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Reorienting Local Housing Development Trends Via Land Value Taxation: A Bottom-Up and Top-Down Quantitative Analysis

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REORIENTING LOCAL HOUSING DEVELOPMENT TRENDS VIA LAND VALUE TAXATION: A BOTTOM-UP AND TOP-DOWN QUANTITATIVE ANALYSIS.

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ABSTRACT

The region surrounding Burlington, Vermont is in the midst of sparse, decentralized growth which threatens the sense of place from which it has thrived. Many have argued that such development tendencies result from a disconnect between land use incentives at the individual level and the fruits of compact settlement, which materialize at larger scales. Two overarching problems are understood to contribute to this disconnect; the ability to privately appropriate the collectively-created value of land, and the inability to recognize ecological opportunity costs of natural land conversion in land use decisions. One proposed solution is the Land Value Tax (LVT). By raising the cost of holding urban land idle and lowering the cost of development, LVT has been shown to increase housing supply and density within existing urban boundaries as well as decrease housing prices. However, despite its purported benefits, the tax reform is value monistic in its definition of optimal land use and therefore does little to address the second overarching problem.

This research sought to explore the efficacy of a conventional and expanded land value taxation scheme to address both aforementioned problems that contribute to urban sprawl. In article 1, we used a top-down empirical approach via a spatial probit model and a random forest classifier model to understand recent housing development choices across Chittenden County, Vermont as they relate to various parcel and locational characteristics. We then used developers' revealed behaviors to forecast future development given various LVT schemes. Results suggest a trend toward suburban sprawl, with developers favoring locations with higher car dependence and commute times as well as locations closer to farmland. A parcel's LVT burden yielded a significant, positive effect on development likelihood such that a one unit increase in log-transformed LVT per acre (a $933 increase for the average parcel) is associated with an 11.7% higher development likelihood. However, predicted development under a higher LVT was not found to support suburban sprawl remediation as hypothesized. In article 2, we utilized a bottom-up theoretical approach via a spatially-explicit agent-based model of land-use behaviors to explore the impact of a conventional and expanded LVT scheme that internalizes the ecological impact of land use change into a parcel's tax burden. Findings suggest that both LVT schemes can increase housing availability and urban infill while mediating the negative effects of land speculation. Furthermore, the expanded land value taxation scheme encouraged more urban density and ecosystem service preservation.

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TABLE OF CONTENTS

LIST OF TABLES

Table Page

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

> Far from being a mere matter of aesthetics, suburbia represents a compound economic catastrophe, ecological debacle, political nightmare, and spiritual crisis — for a nation of people conditioned to spend their lives in places not worth caring about.
>
> —*James Howard Kunstler, The Geography of Nowhere*

Suburban sprawl has dominated the modern landscape in the U.S. among other countries. Such patterns of land use have far-reaching impacts on higher-order social and ecological realities, including ecological deterioration (Simkin et al., 2022), social fragmentation (Mazumdar et al., 2018), and public health degradation (Zhao & Kaestner, 2010). Yet one cannot say the same thing in reverse; patterns of development have largely been driven by myopic individual actions unaware of or ambivalent to their contribution to broader social dilemmas. Even among orthodox economists, acknowledgement of the economic inefficiency of urban sprawl is common (Bento et al., 2011); not only does it greatly increase the cost of supplying public and private services (Gielen et al., 2021), it also diminishes the agglomeration effects from which cities become economic powerhouses (Bettencourt et al., 2007).

Clearly, a disconnect exists between land use incentives at the individual level and the fruits of compact settlement, which materialize at larger scales. Foldvary and Minola (2017) attribute this market failure to horizontal development subsidies, zoning regulation, containment policies and land speculation. In the case of land speculation, the insidious feedback loop referred to as "leapfrog development" can be summarized as: (1) infrastructure is added to serve new development; (2) land values increase as a result (to the benefit of current landowners and to the detriment of prospective residents); (3)

speculative interests then purchase land farther away from the infrastructure to capture lower prices and demand infrastructure near them, thus perpetuating the cycle (Foldvary & Minola, 2017; Junge & Levinson, 2012).

Many have attributed such failures in land markets to the perverse incentives inspired by the rent-generating potential of land (e.g. Clawson, 1962; Foldvary & Minola, 2017). While contemporary economists still disagree on the definition and scope of economic rent—due to the associated social implications—it has been broadly defined as economic returns that aren't the result of labor or sacrifice, but rather emerge from control over scarce or monopolized assets (Stratford, 2022). However, the theory of economic rent originates with the concept of land rents that are present in the seminal texts of classical economics, first with Adam Smith's description of the natural monopoly of land prices and later with David Ricardo's elaboration on the Law of Rent (Ricardo, 1817; Smith, 1776). Land, being entirely fixed in supply, derives its value from its associated demand. It is a parcel's proximal characteristics and its natural endowments that explain its price in relation to other parcels (Foldvary & Minola, 2017). As a settlement develops, its locational desirability and subsequent acceptable price may increase. The resulting increase in a landowner's wealth is not the result of her work but that of the community at large and therefore is considered economic rent. As John Stuart Mill eloquently put it:

> The ordinary progress of a society which increases in wealth, is at all times tending to augment the incomes of landlords; to give them both a greater amount and a greater proportion of the wealth of the community, independently of any trouble or outlay incurred by themselves. They grow richer, as it were in their sleep, without working, risking, or economizing. What claim have they, on the general principle of social justice, to this accession of riches? In what would they have been wronged if society had, from the beginning, reserved the right of taxing the spontaneous

> increase of rent, to the highest amount required by financial exigencies? (Mill, 1848/1909: Book 5, Chapter 2: Section 5)

The social injustices of rent-seeking behavior in land markets became a central tenet of the political economist Henry George in the late 1800s. He emphasized the perpetuation of poverty to be the result of a rentier class who can increase land costs in proportion to any increase in productivity—essentially funneling the benefits of societal progress into the hands of landowners (George, 1879). Today this critique is no less relevant. Economic rent makes up an increasing share of national income and continues to be argued as a root cause of growing inequality (Kasliwal, 2016).

A land value tax (LVT) has long been proposed as a solution to this problem and its subsequent impacts on land use (Batt, 2012; Cho et al., 2011; George, 1879). Taxing land value in place of, or to a higher degree than the value of improvements would effectively de-privatize the public- and nature-derived values of property ownership. In doing so, municipalities can eliminate or dampen the speculative potential of holding land out of the market and internalize the higher public costs of urban sprawl into private land ownership costs (Dye & England, 2010; Foldvary & Minola, 2017).

However, despite its potential improvements both to justice and land-use efficiency by buffering the exploitation of land rents, the taxation scheme remains reliant on markets to define the optimal use for land and therefore lacks the ability to respond to non-market information to, for example, safeguard ecological thresholds (Wyatt, 2022). Originally proposed by George as a more palatable alternative to socializing land, the sustained reliance on markets and their associated value monism presents a fundamental contrast between land value taxation and land socialization, and a shortcoming of the applicability of land value taxation to ecologically-sound land stewardship.

