The land value tax against urban sprawl: a real options approach

Master thesis

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Abstract

Urban sprawl is a pressing issue due to the negative externalities it produces, that result in the general loss of well-being. Ensuring the efficient use of already urbanized land is key to protect unsealed land beyond the urban fringe. Recently, the land value tax (LVT) has gained the attention of researchers due to its potential use as a planning tool for this purpose, yet why its effect on uncertainty and the timing of development has been overlooked seems inexplicable, considering it has been central in other studies investigating the effect of alternative planning tools on development and urban sprawl. The aim of this research is to address this gap in the literature, by conducting an empirical analysis within a real options framework, simulating different LVT rates, and studying the effect of two variables on the timing of development: house price uncertainty because it is an indicator of developers' knowledge of market conditions and willingness to develop, as well as the sensitivity of vacant land to house price uncertainty as distance from the CBD increases, since it could help determine whether the simulated LVT would accelerate development near the CBD or further away causing urban sprawl. I use property tax roll data from the Duval County Assessor's Office, which provides appraisals for land and improvements separately. The proposed methodology may allow to study the effects of a LVT without the need for specific case study data with exogenous variation. Moreover, it could be helpful to policy makers who wish to make an ex-ante assessment of the effects of applying a LVT or of making changes in the capital-land tax-base ratio. The results showed that levying a LVT decreased the value of land and therefore also the volatility of land values, which in turn decreased the negative effect of house price uncertainty on the timing of development, increasing the likelihood of immediate development by 0.13%. In practice this would intensify urban sprawl. Yet, additional results showed that after levying a LVT the sensitivity of vacant land value to house price uncertainty increased with distance from the CBD, suggesting that a LVT could help decrease development at the fringe and encourage it in already urbanized areas near the CBD, thus reducing urban sprawl.

1. Introduction

As the percentage of the world's population living in cities continues to grow (United Nations, Department of Economic and Social Affairs, Population Division, 2018), and urban population densities continue to decline (Angel et al., 2005), urban sprawl is expected to become an increasingly vital theme in policy debate[1] due to the various negative externalities it produces, that result in the general loss of well-being. The phenomenon of sprawl is characterized by the excessive expansion of cities and consequent loss of open land to urban development (Barbero-Sierra et al., 2013; European Commission. Directorate General for the Environment., 2016; Munafò et al., 2013; Scalenghe & Marsan, 2009); increased car dependency and commuting time which lead to higher traffic congestion (Hortas-Rico & Solé-Ollé, 2010) and pollution (Glaeser & Kahn, 2003); higher costs of social interaction (Farber & Li, 2013; Foldvary & Minola, 2017); and higher marginal costs of infrastructure and utilities.[2]

Starting from the standard monocentric models of Mills (1967), Muth (1969) and Alonso (1964), it can be said that urban sprawl is an endogenous process sparked by the preference of households for larger homes and fueled by rising incomes (Margo, 1992) and decreasing transportation costs (Glaeser & Kahn, 2003) which allow households to bid for cheap open land outside of the city (Neuman, 2005).[3] Thus, it is the margin; the "leading edge of urban growth" (Inostroza et al., 2013) that expands in an irregular fashion – often through a process of suburbanization (Galster et al., 2001; Nechyba & Walsh, 2004) – resulting in a discontinuous land use pattern (Siedentop & Fina, 2010) and fragmented development (OECD, 2018). In the absence of planning regulations that control density and urban growth, sprawl is more likely to occur (Cunningham, 2006, 2007). Moreover, the speculative behavior of land owners who hold land near the

[1] At present, advancing policies to curb its negative effects is seen as a key step for reaching the target of the Paris Agreement and Sustainable Development Goals (OECD, 2018; United Nations, 2016); and the New Urban Agenda advocates for "sustainable population densities" and compact city design to counter urban sprawl and marginalization (UN Habitat, 2017). Similarly, the No-net land take by 2050 (European Commission. Directorate General for the Environment., 2016) policy has been adopted in Europe, for monitoring land take and re-converting sealed land for cultivation.

[2] In many cases (unfairly) financed by households living in denser, already developed areas, through a property tax that works through an average cost pricing mechanism (Brueckner, 2000; Carruthers & Ulfarsson, 2003; Foldvary & Minola, 2017).

[3] Although exogenous processes might play a role as well. For instance, Baum-Snow (2007) provides empirical evidence that the construction of the interstate highway system in the United States between 1950 and 1990, lead to the decentralization of central cities within metropolitan statistical areas (MSAs).

CBD expecting higher returns, is also likely to cause low-density development further out (Ottensmann, 1977). The opportunity cost of agricultural land plays an important role in determining the urban extension (Brueckner & Fansler, 1983).[4] The lower the opportunity cost of agricultural land is, the less attractive it will be to hold agricultural land for its later development and the more likely that speculative developers will resort to infill development within the already urbanized area.

Already in the 19th century, Henry George (1879) recognized the negative effects of the outward expansion of cities and the benefits of high urban population densities. As a remedy, he proposed a single tax levied on the value of land that, among other benefits, would discourage land monopolization and speculation. George's ideas became popular in his time, and in several countries a land value tax (LVT) was adopted. More recently, the LVT has become popular among scholars researching its effects on urban development. Empirical research has focused on its incentive effect to increase the capital-to-land ratio. However, the number of studies is somewhat limited, due to the case study type approach, and the relatively few recent cases in which a LVT has been implemented in practice that would allow for exogenous variation. Examples include the work by Bourassa (1987, 1990), Wenner (2018), and Gemmell et al. (2019). To the best of my knowledge empirical research testing for effects of a LVT on urban sprawl within a real options framework, which allows to account for uncertainty in the development decision process, has not been done before. Although a real options approach has been used to study the effects on urban sprawl of other planning tools such as growth controls (Cunningham, 2007) or price-stabilizing policies (Sun et al., 2021). Therefore, the aim of this research is to address this gap in the literature, by conducting an empirical and simulation-based study that helps understand the effect that a LVT would have on the real option to postpone development, and under which circumstances it could be used as a planning tool to control urban sprawl.

The methodology involves simulating the implementation of a LVT at varying rates, calculating the uncertainty of future house prices, and using it as a parameter in survival analysis and OLS models in order

[4] The authors provide empirical evidence showing a negative impact of agricultural rent on urban size.

to analyze its effect on the timing of development and vacant land prices. The main advantage of the proposed methodology is that it may allow studying the effects of a LVT without the need for specific case study data with exogenous variation produced by tax-base modifications, amalgamations, etc. Moreover, it could be helpful to policy makers who wish to make an ex-ante assessment of the effects of applying a LVT, or of making changes to the capital-land tax-base ratio. In order to establish a guide line for this analysis, I put forward the following research question:

What could the effects of a LVT on the decision to develop be, and what can we learn about its use as a tool to prevent urban sprawl?

Further sub questions are necessary to look at each foreseeable effect of the LVT individually so as to make a better-informed judgement that will help answer the research question:

(i) Does a LVT decrease the real option to wait and the timing of development?

(ii) Would implementing a LVT reduce development near the urban fringe, and increase it near the CBD?

(iii) What is the effect of altering the LVT rate?

Based on empirical evidence found in previous studies (Bulan et al., 2009; Cunningham, 2006; Grovenstein et al., 2011; Ooi et al., 2006; Quigg, 1993; Sun et al., 2021), I expect that there will be an implicit option to postpone development in the value of land, and that levying a LVT will reduce the real option to postpone development, and increase the hazard rate of development. Moreover, I anticipate changes in the spatial distribution of real option value and hazard rate of development after the tax is implemented. These will depend on the convexity of the land price function in terms of distance to the CBD, and any particularities specific to the study area.

In the next section, a review of the literature is presented. Section 3 gives an overview of the data and methodology, followed by section 4 in which each step of the methodology is explained in detail, and results are presented. The discussion is found in section 5 and is followed by a brief conclusion in section 6.

2. Theoretical Framework and Existing Research

A. Henry George and the LVT

In Progress and Poverty, George (1879) established a direct link between wages and land, stating that wages were not drawn from capital but were rather produced by labor which could only be exerted on land.[5] Minimum wages would therefore be determined by the produce of laborers in the best available unmonopolized land, i.e., marginal land on which no rent was earned.[6] On the other hand, rent would be determined by the surplus produced on monopolized land over the least productive unmonopolized land. Thus, as the margin of cultivation extended farther out to less productive land, wages decreased but rent increased,[7] leading to an increasingly unequal distribution of wealth between laborers and land owners.[8] Following these premises, he opposed landownership for three main reasons: The monopoly of land allowed landowners to set low wages and retain most of land rent as profit. Moreover, this was an "unearned" profit because the value of land resulted from the productive efforts of all members of society.[9] In addition, landowners expecting a higher future value of their land would often leave it idle, forcing the margin of cultivation "farther than required by the necessities of production." George's proposed remedy, was a single tax on land that would replace all other taxes. This way, landowners would bear the full burden, and the "unearned" profit would be fairly redistributed to all members of society. His ideas became popular in his time, and various countries adopted a land value tax (LVT) (Dye & England, 2009; McCluskey & Franzsen, 2017).

