings by demonstrating that the growth boundary did slow development activity; however, the paper also shows that stringent zoning can reduce option incentives to delay, raising at least the possibility that in other markets land development regulations could accelerate investment.[24]

With regards to the impact of uncertainty on investment, Seattle may be particularly sensitive to real-option considerations.[25] The local economy and therefore the housing market are heavily dependent on the welfare of just two firms, Boeing and Microsoft. Thus, uncertainty as to the future of these businesses' prospects may make it particularly difficult for developers to determine the profit-maximizing land use intensity. Larger, more diversified urban economies may have less uncertainty in the marketplace and there may be less real-option value attached to the land.

These findings offer further evidence for the presence of real options in land development and in investment decisions generally. Furthermore, they highlight the importance of flexible investment intensity and convexity of the underlying profit function in generating option value. These findings also imply that carefully designed urban planning may be used to accelerate development in targeted areas where the optimal use of the land by the development community is uncertain but for where immediate development is a central policy goal.

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[24] Glaeser and Gyourko (2003) and Glaeser, Gyourko, and Saks (2005) do not directly estimate the contribution of zoning to housing prices. Instead they calculate the "zoning tax" as the sales price of housing less construction cost of housing, less their estimate (based on cross-section variation in lot size) of the consumption value of land. Their insight is that if housing is competitively supplied, sales prices should largely reflect the production cost of housing plus the consumption value of the land itself. Their estimate of the regulatory tax on homes is quite large for West Coast cities, including Seattle, as well as New York and Boston.

[25] Quigg (1993) finds evidence of real option in land price valuations using Multiple Listing Service (MLS) data from Seattle in the seventies and eighties.

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Journal	2009 IF	2010 IF	2011 IF	Average IF
JOURNAL OF ECONOMIC LITERATURE	6.91	7.43	9.24	7.86
ACADEMY OF MANAGEMENT REVIEW	7.86	6.72	6.16	6.91
QUARTERLY JOURNAL OF ECONOMICS	5.64	5.94	5.92	5.83
ACADEMY OF MANAGEMENT JOURNAL	6.48	5.25	5.6	5.78
Academy of Management Annals		5.44	4.48	4.96
MIS QUARTERLY	4.48	5.04	4.44	4.65
Technological and Economic Development of Economy		5.6	3.23	4.42
JOURNAL OF MARKETING	3.77	3.77	5.47	4.34
REVIEW OF FINANCIAL STUDIES	3.55	4.6	4.74	4.30
JOURNAL OF MANAGEMENT	4.42	3.75	4.59	4.25
Journal of Supply Chain Management		5.85	2.65	4.25
JOURNAL OF OPERATIONS MANAGEMENT	3.23	5.09	4.38	4.23
JOURNAL OF FINANCE	3.76	4.15	4.21	4.04
STRATEGIC MANAGEMENT JOURNAL	4.46	3.58	3.78	3.94
ADMINISTRATIVE SCIENCE QUARTERLY	3.84	3.68	4.21	3.91
JOURNAL OF FINANCIAL ECONOMICS	4.02	3.81	3.72	3.85
JOURNAL OF ECONOMIC PERSPECTIVES	3.55	3.7	4.21	3.82
American Economic Journal-Macroeconomics			3.8	3.80
JOURNAL OF INTERNATIONAL BUSINESS STUDIES	3.76	4.18	3.4	3.78
ORGANIZATION SCIENCE	3.12	3.8	4.33	3.75
JOURNAL OF MANAGEMENT STUDIES	2.8	3.81	4.25	3.62

JOURNAL OF POLITICAL ECONOMY	3.84	4.06	2.9	3.60
ECONOMETRICA	4	3.18	2.97	3.38
ORGANIZATIONAL RESEARCH METHODS	2.47	4.42	3.25	3.38
OMEGA-INTERNATIONAL JOURNAL OF MANAGEMENT SCIENCE	3.1	3.46	3.33	3.30
Asia Pacific Journal of Management		3.35	3.06	3.21
JOURNAL OF RETAILING	4.56	2.25	2.75	3.19
Academy of Management Learning & Education	2.23	2.53	4.8	3.19
Journal of Business Logistics		3.9	2.35	3.13
Academy of Management Perspectives		2.47	3.75	3.11
BROOKINGS PAPERS ON ECONOMIC ACTIVITY	2.1	3.78	3.4	3.09
JOURNAL OF THE ACADEMY OF MARKETING SCIENCE		3.26	2.67	2.97
REVIEW OF ECONOMIC STUDIES	2.9	3.11	2.81	2.94
JOURNAL OF CONSUMER RESEARCH	3.02	2.59	3.1	2.90
JOURNAL OF ACCOUNTING & ECONOMICS	2.6	2.81	3.28	2.90
Review of Environmental Economics and Policy	3.64	2.78	2.14	2.85
INTERNATIONAL JOURNAL OF MANAGEMENT REVIEWS	2.28	2.64	3.58	2.83
Strategic Organization	4.05	2.72	1.64	2.80
JOURNAL OF MARKETING RESEARCH	3.09	2.8	2.51	2.80
AMERICAN ECONOMIC REVIEW	2.53	3.15	2.69	2.79
Journal of Business Economics and Management	2.01	3.86	2.38	2.75
American Economic Journal-Applied Economics			2.75	2.75
ORGANIZATIONAL BEHAVIOR AND HUMAN DECISION PROCESSES	2.54	2.48	3.12	2.71
REVIEW OF ECONOMICS AND STATISTICS	2.55	2.88	2.66	2.70
JOURNAL OF ECONOMIC GROWTH	3.08	2.45	2.45	2.66
ECOLOGICAL ECONOMICS	2.42	2.75	2.71	2.63
Management and Organization Review		2.8	2.44	2.62
INTERNATIONAL JOURNAL OF PHYSICAL DISTRIBUTION & LOGISTICS MANAGEMENT		2.61		2.61
LEADERSHIP QUARTERLY	2.2	2.9	2.7	2.60
EXPERIMENTAL ECONOMICS	3.3	1.86		2.58
HUMAN RESOURCE MANAGEMENT		2.79	2.37	2.58