This research seeks to contribute to collective knowledge by exploring the hypothetical impact of a LVT on land use in Chittenden County, Vermont. It is organized according to those two overarching problems that disconnect land-use decision-making from higher-order system considerations; the ability to privately appropriate the collective social value of settlements and socialize costs encourages selfish behaviors that undermine collective welfare, and the inability of markets to account for ecological opportunity costs of natural land conversion make for uninformed development decision-making. This research will explore means to address both of these problems through local policy. Chapter 3 considers a means of reorienting developer incentives toward denser urban development through land value taxation. Here we utilize a spatially-dependent discrete choice probit model as well as a random forest classifier model to understand recent housing development choices as they relate to various parcel and locational characteristics. We will utilize developers' revealed behaviors around land-value tax burden to forecast the quantity and location of future development with various taxation schemes. Chapter 4 proposes a theoretical expansion of the scope of land value taxation to encourage more informed, sustainable individual decision-making based on associated ecological pressures of land-use practices. We utilize spatially-explicit agent-based modeling of land-use behaviors given a scenario in which one’s ecological impact is internalized into their tax burden.

CHAPTER 2: BACKGROUND

2.1. Theoretical Framing

2.1.1. The Economy in Society in Nature

Social scientists are unique in their ability to shape the world they are trying to describe. Economics has become a language of power, reforming both state and social institutions towards narrow goals of maximized monetary value (Røpke, 2020). In the face of humankind's transition into a full-world dynamic, the reductive and individualistic goals of neoclassical economics have eroded the incommensurate social and natural systems on which humanity relies (Farley & Kish, 2021).

Almost paradoxically, ecological economists seek to broaden the outlook of economics by emphasizing its social and ecological constraints. They describe economic goals in the context of biophysical limitations to growth and incommensurate values, which require a plurality of formal and informal economic institutions to coordinate (Daly & Farley, 2011).

The limits to economic growth due to the earth's finite biophysical resources imply the necessity to make social justice the domain of distribution of wealth, in contrast to the typical mantra of neoclassical economics that "a rising tide lifts all boats." Just distribution, the first goal of ecological economics, pursues basic sufficiency as a prerequisite for further economic activity. It is based on the belief that everyone is entitled to an equal share of the gifts of nature and the values created by society as a whole. It's also underscored by the conviction that interpersonal preferences are comparable when considering the difference between essential needs and wants (Kapp, 1971).

Urban development is one of the most visible examples of the innate conflict between market forces and more broadly defined goals of communities, as mediated by the pernicious influence exerted by rent-seeking behavior. Gentrification, habitat fragmentation, social isolation, are increasingly predictable development outcomes that result from uncontrolled rentier power. Furthermore, disparities in land ownership embed a systematic flow of wealth from poor to rich (Stratford, 2020). As Matthew Rognolie (2016) demonstrated, land investments capture an increasing share of all economic returns and are understood to play a leading role in the increasing inequality seen today. Moreover, rent-seeking behaviors can lock society into a growth-dependence spiral in which governments feel compelled to pursue economic growth to service inequality, but in doing so they allow rentier power and resulting inequality to expand (Richters & Siemoneit, 2019; Stratford, 2020).

Rent-seeking behavior is only expected to increase in a growth-constrained economy suggesting a heightened urgency in socializing ecologically and socially-created portions of value (Stratford, 2020). Land is necessarily at the center of such efforts. The rent-seeking behavior of land speculation represents a taking of humankind's shared inheritance by those with sufficient power and wealth to do so, often at the expense of those most vulnerable to market exclusion. Furthermore, it embeds an incentive to financialize land to the detriment of all those who favor the use value of this essential resource.

2.1.2. Cities as Economic Hubs

Cities have long been understood to be at the heart of economics. They are, as Jane Jacobs liked to say, the true, salient macroeconomic unit (Jacobs, 1984). Yet the spatially-explicit elaboration of economic models has been slow to capture the complex dynamics of cities as economic engines. Johann Heinrich Von Thünen (1826/1966) was among the first to postulate the impacts of distance to markets (and associated travel costs) on locations of agricultural production; given a central market, costs of transporting goods would gradually increase with distance to this central market until land rents diminished to zero at the boundary of cultivation (Bettencourt, 2021).

Later economists recognized the cause of urban density not to be merely a product of transportation costs, but rather a result of the economic value of human interconnection. Alfred Marshall (1890) provided a novel description of the "external economies" (benefits) of spatial agglomeration, now referred to as economies of scale or network effects. This, and the case of diseconomies of scale and higher public costs at larger scales, led many to postulate on optimality with regard to city size—a concept referred to as the Henry George Theorem (Arnott, 2004).

In reality, urban regions face in tandem centrifugal forces seeking open space and cheaper prices, and centripetal forces seeking a dense, highly networked environment (Colby, 1933). The relative weight of these numerous forces underscores the complexity of cities not represented in traditional economic models.

2.1.3. Cities as Complex Adaptive Systems

The application of complexity science toward urban dynamics coincided with a reformulation of the associated root metaphor from cities as mechanisms to cities as organisms (Sui, 2011). In this sense, cities can be understood as macro phenomena that emerge from the non-linear aggregation of multitudes of micro phenomena. In other words, the actions people take within a city aggregate to create emergent characteristics that in turn affects future actions of people thus creating a recursive system. As such, cities exhibit path-dependence in their trajectories by way of the inertia of their prior collective actions (Atkinson & Oleson, 1996). Such context dispels questions of optimality in urban systems, and instead frames urban processes as exhibiting multiple equilibria, constrained by their history of regional decision-making.

Such a lens has also shed light on universality in urban outcomes. Luis Bettencourt and his colleagues (2007) demonstrated a number of scaling laws shared by cities around the world with implications for municipal costs, economic activity and environmental footprints. For example, new patent creation exhibits strong superlinear scaling whereas road or electrical cable infrastructure exhibits sublinear scaling, perhaps a driver of reduced per capita municipal costs. Land rents have been shown to be among these somewhat universal scaling laws (Shapiro, 2006).

2.2. Urban Sprawl

Despite the range of variations in urban morphology, one pattern has dominated the modern landscape in the US: urban sprawl. This pattern of development (also referred to as suburban sprawl or suburbanization) is often characterized by dispersed, low-density residential buildings reliant on automobile travel for access to amenity or commercial areas (Rafferty, 2019). However, definitions vary widely and tend to be framed as a relative rather than absolute phenomenon as well as a directed process rather than a state (Frenkel & Ashkenazi, 2008; Frenkel & Orenstein, 2011).