B. Effects of the LVT

Because land is spatially fixed and heterogenous, a LVT offers various advantages: It is highly effective because land cannot be hidden and evasion is nearly impossible (Wenner, 2018). Moreover, the value of land reflects the benefits obtained by local public goods, and thus a LVT can be used to optimally finance

[5] Discarding Malthusian ideas commonly accepted at the time.
[6] Here he coincided with David Ricardo.
[7] George acknowledged this happened at the intensive margin as well, where cultivation was forced to "less and less productive points on the same lands."
[8] Capitalists were also in a disadvantageous position according to George.
[9] Thus, George did not condemn population growth, as Malthus had done. According to him, it could only be beneficial, as it would increase the economies of agglomeration and the productiveness of land.

them (Foldvary & Minola, 2017). In theory, a LVT could also prevent the unnecessary extension of the margin of cultivation. For instance, by increasing the costs of holding land, it could discourage speculation and ensure its more productive use (Brown, 1927). Furthermore, it is widely regarded as a better alternative to solve the problem of sprawl compared to a property tax on improvements (i.e., the main structure or any other additions): Because a LVT is unavoidable, it is neutral and does not distort the economic decisions of landowners. On the other hand, due to the elastic supply of improvements (materials and labor are mobile), landowners may choose to reduce the capital-to-land ratio in order to lower their tax burden when improvements are taxed (Banzhaf & Lavery, 2010; Richman, 1964). Therefore, reducing the tax on improvements and shifting the tax burden to the land component will have an incentive effect to develop land more intensively (Bourassa, 1987).[10] Another way in which a LVT could help check urban sprawl is related to how the markets for improvements and land respond differently to changes in demand: The elastic supply of improvements results in price changes that are moderate and mostly consistent within a housing demand, and instead of an equivalent shift in supply to reach a new equilibrium, it remains fixed in the short term and prices rise (or fall). Therefore, volatility of land prices tends to be higher than that of improvements, and in property markets where the value of land rises faster than the value of improvements, property values become more volatile (Bostic et al., 2007).[11] Levying a LVT reduces the value of land (Bourassa, 1990; Oates & Schwab, 2009), therefore dampening the volatility of house prices (Buitelaar & Meijer, 2022). It also implies a lower uncertainty of future house prices and therefore a higher rate of development. The rationale behind this is that due to the irreversible nature of development and large sums of money involved, developers will tend to delay investment until future investment conditions are more certain. If a LVT is levied then land becomes less volatile, future investment conditions become clearer and developers speed development. If this would occur at the urban fringe and more agricultural land is

[10] According to Brueckner and Kim (2003) a smaller city size may also be achieved by a tax on improvements, as such tax could have an alternative effect of reducing dwelling size, ultimately increasing density. Empirical evidence suggests that this dwelling size effect exists (Song & Zenou, 2006), although most studies focus on the incentive effect (Banzhaf & Lavery, 2010; Bourassa, 1990; Oates & Schwab, 1997; Wenner, 2018).

[11] Empirical evidence can be found in Albouy et al. (2018). Furthermore, Davis and Palumbo (2008) and Braun and Lee (2021) show evidence that the gap between land values and structure values has widened in the U.S. and Germany respectively.

converted, then LVT could increase sprawl. However, if development would happen in already urbanized areas, sprawl could be contained.

C. Real options in real estate development

Developers value this possibility to postpone development under uncertain conditions, however, traditional discounted cash flow (DCF) models overlook uncertainty due to its subjective and unquantifiable nature, and therefore tend to undervalue investment opportunities (Lucius, 2001).[12] In contrast, a real options valuation method makes it possible to identify added project value due to the presence of 'options' that provide developers with the managerial flexibility necessary to adapt to uncertain future circumstances (Samis et al., 2003).[13] An option is "a right, but not an obligation, to take some future specified action at a specified cost", that allows decision makers to take a future decision only in the case that it is profitable (Trigeorgis & Reuer, 2017). This limits downside losses and increases upside potential, expanding the value of the investment (Yeo & Qiu, 2003). Real options may be found in real estate development decisions, because they are characterized by irreversible investment and uncertain future demand conditions, both fundamental for the presence of real options according to Pindyck (1986). In real estate development options are generally comparable to European call options because they may be exercised at any time. An important difference is that the exercise time is unknown to developers, who are only able to make an educated guess based on their knowledge of the market. If they are able to postpone development long enough, they are more likely to assess market conditions properly and establish a more adequate highest and best use (HABU) of the land. Then the option is more likely to be 'in-the-money', which in this context means that the payoff from selling the project is higher than the costs of construction, i.e., a positive residual value of the land. Thus, when developers purchase land, they are purchasing an implicit real option that

[12] Knight (1921) describes in detail the difference between risk (present in DCF models) and uncertainty.

[13] The real options valuation method derives from the method developed by Black and Scholes (1973), and Merton (1973) for the valuation of financial options and other derivative securities (Titman, 1985). The main difference between both frameworks concerns the nature of the investment's underlying asset. In a financial options framework, the underlying asset is a security, whereas a real options framework is used when the underlying asset is a tangible, or real, asset (Trigeorgis & Reuer, 2017). It can be applied in a wide variety of contexts involving real assets. A few examples include the work by Slade (2001) on the valuation of options in (copper) mining projects; Moel and Tufano (2002) on the option to close or open (gold) mines; de Jong and Huisman (2002) on the valuation of options on electricity spot prices; Armstrong et al. (2004) on the valuation of oil projects; as well as the work by Insley (2002) on optimal harvest time and forestry investment.

gives them the ability to wait until future market conditions are clearer and to achieve a more optimal development. When uncertainty is high, the likelihood of poorly assessing the market and incurring a loss is higher, and therefore developers will value the real option to delay development even more.

D. Existing empirical research

There are a few empirical studies seeking to explain the effect of uncertainty on land values, based on the theoretical assumption that uncertainty increases the value of the real option to delay development implicit in the value of land.[14] Most of these studies rely on hedonic models that allow estimating the marginal effect of uncertainty and other variables on the value of land. One of the earlier examples is the work by Quigg (1993), who found a real option premium on vacant land in the city of Seattle. Similar studies we done by Grovenstein et al. (2011) in the city of Chicago, and by Cunningham (2006) in King County Washington. Furthermore, some research has centered on the effect of uncertainty on the timing of development. Evidence of a decreasing rate of development following an increase in house price uncertainty in Vancouver, Canada; and King County, Washington has been found by Bulan (2009) and Cunningham (2006) respectively. In addition, a few studies have focused on the effect of planning restrictions on development: Cunningham (2007) found that a growth boundary restricting the maximum allowed density in designated rural areas in King County, Washington would have reduced development by 48% in the absence of real option considerations, but because it simultaneously reduced uncertainty of the HABU, it only reduced the likelihood of development by 39%. Likewise, Sun et al. (2021), using a difference-in-difference approach, found that areas with higher house price risk in Toronto experienced 5% slower growth in urban cover between 1986 and 2016. Subsequently, they simulated the implementation of a price-stabilizing government policy which had the unintended effect of increasing the land cover by 9%.

[14] In most real estate development decisions, the time of exercise is not known, and therefore valuating the option with the Black-Scholes model or other traditional models is not possible.

E. LVT and the real options effect

Applying a LVT could have a similar effect than other planning tools used to check sprawl as it would reduce the value of land, dampening the volatility of house prices (Buitelaar & Meijer, 2022). In theory, this would reduce uncertainty in the housing market and developers would speed investment. Yet, this has not been empirically tested. It is unclear whether this 'real options effect' would hasten development at the urban fringe, or at already urbanized areas. Leading to more urban sprawl, or containing it (see Figure 2.1). In theory, following the standard monocentric models, the main determinant of the value of land is its accessibility to the CBD and therefore the land-value gradient is strongly negative (Heikkila et al., 1989). This means also that volatility of land values is higher near the CBD (Titman & Zhu, 2018). Then the effect of a LVT would be larger on more central locations, which could induce developers to develop there instead of at the fringe.