The trend toward suburban dwelling began in the early 1900s as elite urbanites grew tired of the dirty, crowded cities and the civic responsibility that accompanied urban living (Mumford, 1961). Early suburbanites sought to remove themselves from the broader community, and instead prioritize pleasure, connection to nature and childhood development.

> In the suburb one might live and die without marring the image of an innocent world, except when some shadow of its evil fell over a column in the newspaper. Thus the suburb served as an asylum for the preservation of illusion. Here domesticity could flourish, forgetful of the exploitation on which so much of it was based. Here individuality could prosper, oblivious of the pervasive regimentation beyond. This was not merely a child-centered environment: it was based on a childish view of the world, in which reality was sacrificed to the pleasure principle (Mumford, 1961 p. 494)

Post WWII, a surge of more broadly accessible suburbanization was brought about through lower cost, standardized suburban development as well as a significant investment by the federal government to build the infrastructure necessary for decentralized living (Nicolaides & Wiese, 2017). While the isolation and natural provisions afforded by prewar suburbs may have been lost in this much larger suburbanization process, the cultural foundations in naivete, hedonism and social disembeddedness remained. The significant expansion of suburbs has accelerated natural land conversion, while the associated lifestyle—as a result of car dependence and large, inefficient homes—created a much larger environmental footprint than other patterns of settlement (Jones & Kammen, 2014).

Today, suburban development remains dominant. As of 2017, 52% of U.S. citizens were estimated to live in a suburban area (Bucholtz et al., 2020). The incessance of suburbanization is the result of a number of economic motivations at the individual level. The post-1970 merging of real estate development and finance sectors has expanded use of land as a speculative asset and thus exacerbated the aforementioned phenomenon of leapfrog development (Foldvary & Minola, 2017; Junge & Levinson, 2012; Nicolaides & Wiese, 2017). Furthermore, the fast appreciating land prices in urban centers have forced many—particularly low income households—into exurban neighborhoods (Hochstenbach & Musterd, 2018). Continued sprawl is also a result of the path-dependence innate to urban development. For example, once automobile reliance has set in, residents may oppose denser development projects due to the assumed increase to automobile congestion that they may incur (Atkinson & Oleson, 1996).

2.3. Regional Context

Vermont, like the rest of New England, has a long tradition of compact village-style development separated by rural countryside. Vermonters today strive to maintain these settlement patterns and their associated amenities like a cohesive town identity, walkability, and access to open preserved land (CCRPC, 2018). However, a growing demand for property and severe housing affordability crisis have put pressure on the rural lands historically surrounding the state's city and village cores, as well as the transportation infrastructure on which they rely.

Burlington, the state’s largest city with a population of 44,595, is at the epicenter of the housing crisis (U.S. Census Bureau, 2022). It, along with South Burlington, comprise the anchor cities of the only metropolitan statistical area in Vermont, and a major transit hub for northwest and central Vermont (OMB, 2020). In 2021, the median house price in Burlington was $425,000—14.9% higher than just one year prior (Han, 2021). An estimated 55% of low and middle-income renters are cost-burdened in Burlington (Curtis, 2021). The average Burlington Metropolitan Statistical Area renter is able to afford $467 less per month than the average fair market rent (National Low Income Housing Coalition, 2022). Increasing rental prices have forced many outside of the market. Homelessness across Vermont increased by 7% in 2022 after an increase of 133% in 2021 due to the pandemic (Vermont Coalition to end Homelessness, 2022).

2.3.1. Housing Supply

A conventional response tends to place blame on a stagnant housing supply not keeping up with demand. Annual growth in housing stock across Chittenden County has steadily declined from 2.57% in the 1980s to 1.00% in the 2010s (Vermont Housing Finance Agency, 2020). In absolute terms, market supply of housing available to local residents may actually be decreasing as an increasing percentage of homes are bought for seasonal use. Of all homes in Vermont, 17% are vacation homes, the second highest in the nation (Black-Plumeau & Watson, 2022). In this case, vacation homes are defined as "vacant for seasonal, recreational, or occasional use" (Black-Plumeau & Watson, 2022).

Developers have cited the challenging regulatory hurdles for building, particularly those imposed by Vermont's Act 250 and local zoning ordinances (Edgar & McCallum, 2022). Still others may point to the rising costs of construction. In the context of double-digit increases in land prices, landowners may prefer to speculate on the future value of land rather than invest in producing housing and incur higher property taxes as a result. Anecdotally, 323 Pearl Street, a 12-unit apartment building in downtown Burlington pays 142% more in taxes than its 6-unit neighbor at 307 Pearl Street (Burlington Assessor's Office, 2022a, 2022b).

As the crisis worsens, state and local regulators have taken action to ease restrictions on housing development. State legislators recently passed the HOME Act which removes single-family zoning in areas served by public water and sewer, eases minimum parking requirements and expands Act 250 exemptions in areas planned for growth (Housing Opportunities Made for Everyone Act (S.100), 24 V.S.A. § 4414, 2023).

At the local level, Burlington has had a long history of creative solutions to housing affordability issues. In 1988, Burlington City Council approved a Housing Trust Fund, which directed a portion of tax revenue toward local housing trust organizations building affordable housing (CEDO, 2022). Since its inception, the fund has provided over $5.9 million toward the construction of over 1800 affordable housing units (City of Burlington, 2019). However, in 2006, its funding allotment was reduced from $0.01 per $100 of assessed property value to $0.005, which, along with inflation, has eroded its revenue base (City of Burlington, 2019).

In 1990, the city adopted one of the first inclusionary zoning ordinances in the nation, which requires new residential developments over 5 units or adaptive reuse projects over 10 units to designate a portion of their units as affordable in exchange for density and lot coverage bonuses (Buki et al., 2017). From its adoption in 1990 to 2015, the program was responsible for producing 270 affordable housing units in Burlington (Buki et al., 2017).

More recently, the city has refocused efforts to resolve anemic housing development. Mayor Weinberger recently released a 10 point plan with the goal of doubling the rate of development in Burlington and ending chronic homelessness (Rendell, 2021). Included are zoning reforms to densify portions of Burlington through expanding areas able to accommodate residential development, investing $5 million into building permanently affordable housing through the city's ARPA funds, and creating 30 shelter-pods for those in immediate need of housing. Burlington City Council recently passed a short-term rental ordinance restricting non-owner-occupied units to curb the loss of rentable units in favor of tourist accommodations on sites like AirBnB or VRBO (Goldstein, 2022).

2.3.2. Housing Demand

Focusing on the more locally-visible housing supply challenges, one is likely to miss the fast-growing demand for real-estate from local, national, and international interests. The most obvious cause of increased housing demand stems from more people wanting to move to Northwestern Vermont. Chittenden county is estimated to comprise 89% of the state’s population growth projected for 2020 to 2025 (Vermont Housing Finance Agency, 2020). There are a number of things that are understood to contribute to this. For one thing, Burlington is well loved and its fame has only increased in recent years. In the midst of the Covid-19 pandemic, Forbes ranked Burlington 4th in the country for remote workers (Stahl, 2021). Others have noted climate migration as a leading factor of those who have recently moved to Vermont—the fourth most climate-resilient state, according to the EPA (McCallum, 2022). On top of that, Vermont’s Worker Relocation Incentive Program provides up to $7,500 for those moving here for work or as a remote worker (Vermont Agency of Commerce & Community Development, 2022).

However, an arguably larger portion of new demand comes from those who buy real estate simply to speculate on its potential to increase in value. In 2021 alone, the share of Vermont homes bought by investors more than doubled, now comprising 17% of all sales (Thys, 2022). Low interest rates and increased savings from the pandemic have encouraged many to buy a home (or a second home). Vermont, in this case, is simply part of a much larger trend toward financialization of land and real-estate that has happened over the past few decades (Hudson, 2014). Furthermore, speculative interest leads to a positive feedback loop in which fast appreciating prices cause greater demand, which creates faster appreciating prices. But this dynamic also works in reverse; falling housing prices lead to sell-offs and faster falling prices that locks housing markets into a boom-bust dynamic (Gao et al., 2020).

Vermont legislators have long recognized land speculation as a problem. Beginning in 1973, Vermont imposed a Land Gains Tax as a direct response to land speculation across the state. The tax is applied to the capital gains from land sold within 6 years of purchase, with certain stipulations on eligibility (Tax on Gains from the Sale or Exchange of Land, 32 V.S.A. § 10002, 2022). However, recent amendments to the tax now exempts any land not subdivided during the tax period, and any land located within a "downtown development district, a village center, growth center, or new town center development" (An Act Relating to Changes That Affect the Revenue of the State (Act 71), H541, 2019). The reformed legislature is ineffective at preventing speculation in locations where prices have appreciated the fastest—in or just outside of downtown areas such as Burlington.

2.3.3. Urban Sprawl

Many of the aforementioned local housing dynamics also affect the location of new development and the resulting environmental impact of development. Vermont is estimated to be losing greenspace at a rate of 15,000 acres per year (Cotton, 2022). The lack of affordable housing in Burlington has forced many to seek housing in surrounding towns and commute in for work or recreation. Since 1990, the city has produced an estimated 2500 fewer units than necessary to maintain its portion of regional housing (Buki et al., 2017). The suburbs of Burlington soaked up 61.6% if all development in that time period and has increased its share of population from 46.6% to 50.5%; meanwhile the share of regional population in Burlington has fallen from 29.7% to 29.3% (Buki et al., 2017).

Developers also have cause to favor suburban expansion over urban infill; Vermont Forum on Sprawl noted several elements that contribute to a preference for suburban development, including cheaper land, simpler permitting, site preparation and construction, less restrictive zoning, ample space for parking, and easier ability to meet requirements of national housing merchandisers (Vermont Forum on Sprawl, 1999).

The state has taken some action to address sprawl, largely in the 1970s as a response to prior rapid development. In order to ease the financial pressure for farm owners to sell to developers, the state enacted a Use Value Appraisal program, often referred to as the Current Use Program. The program provides an alternative land valuation, for property tax purpose, which applies a flat rate per acre to certain land uses as opposed to allowing the market to determine land values and subsequent tax burden (Vermont Department of Taxes, n.d.-a).

One of the most influential pieces of legislation aimed at combating sprawling development is Act 250. Enacted in 1970, Act 250 requires larger development projects to demonstrate environmental impact and obtain approval from a citizen-led District Environmental Commission (Vermont Natural Resource Board, n.d.). The state also imposes a Land Use Change Tax at a rate of 10% applied to any agricultural or managed forestland that is developed, or land that is withdrawn from the state's Current Use Program (Vermont Department of Taxes, n.d.-b).

2.4. Land Value Taxation

LVT has been in economic discourse since the beginnings of classical economics, with high-profile proponents including Adam Smith (1776) and David Ricardo (1817). It has been lauded as an optimal tax source because it is non-distortionary; anything less than a 100% tax on land would not affect the tax base (i.e. supply of land) (Dye & England, 2010). As such, it carries no deadweight losses and, if it were to replace a tax on land improvements, would actually result in an improvement to economic efficiency (Chapman et al., 2009). The United States originally utilized land-value taxation as a primary source of revenue to a much higher degree than value-added taxation but had slowly reversed this ratio largely throughout the 19th century (Rybeck, 2000). This trend has been attributed to, among other things, the increasing role of the federal government that largely taxes income and production, the increasingly common practice of sales tax at the state level as well as the power of landed interests to retain land value (Rybeck, 2000). In the late 19th century, the idea was re-popularized in the U.S. by Henry George as a remedy for excessive economic inequality that he concluded to be the result of speculative land pricing that privatized the social value of a community (George, 1879).

With regard to the land and housing market, a few key theoretical dynamics are worth mentioning. First, a LVT is theorized to increase the supply of land on the market as it would remove or lessen the speculative value of land; in essence, removing the subset of consumers who buy land just to hold it out of the market until land values have increased enough to warrant selling it (Kalkuhl & Edenhofer, 2017). Due to the purported increase in supply, decrease in demand and the capitalization of the LVT into prices, the average price of land and housing is theorized to decrease from a transition to LVT (Choi & Sjoquist, 2015; DiMasi, 1987). It is unique amongst tax bases for two reasons: (1) because land supply is fixed, the tax is entirely borne by landowners and cannot be passed onto tenants (Høj et al., 2018; Smith, 1776); and (2) its physical nature means the tax cannot be evaded (Dye & England, 2010).

In practice, jurisdictions have tended to opt for a tax scheme in which tax rates on land value are higher than that of built improvements (henceforth referred to as a split-rate tax), rather than a complete reliance on land-values. For example, in Pennsylvania, where jurisdictions are allowed to tax land and property at different rates, all 18 jurisdictions doing so utilize a split-rate tax system, not a pure land-value tax (Banzhaf & Lavery, 2010).

2.4.1. Optimal Use Development

Given that a LVT applies a fixed tax rate for owning land irrespective of private capital improvements, it encourages development of land to its optimal economic use (Foldvary & Minola, 2017). Several studies have shown as much (e.g. Choi & Sjoquist, 2015; Kalkuhl & Edenhofer, 2017). As a broad-stroke analysis, Plassmann and Tideman (2000) showed that among 15 jurisdictions in Pennsylvania with a split-rate tax system, significantly more building permits were issued between 1972 and 1994 as compared to 204 similar jurisdictions without a split-tax rate. Oates and Schwab (1997) showed similar findings for Pittsburgh, which has had a split-rate tax since 1913. Using regression analysis, the authors find that among 14 other comparable U.S. cities, Pittsburg was the only city to have a large and significant increase in building activity in the 1980s. The authors noted the challenge in separating the effect of the tax reform from the various other concurrent economic factors but find evidence that the increased land-value tax played a significant supporting role in increasing building activity (Oates & Schwab, 1997).