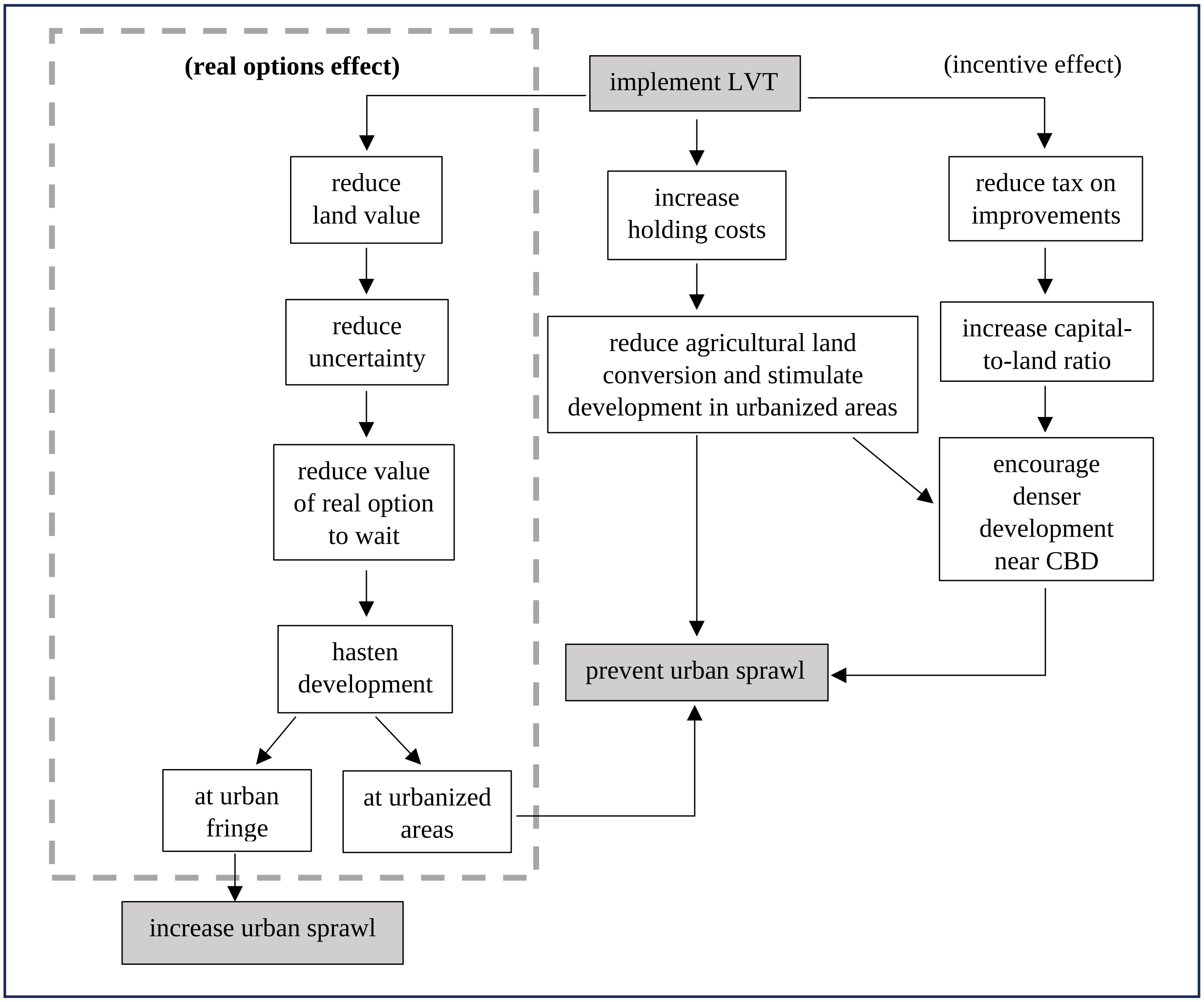

Figure 2.1 Conceptual model of LVT effects on urban sprawl.

3. Methodology

A. Overview of the methodological approach

The methodology is organized within a Real Options Approach (ROA) framework following the work by Cunningham (2006), that allows to determine the effect of house price uncertainty and other covariates on the timing of development (i.e., the speed or rate at which single-family housing is built on vacant land) and on the real option implicit in vacant land values. This approach should be useful for answering the research question and finding out what can be learned about the use of a LVT as a tool to prevent urban sprawl. First, in section 4.A I estimate plot-level changes in land value after simulating the introduction of three different LVT rates. This results in three scenarios with different property values: LVT 1, LVT 2, and LVT 3. Throughout the ROA these scenarios, together with the 'current' scenario in which the unaltered price of individual properties already reflects the prevailing tax rate at the time of the appraisal, allow to study the effect of a LVT on house price uncertainty, and consequently, on the timing of development and real option value. In sections 4.B through 4.E, I describe the ROA in detail. In 4.B I create a quality-adjusted house price index which allows to estimate house prices based on a set of housing and lot characteristics; in 4.C I forecast future house prices and subsequently calculate uncertainty; in 4.D I assess the effects of house price uncertainty on the timing of development (i.e., the speed or rate at which single-family housing is built on vacant land). In the presence of real options, this effect should be negative, therefore I expect that higher uncertainty will reduce the rate of development as developers prefer to wait and observe market conditions. Furthermore, according to the theory a LVT should decrease uncertainty, therefore reducing the real options effect; and finally, in 4.E I assess the effects of house price uncertainty on individual vacant lot prices. In this case the effect should be positive, therefore I expect that higher uncertainty will increase the real option premium to postpone development that is implicit in the value of land. Again, I expect that a LVT will reduce the real options effect.

B. Context and Data

I use property tax data from Duval County, upstate Florida. Upon request, the data was made available by the Duval County Assessor's Office (Duval County Property Appraiser, 2023), including tax rolls for all parcels from 2008-2022 (n=5,989,317) as well as GIS files of individual plot location and shape. Additional data includes median household income by ZIP Code Tabulation Area (ZCTA) (US Census Bureau, 2023), ZCTA boundary shapefiles (US Census Bureau, 2023), and the market yield on U.S. Treasury securities at 10-year constant maturity (FRED, 2023). Only parcels within the city of Jacksonville were included. ZCTAs that were considered are shown in Figure 3.1.[15]

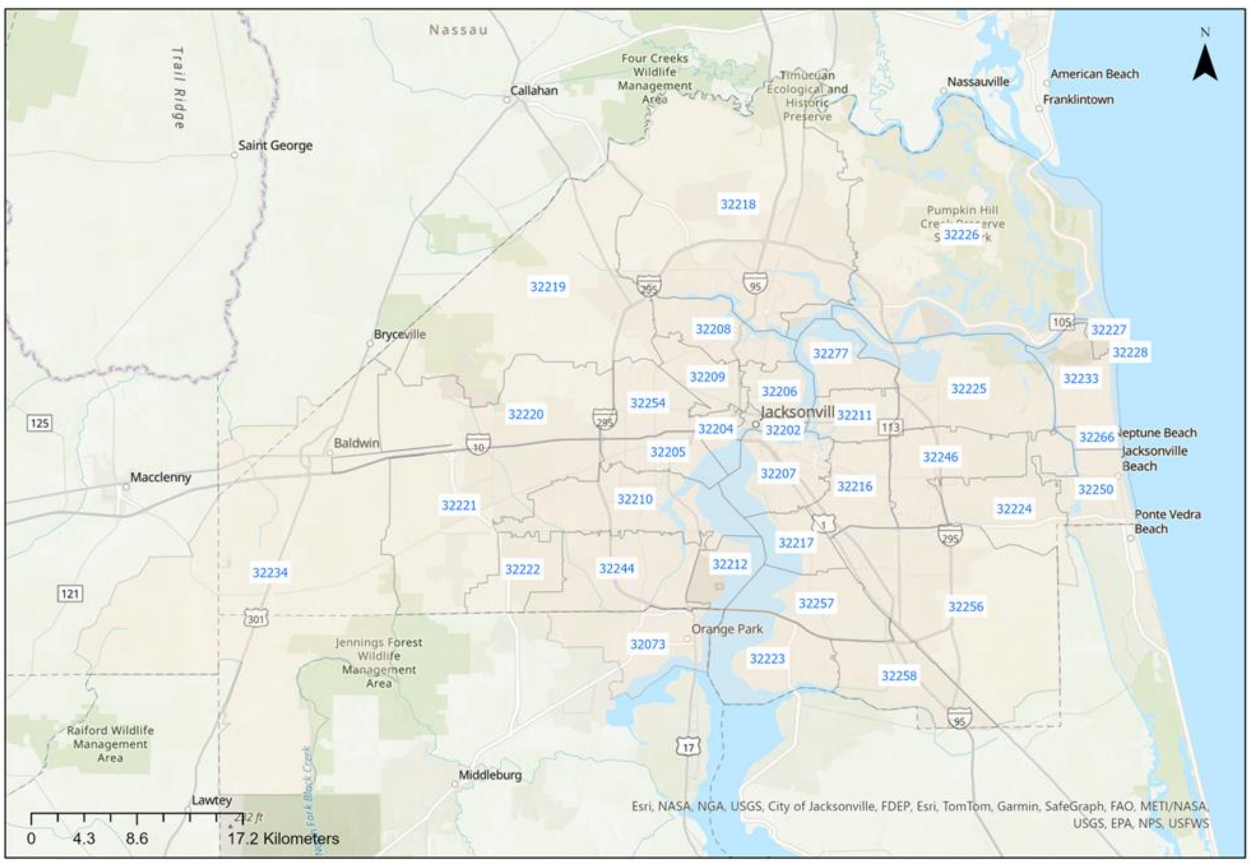

Figure 3.1 Map of Jacksonville with ZCTA boundaries.

[15] Although due to insufficient number of observations for 8 ZCTAs (The rule of thumb for minimum failed plots in survival analysis is $n \geq 10$, although for multivariate analysis $n \geq 20$ is preferred. See for instance (Ogundimu et al., 2016), I merged them with other ZCTAs. Thus, 32073 is merged to 32223; 32202 to 32206; 32204 to 32205; 32212 to 32257; 32227 and 32228 to 32233; 32234 to 32220; and 32266 to 32250. This resulted in a total of 27 ZCTAs, down from the original 35).

Appraisals of single-family properties for taxation purposes in Duval County are mostly done using Computer Assisted Mass Appraisal systems (CAMAs). These automated valuation models rely on data and require that land and building values are calculated separately for a higher precision. Land values are calculated using sales data with the sales comparison approach, while structure values are calculated using cost data with the replacement cost method. Thus, appraisal values within the data used can be found separately for land and improvements, obviating the need of using a method for disentangling both components (see for instance the work by Francke & van de Minne, 2017).