The findings in Pittsburgh illustrate another purported benefit of land-value taxation; the ability for real estate markets to more effectively weather boom-bust cycles (Oates & Schwab, 1997). During the study period, most rust belt cities were suffering significant decline. Only 2 out of 15 cities in the study showed an increase in building activity and of those two cities, Pittsburgh was a remarkable outlier; it saw a 70% increase in real value of building permits relative to its prior 20 years before the tax reform (Oates & Schwab, 1997).

This effect of economic resilience from land value taxation has received little attention among researchers; however, one other counterfactual study by Cocconcelli and Medda (2013) reinforces the claim by showing a stabilizing effect of land value taxation in Estonia during a real estate bubble. The country transitioned to a land-value tax system in 1994; however, land assessments were infrequent and so unable to capture the significant increase in value during the bubble (Cocconcelli & Medda, 2013). Assuming, instead, that the land was assessed every year, they found that the more effective land value tax would have significantly reduced the negative impacts of the real estate bubble on the housing market.

Optimal urban development is not only limited by the desire for private development, but also the ability for public services (i.e., infrastructure) to keep up with increasing demand. However, a LVT doesn't just incentivize private development, it also allows municipalities to recoup costs of public projects as the resulting land value increases would be largely returned to the local government (Foldvary & Minola, 2017; Junge & Levinson, 2012). Furthermore, if a LVT were to result in more compact cities, municipalities would be faced with cheaper infrastructure costs per capita overall (Collier & Venables, 2016).

2.4.2. Urban Densification

Land values tend to naturally decline with distance from a city center due to the decrease in optimal use value of plots in more remote settings. Because of this, owners of urban plots are incentivized to build more capital per land unit than those owning land in outer regions. Thus, development is expected to densify with the application of a LVT. Choi and Sjoquist (2015) demonstrated this using an urban computable general equilibrium model, benchmarked to Atlanta, Georgia. The city was simplified as concentric rings emanating from a central business district (CBD). Residents, faced with budget and time constraints, made tradeoffs between housing features, commuting distance, and leisure time. The authors found that a LVT increased housing capital density in rings closer to the CBD and that resulting higher density was predicted to shrink the urban boundary.

Studies have also utilized more location-explicit analysis of hypothetical LVT impacts, emphasizing regions that are in the midst of urban sprawl issues (Cho et al., 2011; Junge & Levinson, 2012; Kim & Claassen, 2016). Cho et al. (2011) used a spatial-probit model to predict changes in development decisions given varying LVT rates across Nashville, Tennessee. Their methods allow one to base outcomes, not just on parcel-level attributes, but also the qualitative spatial variables like neighborhood spillover (how neighboring development may affect nearby development decisions). The results—consistent across lower, median and upper quartiles of existing density—predict shortest distances from new development to existing non-sprawl development at the highest (200% higher) LVT rate, followed by the 100% higher LVT rate and then the status quo property tax scheme (Cho et al., 2011). The authors noted one challenge of the study was the classification of sprawl---new development even in close proximity to existing development may be characterized as sprawl if the existing proximal development is representative of sprawl. They settled for a time-based classification where non-sprawling regions were those where old-built housing was in close proximity to other old-built housing as measured by local indictors of spatial association.

Likewise, Junge and Levinson (2012) analyzed the density effects of a hypothetical split-rate tax in Minneapolis, Richfield and Bloomington, Minnesota. The authors found a significant increase in expected densities for both residential and commercial development in all three cities (Junge & Levinson, 2012). Furthermore, the percentage of increased development was positively correlated with the ratio of land to property tax rates. The authors noted that their analysis was focused on supply-side dynamics of land development but does not model how demand would be affected by the increased supply of higher-density development (Junge & Levinson, 2012).

Given that much of the prior research has conflated housing capital with density, some researchers continue to debate whether the reduced tax on building improvements through a LVT would result in an increase in home size or more housing units per parcel; the latter being more indicative of denser development. Banzhaf and Lavery (2010) offered unique contribution to this debate by distinguishing such outcomes in 16 Pennsylvanian jurisdictions with a LVT. Using a statistical model known as "difference-in-difference-in-differences" and data comprising demographics (population density, age, ethnicity, income), land development metrics (housing stock and rooms per unit), and tax rate (ratio of land to property tax and change over time) across several decades, the authors found that the split-rate tax was associated with 5-6% more rooms per unit of land as compared to trends prior to the LVT, and this primarily stemmed from increased housing units per parcel, not larger houses.

2.4.3. Conservation and Ecological Restoration

LVT has received notable attention for its ability to support land conservation efforts. Given the expected denser development, smaller urban boundary, and lower price for land, an LVT system could lay a foundation for more aggressive conservation policy. It has also been shown to support global initiatives for conservation and payment for ecosystem services like REDD+ (Kalkuhl & Edenhofer, 2017), and could arguably be seen as complementary to smaller-scale initiatives like conservation easements given the expected decrease in rural land cost (Choi & Sjoquist, 2015). Using a multi-sector general equilibrium growth model, Kalkuhl and Edenhofer (2017) found that because of the aforementioned reduced demand for developing agricultural land, a LVT would increase, or at least help maintain area devoted to conserved wilderness in areas distant enough from urban centers to have very low land values. They concluded that a LVT on non-wilderness land can act as a Pigouvian tax, internalizing the cost of deforestation, and therefore can help complement conservation policies (Kalkuhl & Edenhofer, 2017).

An LVT tax system can also be fine-tuned to further address conservation goals. Lafuite et al. (2018) examined the effectiveness of a type of land-value tax, the natural land depletion tax (NLDT), in preserving biodiversity and promoting sustainable processes within the economy. Simulating the complex interplay of agricultural production, industrial production, biodiversity-dependent ecosystem services and technological efficiency on carrying capacity, land-use and welfare in a hypothetical, closed economy, the authors showed that a NLDT has the effect of internalizing the value of biodiversity, resulting in more diversity preserved at equilibrium through more labor-intensive agricultural practices that reduce natural land conversion. The tax was also predicted to mitigate the vulnerability of the economy to overshoot and collapse given time-delayed externalities of biodiversity-loss—another important facet of sustainability in economics (Lafuite et al., 2018).

2.4.4. Equity and Distributional Effects

The equity and wealth distributional impacts of a revenue-neutral LVT have garnered little consensus among researchers (Kalkuhl et al., 2018; Wyatt, 2019). This is not unexpected given how context dependent the relative tax burden would be; among other things, it is highly dependent on how land ownership is distributed and how resulting revenue is spent (Kalkuhl et al., 2018). If high-value land is concentrated in the hands of the wealthy as many believe it to be in the U.S. (Stiglitz, 2015), the tax would have an inherently progressive distributional effect. Furthermore, given expected land price reductions (Choi & Sjoquist, 2015; DiMasi, 1987), and the theorized inability to pass the tax onto tenants (Smith, 1776), a potentially beneficial effect on poor households would seem to result.

Choi and Sjoquist (2015) found that among three hypothetical income classes with different land and capital holdings representative of the U.S., a revenue-neutral switch to a LVT would be progressively distributed among income classes. England and Zhao (2005) found that a hypothetical revenue-neutral switch to LVT in Dover, New Hampshire would be regressive in nature and would increase the tax burden on single-family residential owners. However, Bowman and Bell (2008) replicated the study in Roanoke, Virginia with opposite results; revenue neutral land value tax shift would most benefit areas with the lowest income and highest poverty rates. The authors attributed the difference in their results (as compared to England and Zhao (2005)) to their use of census tract income and poverty data, which more accurately represented local wealth characteristics (Bowman & Bell, 2008).

Another potential distributional issue is the relative tax revenue coming from commercial and residential land uses. Peter Wyatt (2019), in his exploration of a hypothetical shift from property tax to LVT in an English town, found that the tax base would shift from being largely business-derived to largely from residential—particularly low-density residential. Furthermore, because of the price reduction in land due to the elimination of speculative values, current owners or real estate investors could see a significant windfall loss of resale value (Wyatt, 2019). This could be particularly problematic for economies that rely heavily on wealth in real estate value as debt collateral.

2.4.5. Synthesis

The examination of land-value taxation over the last two centuries has yielded consensus on many of the general impacts of a land value tax on land development patterns; more improvement of land (development) and an increase in capital to land ratios of developments are consistently demonstrated (e.g. Choi & Sjoquist, 2015; Junge & Levinson, 2012). Research also suggests that the increasing capital intensity per land unit is the result of higher density, not larger dwellings (Banzhaf & Lavery, 2010). Thus, a LVT has the potential to reverse the prevalent urban sprawl development that has occurred over the past century. The wide-range of conflicting results with regard to equity and distributional effects of a LVT speak to the high degree of context-dependence of outcomes; a particular finding, even if accurate to a locality, would likely have very limited applicability for another locality.

Little attention has been directed to land use changes across rural areas and land-intensive industries like agriculture—a vital open question when considering a LVT in Vermont. Nor to the predicted effects a LVT on land conservation and ecological value enhancement. The concluded benefit to conservation from Kalkuhl and Edenhofer (2017) and Lafuite, Denise and Loreau (2018) seems to be largely based on the assumption that the tendency to densify development as a result of a LVT will leave enough surplus of land without much economic use, the validity of which is largely based on the population per land area and level of economic development and affluence of the country and region. Furthermore, real estate markets only recognize the economic-use value of land and thus areas of development vs. conservation are not affected by the wide-ranging ecological value of the land (Wyatt, 2022). Without the ability for land value assessments to account for variation in ecological value, the distribution of conservation across the U.S. would be quite uneven. Therefore, a complementary ecological assessment utilized in determining LVT rates could serve to internalize ecological value into land costs. This could also help surmount political feasibility challenges by connecting it to a well-established sustainability agenda.

2.5. Research Overview

The local housing development trends, interest among legislators for innovative solutions, and extensive body of work justifying land value taxation as a solution suggest that more detailed assessment of current land-use trends as well as their potential improvement through land value taxation would be of value to community researchers and practitioners. In light of this and inspired by the hypothesized foundations of perverse land use incentives (see Introduction), this research will focus on (1) a context-specific empirical analysis of LVT across Chittenden County, Vermont given existing development trends, and (2) a hypothetical exploration of an LVT with explicit connection to ecological amenities or disamenities of its land use. More specifically, this research will seek to answer the following questions:

Study 1:

1. What parcel, neighborhood, and locational factors contribute most to local developer decision-making, and what does this imply for future land-use patterns across Chittenden County?

2. How might the location of probable future development, with regard to residential density and distance from urban or village centers, change given various land value taxation schemes?

Study 2:

1. To what degree can a land value tax intervention increase housing development and remediate sprawling land development patterns given the complex interactions between residential preferences, environmental change and profit-seeking developers and speculators?

2. How might the introduction of a land value tax burden which incorporates a parcel's current and potential ecological value affect the preservation of ecologically-important land within and outside of a city relative to a conventional property tax?

The choice of methods was an important consideration in the undertaking of this research. Social scientists have tended to utilize statistics to provide a macro-level explanation of an outcome by demonstrating the relationship between variable factors and the probability of an outcome occurring (Bianchi, 2012). This approach has been criticized for not addressing the black box of micro-level mechanisms that lead to the macro phenomenon (Elster, 1989). Furthermore, many common statistical methods rely on the assumptions that no one observation exerts influence on another (no endogeneity) and that interactions are linear (van den Berg, 2022), which limits a realistic depiction of the sociality and complexity inherent to human systems. Some have called for a broader analytical process, which involves statistics-based macro exploration of social outcomes as well as micro analysis, such as agent-based modeling, to explain the underlying mechanisms at the heart of the social phenomenon (Bianchi, 2012).

This research, though not a direct emulation of this proposed analytical process, takes inspiration from the necessity of utilizing macro and micro focused methods to explain social phenomena more comprehensively. In chapter 3, we used a top-down empirical approach via a spatial probit model and a random forest classifier model. The spatial probit model allows one to model the spatial clustering of outcomes (endogeneity) while the random forest model allows one to relax the assumption of linear relationships. In chapter 4, we applied a bottom-up theoretical approach via a spatially-explicit agent-based model of land-use behaviors. The agent-based model allows one to explore emergent outcomes solely through the specification of individual agent behavior rules and system context.

CHAPTER 3: A SPATIAL ECONOMETRIC EXPLORATION OF DEVELOPMENT DECISION-MAKING & LAND VALUE TAX BURDEN IN CHITTENDEN COUNTY, VERMONT

3.1. Abstract

Like much of the U.S., the region surrounding Burlington, Vermont is quickly suburbanizing. This sparse, decentralized growth is arguably a leading cause of the region's severe housing affordability crisis and fast pace of deforestation. Evidence suggests a Land Value Tax can resolve each of these associated problems. Taxing land value in place of, or to a higher degree than a property's improvement value shifts financial incentives toward denser urban infill. This research seeks to explore the efficacy of land value taxation in Chittenden County, Vermont as a means to encourage development in existing urban and village cores. We utilized a spatial probit model as well as a random forest classifier model corresponding to a discrete choice of development to understand recent housing development choices as they relate to various parcel and locational characteristics. We then utilized developers' revealed behaviors to forecast the quantity and location of future development given two hypothetical land value taxation schemes. Results confirm a trend toward suburban sprawl, with regional developers favoring locations with higher car dependence and commute times as well as locations closer to farmland. A parcel's land value tax per acre yielded a significant, positive effect on development likelihood such that a one unit increase in log-transformed land value tax per acre (a $933 increase for the average parcel) is associated with an 11.7% higher development likelihood. However,

predicted development under the higher land value tax was not found to mediate urban sprawl remediation as hypothesized.