4. Results

A. Land value estimation after LVT changes

Empirical specification

Having obtained the value of land and structure separately, I may estimate changes in land value after a LVT is introduced, and modify the value of the land accordingly. In a stock-flow model (DiPasquale & Wheaton, 1994; Poterba, 1984), used to analyze gradual adjustments in the property cycle, house price in equilibrium is a function of supply and demand, including user costs such as property taxes, and a parameter that measures the responsiveness of homeowners (elasticity) to changes in the user cost. A similar framework may be applied in the case of land values to estimate how much the value of land decreases when a LVT is introduced. Høj et al. (2018), use a framework of household mobility and the housing market based on the work of Brueckner (1982), and show that under the assumption of full tax capitalization, "the relative effect on the value of a property caused by a change in the land tax rate depends only on the ratio of the land value to the value of the property":

$$\frac{\Delta V}{V} = \frac{\Delta \mathrm{LTR}}{r} \cdot \frac{\mathrm{L}}{V} \qquad (1)$$

Thus, assuming taxes are fully capitalized into house prices it is no longer necessary to estimate a responsiveness parameter such as the one in a stock-flow model, because at this point, the ratio of land value to total value would already be known. Here, V is the total property value, L the value of the land, ΔV is change in land value, and ΔLTR is the change in the land tax rate. The discount rate r is the household discount rate, i.e., the rate at which households discount all future after-tax value (utility) derived from living in a property. Since it reflects how future cash flows (including property tax payments) are valued by households, it should be in line with long-term financial instruments that households typically have access to. I use the market yield on U.S. Treasury securities at 10-year constant maturity, which lies between 0.93% and 3.91% from 2008 until 2022 (FRED, 2023). Thus, the change in property value after a change in land tax rate is introduced is given by:

$$\Delta \mathrm{V} = \frac{-\Delta \mathrm{LTR\ x\ L}}{r} \tag{2}$$

The property tax base rate for each period is the yearly millage rate[16] for Duval County property that lies between 16.5 and 19.2 from 2008 until 2022. For simplification percentage-point rates are considered hereafter. To gain a clearer understanding of how a LVT might affect urban sprawl at various rates, I simulate the implementation of three different property tax rates that will determine ΔLTR[17]: (1) increase the property tax rate by 0.1%, which is a realistic scenario for yearly property tax change in Duval County; (2) increase the property tax rate by 0.5%; and (3) consists in shifting the current property tax to the land component only. In (1) and (2), the change is applied to the full property tax, and then the new rate is separated into its land and improvement components based on the value of each, to obtain the change to the LVT.

Results

Property value change by year after implementing different tax rates are shown in Figure 4.1. Throughout the entire sample period, there is a lower change in property value for the LVT 1 scenario. The average percentage change of property value in this scenario is -0.5%, ranging from -0.2% in 2008 to -1.1%

[16] A tax rate representing a dollar per thousand of a property assessed value.
[17] Note that this acronym is equivalent to ΔLVT.

in 2021 when the change in property values was highest[18]. The change in property value for the LVT 2 scenario is higher than for LVT 3 in 2008, but in all other years LVT 3 is higher. On average the percentage change of property value in the LVT 2 scenario is -2.44%, ranging from -1.1% to -6.1%, and -2.39% for the LVT 3 scenario, ranging from -1.1% to -6.3%.

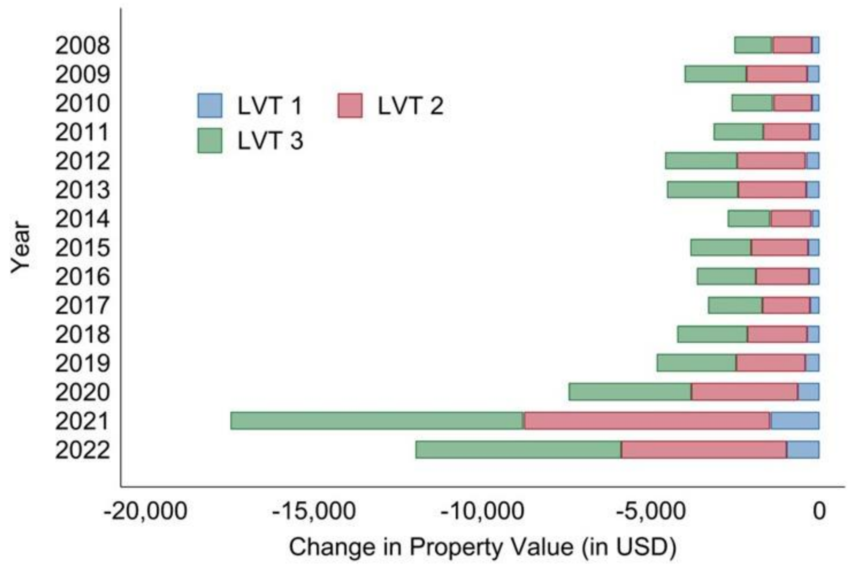

Figure 4.1 Changes in median property value by year after simulating the introduction of a LVT at different rates

[18] This in spite that house prices were highest in 2022.

B. ROA part 1

Empirical Specification

In order to explore how house prices varied from 2008 to 2022 between ZCTAs, as well as to further understand developers' future house price expectations, I create a quality-adjusted house price index using

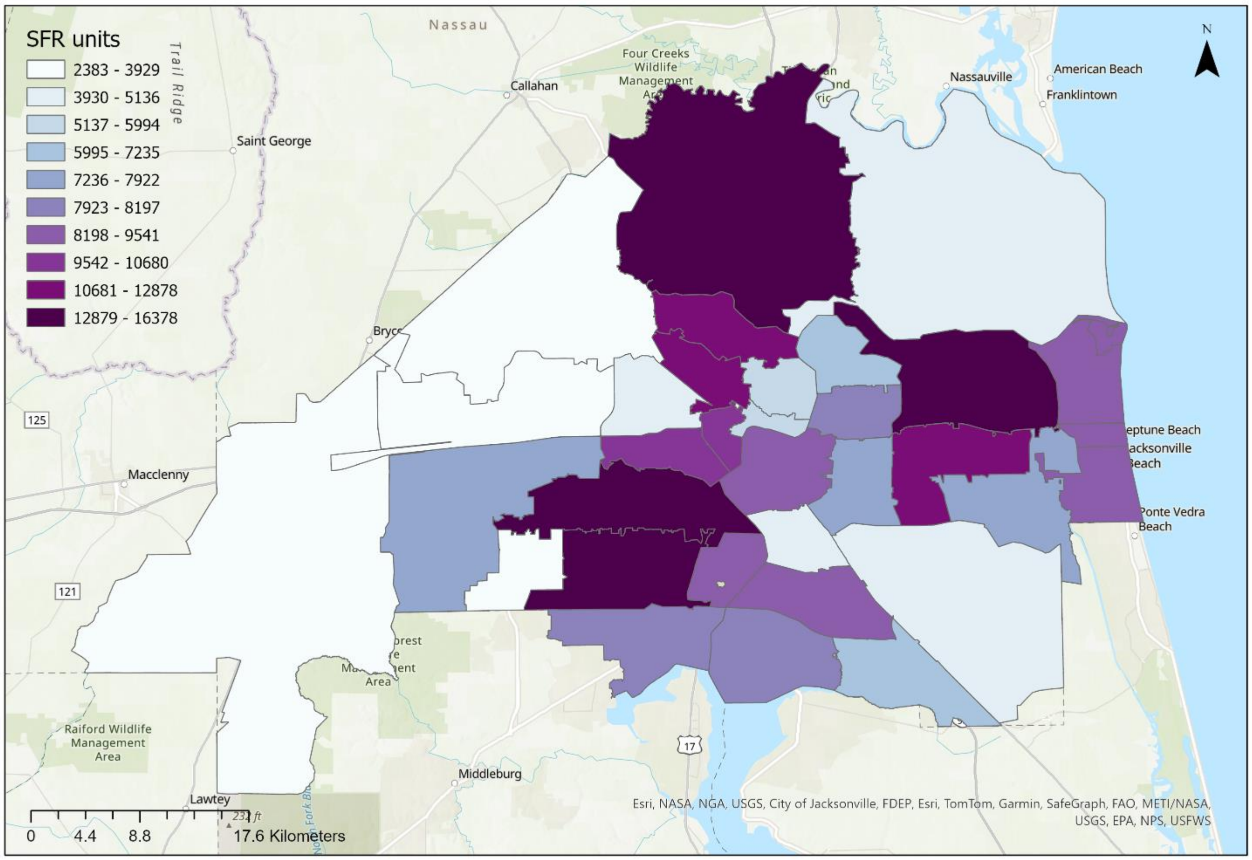

Figure 4.2 Single family residential units by ZCTA in 2008

only individual improved plots of land containing single family housing (see Figure 4.2) which allows me to include structural characteristics in the model. Additions such as porches and balconies were not considered. Due to its panel structure, it is possible to subdivide the data by ZCTA and year in order to allow for time and locational variation in the price indices. Therefore, I perform a total of 405 regressions using a combination of year (2008 – 2022) and ZCTAs. The model specification is expressed as follows:

$$\ln(p_{ijt}) = \alpha_{jt} + H'_{it}\Phi_{jt} + L'_{i}\chi_{jt} + \varepsilon_{ijt} \quad (3)$$

Where $\ln(p_{ijt})$ is the natural logarithm of the price of property i in a ZCTA j and year t. α is the intercept; H_{it} is a vector of housing characteristics including building age, building quality, heated area, and number of bedrooms; L'_{i} a vector of lot characteristics including distance to CBD and lot area; and ε_{ijt} is the error term. Φ and χ are the marginal effects of housing characteristics and lot characteristics respectively. These same series of regressions are performed again for property values calculated after introducing different LVT rates in the previous section (LVT 1, LVT 2, and LVT 3). Descriptive statistics for each of the variables included in the regressions can be found in Table 4.1.[19] The obtained parameter estimates are now used to estimate the value of house prices specific to each year and ZCTA. Again, the same procedure is repeated for LVT 1, LVT 2, and LVT 3.