3.2. Introduction

Vermont, like much of New England, has a long tradition of compact village-style development separated by rural countryside. Vermonters today strive to maintain these settlement patterns and their associated amenities like a cohesive town identity, walkability, and access to open preserved land (CCRPC, 2018). However, a growing demand for property and severe housing affordability crisis have put pressure on the rural lands historically surrounding the state's city and village cores, as well as the transportation infrastructure on which they rely. The state is estimated to be losing greenspace at a rate of 15,000 acres per year (Cotton, 2022). In Burlington, Vermont’s largest city, the lack of affordable housing has forced many to seek housing in surrounding towns and commute in for work or recreation. Since 1990, Burlington has produced an estimated 2500 fewer units than necessary to maintain its portion of regional housing (Buki et al., 2017). The suburbs of Burlington soaked up 61.6% of all development in that time period and has increased its share of population from 46.6% to 50.5% (Buki et al., 2017). Increased speculator interest has put further upward pressure on prices; the share of Vermont homes bought by investors more than doubled in 2021, now comprising 17% of all sales (Thys, 2022).

Suburban sprawl presents compound risks, not only to immediate social dilemmas ecological deterioration (Simkin et al., 2022), social fragmentation (Mazumdar et al., 2018), and public health degradation (Zhao & Kaestner, 2010), but also to the region’s ability to transition to a low-carbon economy in the coming years. Even among orthodox economists, acknowledgement of the economic inefficiency of urban sprawl is common; not only does it greatly increase the cost of supplying public and private services (Gielen et al., 2021), it also diminishes the agglomeration effects from which cities become economic powerhouses (Bettencourt et al., 2007; West, 2018).

A disconnect exists between land use incentives at the individual level and the fruits of compact settlement which materialize at larger scales. Foldvary and Minola (2017) attribute this market failure to horizontal development subsidies, zoning regulation, containment policies and land speculation. In the case of land speculation, the insidious feedback loop referred to as "leapfrog development" can be summarized as: (1) infrastructure is added to serve new development; (2) land values increase as a result (to the benefit of current residents and to the detriment of prospective residents); (3) new residents then settle farther away from the infrastructure to capture lower prices and demand infrastructure near them, thus perpetuating the cycle (Foldvary & Minola, 2017; Junge & Levinson, 2012).

Perverse incentives toward speculation emerge from the ability to capture economic rent, or economic returns that aren't the result of labor or sacrifice, but rather emerge from control over scarce or monopolized assets (Stratford, 2022). Such elaborations date back to the seminal texts of classical economics; first with Adam Smith's description of the natural monopoly of land prices and later with David Ricardo's elaboration on the Law of Rent (Ricardo, 1817; Smith, 1776). Land, being entirely fixed in supply, derives its value from its associated demand. It is a parcel's proximal characteristics and its natural endowments which explain its price in relation to other parcels (Foldvary & Minola, 2017).

As a settlement develops, its locational desirability and subsequent acceptable price may increase. The resulting increase in a landowner's wealth is not the result of her work but that of the community at large and therefore is considered economic rent.

A land value tax (LVT) has long been proposed as a solution to this problem and its subsequent impacts on land use (Batt, 2012; Cho et al., 2011; George, 1879). Taxing land value in place of, or to a higher degree than the value of improvements can eliminate or dampen the speculative potential of holding land out of the market and internalize the higher public costs of urban sprawl into private land ownership costs (Dye & England, 2010; Foldvary & Minola, 2017). Plassmann and Tideman (2000) found that among 15 jurisdictions in Pennsylvania with a split-rate tax system, significantly more building permits were issued between 1972 and 1994 as compared to neighboring jurisdictions without a split-tax rate. Oates and Schwab (1997) showed similar findings for Pittsburgh which has had a split-rate tax since 1913. Using regression analysis, the authors found that among 14 other comparable U.S. cities, Pittsburg was the only city to have a significant increase in building activity in the 1980s.

Furthermore, given the natural tendency for land within urban cores to have the highest land values, and thus greatest pressure to develop, a LVT is also found to encourage urban infill and decrease pressures for rural land development (Cho et al., 2011; Choi & Sjoquist, 2015; Kalkuhl & Edenhofer, 2017). Banzhaf and Lavery (2010) found that among 16 Pennsylvanian jurisdictions, a split-rate tax was associated with 5-6% more rooms per unit of land as compared to trends prior to the LVT, and this primarily stems from increased housing units per parcel, not larger houses. Cho et al. (2011) used a spatial-probit model to predict changes in development decisions given varying hypothetical LVT rates across Nashville, Tennessee. The authors found that the existing LVT burden had a significant, positive association with development likelihood and that higher LVT rates led to shortest distances from predicted development to existing non-sprawl.

In this study, we sought to emulate the study design of Cho et al. (2011) to understand recent development trends in Chittenden County and forecast the relative quantity and location of future development with various taxation schemes given developers' revealed behaviors. We relied on two models to accomplish our intent. First, we utilized a spatial probit model to identify preferred parcel, neighborhood, and locational characteristics of recent housing development across Chittenden County. Second, we employed a random forest classifier model to predict locations of future housing development given three tax scenarios: status quo, a doubling of the land value tax rate (2x LVT), and a quadrupling of the land value tax rate (4x LVT). Ex-ante analysis of the most probable development locations was conducted to estimate the relative sprawl potential of predicted future development across the three tax scenarios.

3.3. Methods

Discrete choice models estimate the probability of a binary categorical outcome according to any variety of independent variables that are believed to influence that choice. They have been used extensively to predict land use change as a function of parcel-level characteristics (e.g. Carrión-Flores & Irwin, 2017; Claassen & Tegene, 1999). However, development choices have been shown to exhibit spatial dependence in which the outcome of one parcel is affected by the outcome of surrounding parcels (Ismail, 2006). To account for spatial dependence or spatial spillover effects in choices such as land development, a spatial autoregressive model (SAR) can be combined with the discrete choice model (LeSage & Pace, 2009). In these cases, a matrix of outcomes of neighboring parcels, often weighted by their proximity, is used to influence the estimated outcome (LeSage & Pace, 2009).