Table 4.1 - Descriptive Statistics (aggregated) for quality-adjusted house prices

Variable	Current	LVT 1	LVT 2	LVT 3
Improved land value (in logs)	**11.809**	**11.794**	**11.775**	**11.771**
	(0.758)	**(0.700)**	**(0.695)**	**(0.696)**
Distance to CBD	13,838.870	13,838.870	13,838.870	13,838.870
(meters)	(6,543.774)	(6,543.774)	(6,543.774)	(6,543.774)
Plot area (in logs)	9.344	9.344	9.344	9.344
(sqft)	(1.014)	(1.014)	(1.014)	(1.014)
Building age	41.411	41.411	41.411	41.411
	(21.431)	(21.431)	(21.431)	(21.431)
Building quality	3.359	3.359	3.359	3.359
	(2.903)	(2.903)	(2.903)	(2.903)
Heated area (in logs)	7.401	7.401	7.401	7.401
(sqft)	(0.372)	(0.372)	(0.372)	(0.372)
Bedrooms	2.012	2.012	2.012	2.012
	(12.985)	(12.985)	(12.985)	(12.985)
Number of observations	3,624,952	3,624,952	3,624,952	3,624,952

Notes: Mean values. Standard errors in parentheses. Distance to CBD is calculated as euclidean distance from each plot to the centroid of ZCTA 32202.

[19] Includes observations for the whole sample, and is not disaggregated for each of the 405 regressions.

Results

I use the mean absolute percentage error (MAPE) as a goodness-of-fit measure to evaluate the accuracy of the estimated values in the regression. In all scenarios, predicted values for house prices are overestimated by less than 12%, which is still a relatively accurate result. Good but not highly accurate, according to Moreno et al. (2013). Median estimated house prices are lowest in 2013: $99,546.49; $99,027.22; $96,844.32; $96,329.51 for the scenarios 'current', LVT 1, LVT 2, and LVT 3 respectively. The highest values are in 2022: $231,211.93; $229,932.25; $224,605.32; $223,098.80. At this point it is already possible to observe the spatial distribution of estimated house prices[20] by ZCTA and year in the city of Jacksonville (Figure 4.3)

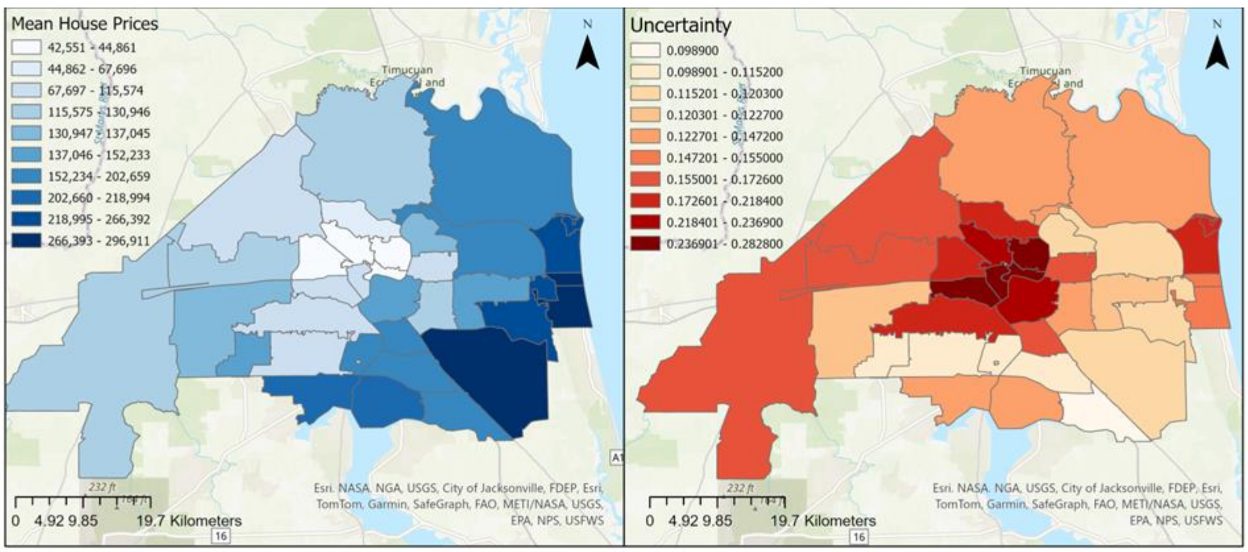

Figure 4.3 Full period mean house prices and uncertainty (3-year moving variance of residuals. Shown as S.D.) by ZCTA.

[20] Land values follow an almost identical spatial distribution.

C. ROA Part 2

Empirical Specification

The next step is used to calculate uncertainty of future house prices. First, I obtain the ZCTA-level price trajectory over the three years ahead from the price indices estimated in the previous step:

$$P_{jt}^{\bar{q}} = \alpha_{0j} + \alpha_{1j} P_{jt-3}^{\bar{q}} + \varepsilon_{jt} \tag{4}$$

In the literature, the one year-ahead price is usually chosen (i.e., 4 quarters), arguably because this is the time needed to build a single-family home and may be considered as a short-term time horizon by developers (Bulan et al., 2006; Cunningham, 2006; Somerville, 2001). However, considering property-tax roll data is gathered on a yearly basis only, I use a 3-year-ahead house price instead which still allows capturing some volatility and may be a plausible longer short-term time horizon for developers. Subsequently, I calculate uncertainty with the 3-year moving variance of residuals from the previous equation:

$$\hat{\sigma}_{jt}^2 = \sum_{k=1}^{3} \left(\hat{e}_{jt-k} - \hat{e}_{jt}\right)^2 / 3 \tag{5}$$

This would be the equivalent to a developer assessing uncertainty looking back at their own assessment of uncertainty in three previous periods. The same procedure is repeated for LVT 1, LVT 2, and LVT 3.

Results

Uncertainty was lowest in 2011. In this year, the different scenarios ordered from highest to lowest uncertainty were ‘current’, LVT 3, LVT 2, and LVT 1. The year with the highest uncertainty was 2016, and the same order from highest to lowest uncertainty was found for the four scenarios. In all years LVT 2 and 3 showed the most similar results, although from 2011-2017 uncertainty was higher for LVT 3, and from 2018-2022 for LVT 2. Figure 4.4 displays the spatial distribution of uncertainty by ZCTA and year in the city of Jacksonville for the ‘current’ scenario. It can be seen that there is serious house price variation in levels but other than that they remained relatively stable over time. Scenarios LVT 1, 2 and 3 follow a similar distribution.

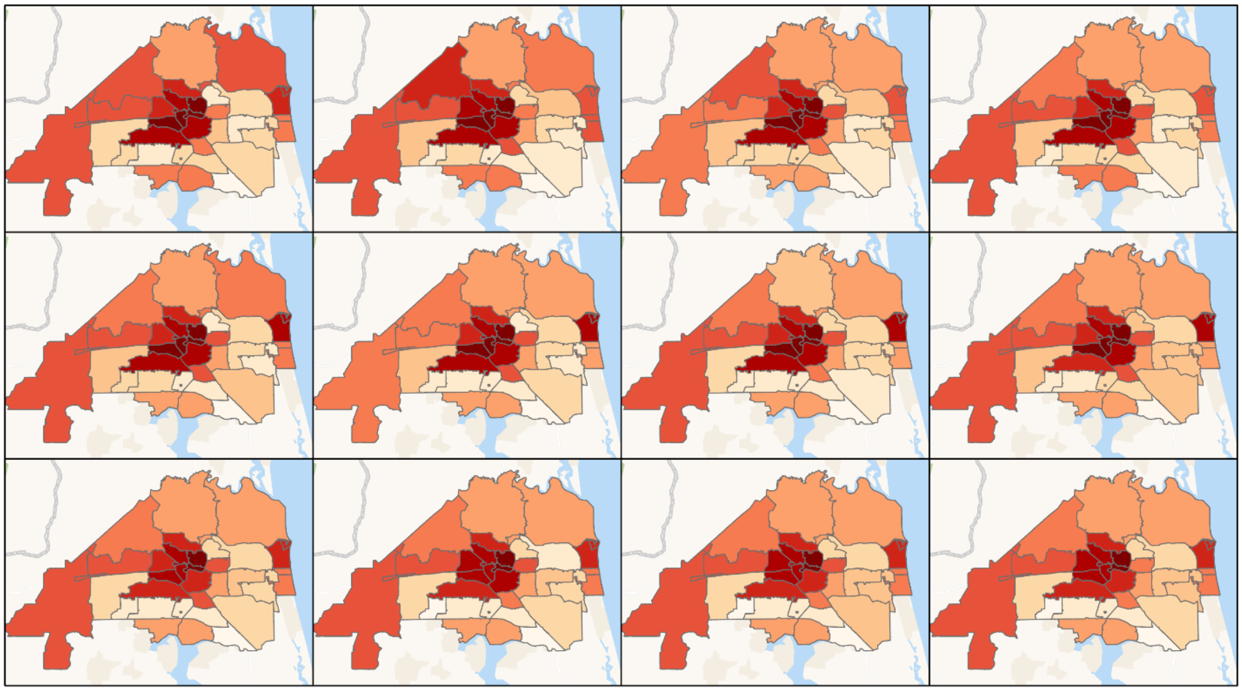

Figure 4.4 House price uncertainty (3-year moving variance of residuals. Shown as S.D.) 2011-2022.

D. ROA Part 3

Empirical Specification

In this section I perform a survival analysis, used across the physical, engineering, biological, and social sciences (Klein & Goel, 1992) to address questions regarding the time until the occurrence of an event (Guo, 2010), commonly referred to as the time of failure. Here, the event of interest is land conversion (development), that is, when a single-family home is built on a vacant plot. Determining the hazard rate of failure, or in this case, the hazard rate of development, requires data containing information about new housing starts or permits (Bulan et al., 2006; Cunningham, 2006). However, for property tax roll data land values are appraised separately from the value of improvements and, therefore, it is possible to know when a property was developed because the value of improvements changed from 0, to something else.

Furthermore, it is important to establish the time frame for the analysis. Because uncertainty was calculated as the 3-year moving variance of residuals at the ZCTA level, I exclude 2008, 2009 and 2010. Therefore, only plots of land that entered the sample as vacant in 2011, and that were developed at some point until 2022, are considered. To control for location fixed effects, I include ZCTA dummies. I do not control for year fixed effects, however, because the tax roll year is perfectly correlated with the timescale chosen for the analysis (also years) and could cause problems when fitting the model and interpreting results. Given the semi-parametric nature of Cox proportional hazard model, it tends to be preferred over less flexible parametric alternatives (Nardi & Schemper, 2003). However, the proportional hazards assumption (Teshnizi & Ayatollahi, 2017) was not met in any of the four scenarios using this model. Therefore, a parametric model was specified. More specifically, the Weibull distribution was selected because it had the lowest AIC value. $\lambda(t) = \rho\lambda t^{\rho-1}$ is the Weibull baseline hazard function, with scale parameter λ and shape parameter ρ. The model is specified as follows:

$$\lambda(t) = \lambda_{0,s}(t) exp\{E\left[P_{jt+3}^{\bar{q}}\right] + \hat{\sigma}_{jt}^2 + DIST_i + AREA + DEPTH_i + INCOME + RATE_t + ZCTA_{FE_j}\} \quad (6)$$

Where $\lambda(t)$ is the hazard rate of development; Subscripts *i*,*j* and *t* denote variation by individual plot, ZCTA, and year respectively; $E\left[P_{jt+3}^{\bar{q}}\right]$ is the 3-year ahead expected house price; $\hat{\sigma}_{jt}^2$ is price uncertainty; $DIST_i$ is the distance from the CBD (note that for the survival analysis, distance to CBD is calculated using 2 km buffer rings, thus it is really only an approximation of the true individual plot-specific distance denoted by the subscript *i*); $AREA_i$ is the natural logarithm of the plot area; $DEPTH_i$ is the plot depth; $INCOME_{jt}$ is the household income; $RATE_t$ is the yearly interest rate; and the $ZCTA_{FE_j}$ vector has ZCTA dummy variables.[21]

If the coefficient for price uncertainty is significantly different from 0, then it is possible to say that price uncertainty indeed has an effect on the timing of development. In the presence of real options, this

[21] The interaction variable $\hat{\sigma}_{jt}^2 * dist_i$ was omitted in the survival analysis because it was insignificant at the 5% level.

relationship should be negative, since they allow developers to delay development as they wait and observe market conditions. Moreover, distance to CBD and the interaction term should provide additional information about the level variation and effects of uncertainty on the timing of development. Finally, a look at each individual scenario may shed light on the effects that introducing different LVT rates will have on urban sprawl. Descriptive statistics are shown in table 4.2.

Table 4.2 - Descriptive Statistics for survival analysis

Variable	Current	LVT 1	LVT 2	LVT 3
Predicted house price (in logs)	**11.658**	**11.643**	**11.620**	**11.617**
	(0.799)	**(0.752)**	**(0.743)**	**(0.745)**
House price uncertainty	**0.0349**	**0.0205**	**0.0220**	**0.0219**
	(0.028)	**(0.015)**	**(0.016)**	**(0.016)**
Distance to CBD	13.057	13.057	13.057	13.057
(kilometers)	(6.091)	(6.091)	(6.091)	(6.091)
Plot area (in logs)	9.230	9.230	9.230	9.230
(sqft)	(0.570)	(0.570)	(0.570)	(0.570)
Plot depth	100.067	100.067	100.067	100.067
(ft)	(74.285)	(74.285)	(74.285)	(74.285)
Household income	50,614.550	50,614.550	50,614.550	50,614.550
	(16,633.990)	(16,633.990)	(16,633.990)	(16,633.990)
Interest rate	2.108	2.108	2.108	2.108
	(0.533)	(0.533)	(0.533)	(0.533)
Number of observations	1,944,891	1,944,891	1,944,891	1,944,891
Number of parcels	185,013	185,013	185,013	185,013
Number of failures	3,537	3,537	3,537	3,537

Notes: Mean values. Standard errors in parentheses. Distance to CBD is calculated with 2km buffer rings intersecting each ZCTA.

Results

The shape parameter for the Weibull specification was higher than 1 in every scenario, which means that the hazard rate of development increased with time. Table 4.3 shows the survival analysis results. Predicted house price had a significant positive effect on the hazard rate of development, and this effect became larger after changes in the land tax rate. The parameter of interest for this analysis, house price uncertainty, showed a significant negative effect in all scenarios. A 1 standard deviation increase in house price uncertainty lowers the hazard rate of development by 0.37%, 0.22%, 0.27%, and 0.24% in scenarios ‘current’, LVT 1, LVT 2, and LVT 3 respectively.[22] These effects represent the percentage by which the likelihood of immediate development decreases in each scenario. These are relatively modest (in section 5 I go into more detail). A simple scatterplot (Figure 4.5) shows a positive linear relationship between mean house price uncertainty and the number of failed plots by ZCTA which contradicts the results described above, although the strength of this relationship is very weak. The coefficients for distance from the CBD were all significantly negatively related to the hazard rate. A 1-kilometer increase in distance from the CBD lowers the hazard rate of development by 2.61%, 4.12%, 4.20%, and 4.24%. This effect seems high, although it should be taken carefully, as it seems unlikely that every kilometer further from the CBD the likelihood of immediate development would increase by the same percentage, especially in light of specific characteristics of Jacksonville discussed in section 5. The coefficient for plot area is also significant and negative, suggesting that larger plots would be less likely to be developed. This effect became larger when the land tax rate was altered. Lastly, interest rate was significant and had positive effect on the hazard rate, and the effect became larger after the land tax rate was altered.

[22] The percentage shift in the hazard rate for a 1 standard deviation change in uncertainty is calculated as $[\exp(\beta_2 \times \Delta\sigma^2)]-1$.

Table 4.3 - Survival analysis: Effect of house price uncertainty on the timing of development

Variable	Current	LVT 1	LVT 2	LVT 3
Predicted house price	1.924827***	2.432864***	2.463089***	2.443740***
	(0.0325)	(0.0303)	(0.0299)	(0.0302)
	[6.8540]	[11.3915]	[11.7410]	[11.5160]
House price uncertainty	-9.14073***	-8.30254***	-7.96435***	-7.74970***
	(0.8955)	(1.6022)	(1.4743)	(1.5258)
	[0.0001072]	[0.000248]	[0.000348]	[0.000431]
Distance to CBD	-0.026402***	-0.042024***	-0.042861***	-0.043355***
	(0.0092)	(0.0089)	(0.0089)	(0.0089)
	[0.9739]	[0.9588]	[0.9580]	[0.9576]
Plot area	-1.444989***	-1.690891***	-1.699251***	-1.687653***
	(0.0420)	(0.0420)	(0.0416)	(0.0418)
	[0.2357]	[0.1844]	[0.1828]	[0.1850]
Plot depth	0.0000003	0.0000002	0.0000002	0.0000002
	(0.000003)	(0.000003)	(0.000003)	(0.000003)
	[1.00]	[1.00]	[1.00]	[1.00]
Household income	-0.0000431***	-0.0000441***	-0.0000419***	-0.0000435***
	(0.000003)	(0.000003)	(0.000003)	(0.000003)
	[0.999957]	[0.99996]	[0.99996]	[0.99996]
Interest rate	0.2167667***	0.2794889***	0.2261936***	0.2276495***
	(0.0347)	(0.0348)	(0.0349)	(0.0349)
	[1.2421]	[1.3225]	[1.2538]	[1.2556]
Constant	-15.71851***	-19.79028***	-19.95517***	-19.77289***
	(0.3786)	(0.3663)	(0.3636)	(0.3660)
ZCTA fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	No	No	No	No
Log likelihood	-15,746	-14,874	-14,736	-14,822
Number of observations	1,944,891	1,944,891	1,944,891	1,944,891
Number of parcels	185,013	185,013	185,013	185,013
Number of failures	3,537	3,537	3,537	3,537

Note: Each cell presents the coefficient estimate, standard error (in parentheses), and hazard ratio (in brackets).
*, **, *** Significance at 10%, 5%, and 1%, respectively.

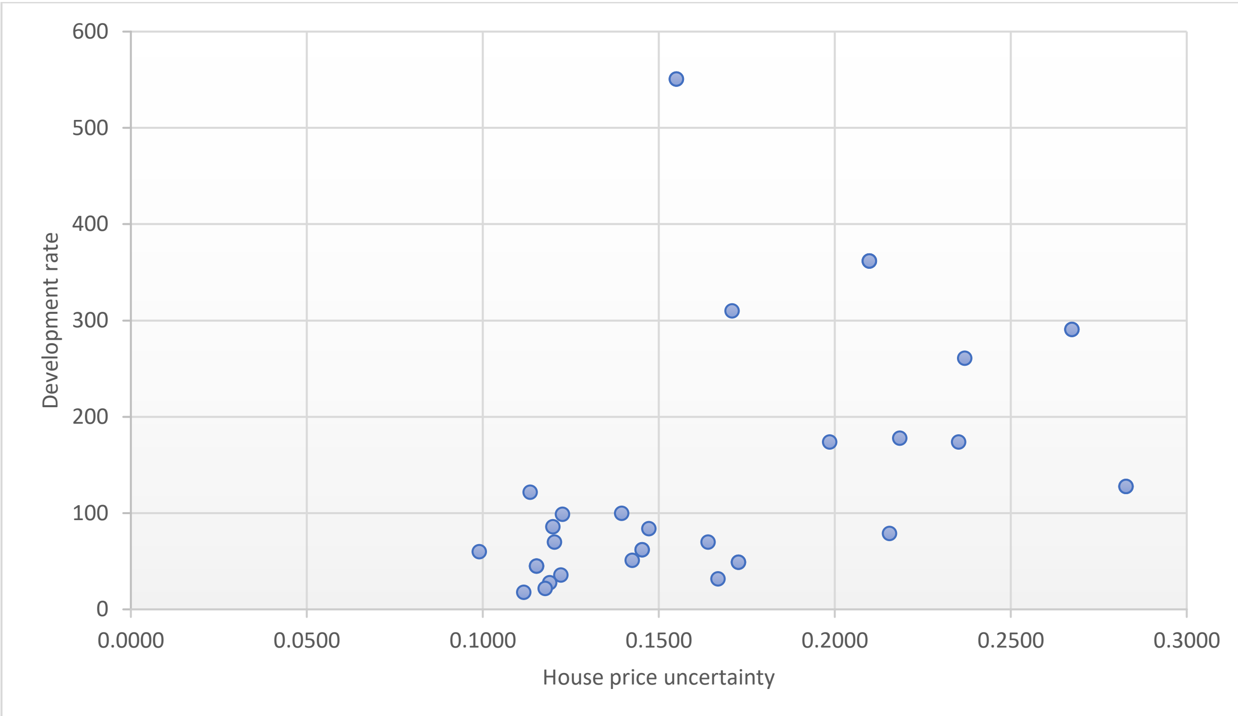

Figure 4.5 Relationship between full-sample mean development rates (number of failed plots) and house price uncertainty (S.D.) by ZCTA.

E. ROA Part 4

Empirical Specification

The last part of the methodology consists of a multiple linear regression, used to analyze the effect that house price uncertainty and other covariates have on the value of vacant land. Here I include only plots of land that remained vacant from 2011 until 2022. As in the previous step, I exclude 2008, 2009 and 2010 because uncertainty was calculated as the 3-year moving variance of residuals at the ZCTA level. To control for location, and year fixed effects, I include ZCTA and year dummies. The model is specified as follows:

$$ln(LAND)_{ijt} = \alpha + \beta_1 \hat{\sigma}_{jt}^2 + \beta_2 DIST_i + \beta_3 \hat{\sigma}_{jt}^2 * DIST_i + \beta_4 AREA_i + \beta_5 DEPTH_i + \beta_6 FRONT_i + \beta_7 INCOME_{jt} + \beta_8 RATE_t + ZCTA_{FE_j} + YEAR_{FE_t} + \varepsilon_{ijt} \quad (7)$$

Where the dependent variable $ln(LAND)$ is the natural logarithm of vacant land value; Subscripts i,j and t denote variation by plot, ZCTA, and year respectively; α is the intercept; ; $\hat{\sigma}_{jt}^2$ is price uncertainty; $DIST_i$ is the distance from the CBD; $\hat{\sigma}_{jt}^2 * DIST_i$ is an interaction term between price uncertainty and distance to CBD; $AREA_i$ is the natural logarithm of the plot area; $DEPTH_i$ is the plot depth; $FRONT_i$ is the plot frontage; $INCOME_{jt}$ is the household income; $RATE_t$ is the yearly interest rate; $ZCTA_{FE_j}$ and $YEAR_{FE_t}$ are vectors with ZCTA and year dummy variables respectively; and ε_{ijt} is the error term.

Again, I am interested in the coefficient for price uncertainty. If it is significantly different from 0, then we may say that there is a relationship between house price uncertainty and vacant land values. In the presence of real options, this relationship should be positive. Thus, higher house price uncertainty should increase the real option premium to postpone development that is implicit in the value of vacant land. Distance to CBD and the interaction term may provide additional information about the spatial variation and effects of uncertainty on the real option premium. Moreover, a look at each individual scenario may prove useful in understanding the effects that introducing different LVT rates will have on urban sprawl. Descriptive statistics are shown in table 4.4.

Table 4.4 - Descriptive Statistics for regression (land values)

Variable	Current	LVT 1	LVT 2	LVT 3
Unimproved land value (in logs)	**8.991**	**8.982**	**8.780**	**8.696**
	(1.542)	**(1.481)**	**(1.427)**	**(1.459)**
House price uncertainty	**0.0501**	**0.0293**	**0.0315**	**0.0314**
	(0.040)	**(0.019)**	**(0.020)**	**(0.020)**
Distance to CBD	10.248	10.248	10.248	10.248
(kilometers)	(7.095)	(7.095)	(7.095)	(7.095)
Plot area (in logs)	8.991	8.991	8.991	8.991
(sqft)	(0.947)	(0.947)	(0.947)	(0.947)
Plot depth	58.917	58.917	58.917	58.917
(ft)	(82.364)	(82.364)	(82.364)	(82.364)
Plot frontage	30.512	30.512	30.512	30.512
(ft)	(43.291)	(43.291)	(43.291)	(43.291)
Household income	42,127.580	42,127.580	42,127.580	42,127.580
	(17,486.890)	(17,486.890)	(17,486.890)	(17,486.890)
Interest rate	2.211	2.211	2.211	2.211
	(0.616)	(0.616)	(0.616)	(0.616)
Number of observations	127,948	127,948	127,948	127,948

Notes: Mean values. Standard errors in parentheses. Distance to CBD is calculated as Euclidean distance from each plot to the centroid of ZCTA 32202.

Results

Lastly, regression results for ROA part 4 are shown in table 4.5. Uncertainty had a significant positive effect on vacant land values in all scenarios. A 1 standard deviation increase in house price uncertainty increases the value of vacant land by $3.38; $2.35; $2.42; $2.37 USD in scenarios 'current', LVT 1, LVT 2, and LVT 3 respectively. On the other hand, distance to the CBD had a significant negative effect on vacant land values. A 1-kilometer increase in distance from the CBD decreases land value by $117.18; $145.62; $147.99; $134.56. Furthermore, the interaction term between uncertainty and distance to CBD was significant in all scenarios. In the 'current' scenario, the interaction effect is negative, whereas in scenarios LVT 1,2, and 3, the effect is positive. In addition, the effect of plot area on land values was significant and positive and very similar across the four scenarios. In contrast, the coefficient for interest rate was significant and negative in all scenarios. The effect became smaller after changing the tax rate, and scenario LVT 2, showed a substantially lower effect.

Table 4.5 - Regression: Effect of house price uncertainty on land values

Variable	Current	LVT 1	LVT 2	LVT 3
House price uncertainty	1.024569***	1.106093***	1.110594***	1.252854***
	(0.1159)	(0.3074)	(0.2883)	(0.3000)
Distance to CBD	-0.0147000***	-0.0183000***	-0.0186000***	-0.0168975***
	(0.003560)	(0.003520)	(0.003330)	(0.003642)
House price uncertainty * Distance to CBD	-0.0210000***	0.1117713***	0.0887924***	0.0468316**
	(0.00405)	(0.02412)	(0.02280)	(0.02394)
Plot area	0.894707***	0.875377***	0.901266***	0.894954***
	(0.0110)	(0.0106)	(0.0101)	(0.0110)
Plot depth	0.0000001	0.0000001	0.0000001	0.0000001
	(0.0000002)	(0.0000002)	(0.0000002)	(0.0000002)
Plot frontage	0.000085***	0.000085***	0.000082***	0.000086***
	(0.00002)	(0.00002)	(0.00002)	(0.00002)
Household income	0.000006***	0.000007***	0.000008***	0.000006***
	(0.0000005)	(0.0000005)	(0.0000005)	(0.0000005)
Interest rate	-0.196708***	-0.191602***	-0.097688***	-0.188814***
	(0.0044)	(0.0045)	(0.0046)	(0.0048)
Constant	1.722964***	1.789052***	1.088017***	1.664211***
	(0.1109)	(0.1090)	(0.1045)	(0.1127)
ZCTA fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
R^2	0.4797	0.4882	0.5043	0.4803
Number of observations	127,948	127,948	127,948	127,948

Note: Each cell presents the coefficient estimate and standard error (in parentheses).
*, **, *** Significance at 10%, 5%, and 1%, respectively.

5. Discussion

A. Land taxation and the timing of development

It is commonly agreed in the literature that a LVT does not affect the timing of development (Foldvary & Minola, 2017). Why would it, if it is levied on the HABU of land? When developers assess whether to develop now, or later, they compare two discounted cashflows using the same HABU and therefore also the same tax rate (Oates & Schwab, 2009). Indeed, it would seem that a LVT is not factored into developers' timing considerations. However, all of these studies fail to recognize the real options effect. When land is taxed, its value diminishes, and the volatility of house prices decreases (Buitelaar & Meijer, 2022). Therefore, the value of the real option to delay development implicit in the value of land also decreases and the rate of development increases. Why this effect has been largely overlooked by researchers investigating the effects of a LVT seems odd, considering it has been central in other studies investigating the effect of alternative planning tools on development and urban sprawl (Cunningham, 2007; Korthals Altes, 2019; Sun et al., 2021). On the other hand, within a real options framework, it is counterintuitive to say that a LVT might reduce urban sprawl. After all, cities with higher volatility tend to be more compact (Capozza & Li, 1994, 2002). Yet, in this study I have incorporated distance to the CBD into the empirical models, in order to account for the concave bid-rent curve in standard monocentric models, where in theory a LVT would have a much higher effect on higher-value plots of land near the CBD, therefore shifting development to already developed areas.

B. House prices and uncertainty in Jacksonville

Downtown areas in the U.S. have been subject to urban blight for many decades, largely due to urban sprawl led by post-war suburbanization (Brueckner & Helsley, 2011; Hortas-Rico, 2015). In order to revitalize and stabilize blighted areas, local governments throughout the U.S. have designated special districts called Community Redevelopment Areas (CRAs).[23] In the state of Florida, most downtown areas

[23] In order to qualify as a CRA, certain conditions such as "the presence of substandard or inadequate structures, shortage of affordable housing, inadequate infrastructure, and inadequate parking" (Downtown Investment Authority Jacksonville Florida, 2022), must be present.

including Jacksonville's, are CRAs.[24] This might explain why estimated house prices at the ZCTA level (Figure 4.3) did not follow the expected spatial distribution based on a monocentric model.[25] Only in line with theoretical assumptions are lower house prices on the westernmost part of the city, possibly attributable to the high proportion of land that is still in agricultural use and far away from the main urbanized areas. Higher house prices on the eastern part of the city are likely due to the accessibility to natural amenities, namely beaches.

The finding that uncertainty was higher near the CBD, was as expected, albeit not in accordance with theory because ZCTAs near the CBD had the lowest land values. The actual cause may be the special designation of the downtown area as CRA, and its long-term (and uncertain) redevelopment plan. Similarly, the westernmost part of the city, also an area with low land values, showed high uncertainty of house prices. Here the cause of uncertainty may be a combination of factors: the disconnectedness from already urbanized areas, the high portion of land owned by the local government, and the recent rezoning of some areas as Planned Unit Development (PUD) districts (City of Jacksonville, 2023). These are non-conventional zoning districts that allow one or more uses, providing flexibility in the planning and development process. Rezoning agricultural land as PUD districts is an indication that development will occur in that area, possibly affecting homebuyers' expectations of future house prices. And these could become more uncertain due to the flexibility of land uses allowed, large-scale of projects and long-term plans involved in PUDs. It is also important to consider that in the state of Florida, land is classified for assessment purposes as agricultural or non-agricultural on an annual basis.[26] Land classified as agricultural is taxed at its current value in agricultural use rather than at its market value determined by its HABU. This is done to protect farmers from being out-taxed. In Jacksonville this classification is also referred to as the 'green belt' (Duval County Property Appraiser, 2023), although it is only used for taxation purposes and is not a

[24] Jacksonville's downtown area is divided into two CRAs, Downtown Northbank and Downtown Southbank, governed separately by the Downtown Investment Authority (Jacksonville Office of Economic Development, 2023). Both were created in the 1980's and shall continue to exist for the duration of the CRA plan until 2045, although it is unclear whether the revitalization process will be completed before this period.
[25] These are not weighted by number of properties and so it is not possible to make assumptions of association or causality.
[26] Florida statute 193.461 (Florida Legislature, 2023). In Duval County, approximately 4% of parcels are classified as agricultural.

protected area. In fact, the change of land use for urban use happens quite frequently. Therefore, although the urban fringe is indeed somewhat defined by non-developed agricultural land, it seems quite diffuse.

C. Real options and the timing of development

Results from the survival analysis showed that uncertainty of future house prices had a significative negative effect on the timing of development. In the 'current' scenario, a 1 standard deviation in house price uncertainty lowered the likelihood of immediate development by 0.37%. This shows that developers in Jacksonville do tend to postpone investment under uncertain conditions. Yet, although confirming my initial expectations, this effect was low relative to those found in previous empirical research. For instance, in the study by Cunningham (2006) the same increase in uncertainty lowered the likelihood of immediate development by 10.7%, and an even larger decline of 13% was found by Bulan (2006). Regression results suggest that a delay premium can be found in the value of vacant land in Jacksonville. In the 'current' scenario, a 1 standard deviation increase in house price uncertainty raised the value of vacant land by 0.042%. This effect was again very small compared to results found in earlier studies. Cunningham found a 1.6% increase in vacant land price following a 1 standard deviation increase in house price uncertainty, while Quigg (1993) and Grovenstein et al. (2011) found delay premiums of on average 6% of land value.

D. The LVT versus urban sprawl

In the simulation scenarios higher uncertainty still lowered the hazard rate of development but not as much as before land was taxed. Levying a LVT decreased the negative effect of house price uncertainty on the timing of development, increasing the likelihood of immediate development by 0.15%, 0.1%, and 0.13% in scenarios LVT 1, 2 and 3 respectively. This effect seems almost trivial compared to the effects found in similar studies focusing on alternative planning tools: the urban growth boundary investigated by Cunningham (2007) increased the likelihood of immediate development by 9%, while the price-stabilizing government policy simulated by Sun et al. (2021) led to a 9% extra urban cover area over an initial pre-simulation 15%. Regression results are also in line with theory, as they show that a LVT lowered the effect of uncertainty on vacant land values 0.0124%, 0.0048%, and 0.0024% for scenarios LVT 1, 2 and 3 respectively. This would indeed accelerate the rate of development, although the effect is very small.

The coefficient of distance to the CBD on the timing of development was significantly negative. This means that in the 'current' scenario, the likelihood of immediate development decreases by 2.61% every kilometer further from the CBD. Contrastingly, Cunningham (2006) found that the likelihood increased by a much lower 0.91%. That plots are less likely to be developed further from the CBD, could mean that the implicit real option to delay development becomes larger. Yet the interaction variable included in the regression model suggests that as the distance to the CBD in the 'current' scenario increases, the sensitivity of vacant land value to house price uncertainty decreases, which would imply that actually implicit real options are lower further from the CBD. It is difficult to say for sure, also considering the specific context of Jacksonville, where uncertainty of development is high in downtown CRAs, as well as in agricultural land at the fringe designated as PUD. In addition, results showed that levying a LVT would almost double the negative effect of distance on the likelihood of immediate development (4.12%, 4.20%, 4.24% for scenarios LVT 1,2 and 3 respectively). Interestingly the interaction effect was inverted when the LVT was levied. Then, as the distance to CBD increases, the sensitivity of vacant land value to house price uncertainty increases, possible meaning that implicit real option value would become higher further from the CBD. If this is the case, then a LVT could indeed help decrease development at the fringe.

E. Shortcomings of the research design

This study had a few shortcomings that are important to consider when interpreting results. First, property values from appraisal data may differ from the actual price paid for the property, i.e., from its transaction value. Evidence also suggests that assessment rates tend to be higher for lower priced homes (McMillen & Singh, 2020). On the other hand, evidence supporting the accuracy of assessment data is also available (Haan, 2013). In Duval County, property tax data is appraised at market value, and then transaction costs are subtracted leaving the ad valorem taxable value which is on average 15% lower than the market value.[27] Another drawback is that full tax capitalization may not hold in practice. For instance, empirical evidence by Giertz et al. (2021) shows that less than 70% of property tax changes are capitalized in Dallas. Investigating what this percentage is for Jacksonville could improve the quality of this research. In addition, it could be argued that for the specific context of the U.S., considering land use types would be helpful. This has been done already by Quigg (1993) and Grovenstein et al. (2011) within a real options framework. Lastly, the different tax rates chosen for the LVT scenarios were not very informative. Using an arithmetic sequence with constant change, as well as more scenarios could be more helpful.

6. Conclusion

The aim of this research was to test the effect of a LVT on the timing of development, and to determine whether it could work as a planning tool to reduce urban sprawl. I used a real options approach based on the work by Cunningham (2006) in order to test the effect of house price uncertainty and distance to the CBD among other covariates, on the timing of development and on the real option to delay development implicit in the value of vacant land. Results showed that a 1 standard deviation in house price uncertainty lowered the likelihood of immediate development by 0.37% and raised the value of vacant land by 0.042%. This effect, although very small, confirmed my initial expectations based on the theoretical assumption that uncertainty increases the real option to delay investment. Additionally, I simulated different scenarios to analyze the LVT against sprawl by testing the aforementioned effects under different land tax rates. The results showed that levying a LVT decreased the negative effect of house price uncertainty on the timing of development, increasing the likelihood of immediate development by 0.13%. In practice this would intensify urban sprawl. Yet, additional results showed that after levying a LVT the sensitivity of vacant land value to house price uncertainty increased with distance from the CBD, suggesting that a LVT could help decrease development at the fringe and encourage it in already urbanized areas near the CBD, thus reducing urban sprawl.

[27] 15% of market value is the standard estimated cost of sale (transaction costs) used by appraisers in Duval County for taxation purposes.

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