Given the binary observed outcome, A SAR probit regression model estimates an unobserved latent variable (y*) with the structural model:

$$y^* = \rho W y^* + \beta X + \varepsilon \tag{3. 1}$$

where W is a (n x n) matrix representing the neighboring connections, ρ is a scalar coefficient to be estimated for the spatial autocorrelation term, β is a vector of coefficients for the (n x k) X variable matrix, and ε is the residual. The reduced form of the latent variable is:

$$y^* = (I - \rho W y^*)^{-1} \beta X + \varepsilon \tag{3. 2}$$

The latent variable y* then links to the observed binary outcomes (y_i) as:

$$y_i = \{1 \text{ if } \Phi(y_i^*) > 0 \ ; \ 0 \text{ if } \Phi(y_i^*) > 0\} \tag{3. 3}$$

The spatial interdependence of outcomes in spatial autocorrelation term present endogeneity which makes standard probit estimation inappropriate (Franzese & Hays, 2008). Instead, a Bayesian Markov-Chain-Monte-Carlo (MCMC) method can be used to estimate a highly precise (but still imperfect) estimation for the model (LeSage & Pace, 2009). MCMC works by iteratively sampling coefficient values based on their prior probability distributions, then using the posterior probability distribution (likelihood function) to estimate fit (Franzese & Hays, 2008). With enough samples, parameters converge on highly likely coefficient values. In the case of spatial probit models, priors are complex multivariate normal distributions, conditional on one another. The R package “spatialprobit” has pre-specified such distributions to allow for easier implementation (Wilhelm & Matos, 2013).

The application of spatial regression techniques toward land use and land cover change examination is extensive (e.g. Arima, 2016; Carrión-Flores et al., 2018; Robertson et al., 2009; Wang et al., 2014). Some have even explicitly analyzed the effects of land value taxation on land development (Cho et al., 2011, 2016; Kim et al., 2012; Kim & Claassen, 2016). For example, Cho et al. (2011) applied a spatial-probit model to explore issues of urban sprawl and their potential resolution through land value taxation. Because conventional property tax rates are applied equally to land and improvement value, one can include the land portion of property tax as a regressor variable. Their model was able to correctly predict 93% of parcel development in the year 2007. Results indicated a 6.9% increase in development probability for every $1000 increase in per acre land value tax rate. Subsequent exploration of the locations of predicted development revealed a 20% reduction in distance to pre-existing development.

In more recent years, machine learning techniques have been used to improve classification models and circumvent the constraining assumptions of generalized linear models (GLMs). One such example is the Decision Tree, which is a supervised machine learning algorithm that uses a series of data categorization rules to sequentially subset data and draw conclusions about data’s likely classification. The method is often used in ensemble, called a Random Forest Classifier, to account for the overfitting of data to which decision trees are prone. Couronné et al. (2018) found random forest classifiers to significantly outperform logistic regressions in binary prediction accuracy.

Random forest classifiers have seen limited adoption in land development modeling, and where they have been used, it's often toward land type classification or predictions rather than a focus on those attributes that drive land use change (e.g. Belgiu & Drăguţ, 2016). An exception is Wu et al. (2021) who demonstrated a means to analyze driving factors of land use change by estimating the permutation-based feature importance of the random forest.

However, random forests—while they can determine the relative importance of each feature in the model prediction—lack the broader interpretability of GLMs which can describe the slope and direction of the relationship between variables. For this reason, we estimate a spatial probit model to explore the effect of predictor variables on development likelihood, as well as a random forest classifier to make accurate predictions about probable future development according to those predictor variables.

3.4. Data

We first established our population of developed and undeveloped parcels across Chittenden County, Vermont by combining subsets of two existing datasets. Chittenden County Regional Planning Commission's (CCRPC) Housing 2021 dataset was used to determine all recently developed housing (CCRPC, 2022). The dataset provides a spatial representation of all Chittenden County housing units, as well as associated characteristics including year built, housing type, tax parcel ID, and dwelling unit count. We subset the

Housing 2021 dataset to housing built between 2016 and 2021 for the purpose of establishing our "developed" parcel observations (n=1,995).

We then established our "undeveloped" parcel observations using Vermont's 2021 Grand List property tax assessment (VT Department of Taxes, n.d.). Undeveloped parcels are defined as those meeting either of two conditions: having a land use category of miscellaneous or woodlands (which the state uses to categorize vacant land), or parcels having an improvement value to land value ratio of less than or equal to 0.2. The later condition integrates parcels that may not be listed as vacant, but may still be seen as "developable" by developers. A total of 2,456 parcels met these conditions. Parcel coordinates and shape data were then joined with each undeveloped parcel using Vermont Center for Geographic Information's Parcel Database (VCGI, 2022).

Next, we established our set of explanatory variables for each parcel according to its parcel ID or location. Table 1 provides a listing and description of all explanatory variables. For developed parcels, the parcel ID was first used to join additional parcel characteristics (e.g. lot size, land value) from Vermont's 2021 Grand List property tax assessment (VT Department of Taxes, n.d.). Many of the variables characterize a parcel's driving distance to particular regional features (e.g. highway, preserved land, Burlington city center) which are shown to influence residential preferences (Schirmer et al., 2014). The data for those variables were ascertained through use of the ArcGIS Network Analysis Suite and noted in Table 1 as "driving distance". In cases such as distance to Lake Champlain, where general proximity may be more important than driving distance, Euclidean distance was used.

Table 1:

Development Decision-Making Regressor Variables

Variable Name	Description	Source
Development Status	1 if a parcel was developed for residential housing in 2016 or later, 0 if undeveloped	Housing 2021, Chittenden County (CCRPC), 2021 Vermont State Grand List
Slope	Percent slope based on 2016 Lidar imagery	2017 Slope (Lidar), Vermont Center for Geographic Information (VCGI)
Lot Size	Size of the parcel (acres)	2021 Vermont State Grand List
Land Value Tax (LVT) per Acre	Tax burden for land value portion of property tax in 2021 (based on non-homestead rate by town)	2021 Vermont State Grand List
Tree Area	Area of tree canopy within 500m radius	2016 Tree Canopy Land Cover, VCGI
Residential Density	Density of residential buildings within a 1000m radius	VT Building Density (Vermont Center for Geographic Information, based on E911-ESITE data)
Housing Unit Density	Average density of residential buildings within the Census Block Group	2020 ACS 5-Year Estimates. DP03 Selected Economic Characteristics (U.S. Census Bureau)
Unemployment	Estimated unemployment rate at census block group level	2020 ACS 5-Year Estimates. DP03 Selected Economic Characteristics (U.S. Census Bureau)
Occupied Housing Rate Over 97%	Binary of whether the census block group's percentage of occupied housing units is over 97%	2020 Decennial Census (U.S. Census Bureau)
Poverty Rate	Percentage of population with incomes below the federal poverty level	2020 ACS 5-Year Estimates. DP03 Selected Economic Characteristics (U.S. Census Bureau)
No Car Rate	Percentage of census block group population without a car	2020 ACS 5-Year Estimates. DP03 Selected Economic Characteristics (U.S. Census Bureau)
15 Minute Work Commute	Percentage of census block group population with a work commute time of 15 minutes or less	2020 ACS 5-Year Estimates. DP03 Selected Economic Characteristics (U.S. Census Bureau)
Walkability Score	Census block group score on the EPA's national walkability index	Smart Location Database v3 2021 (EPA)

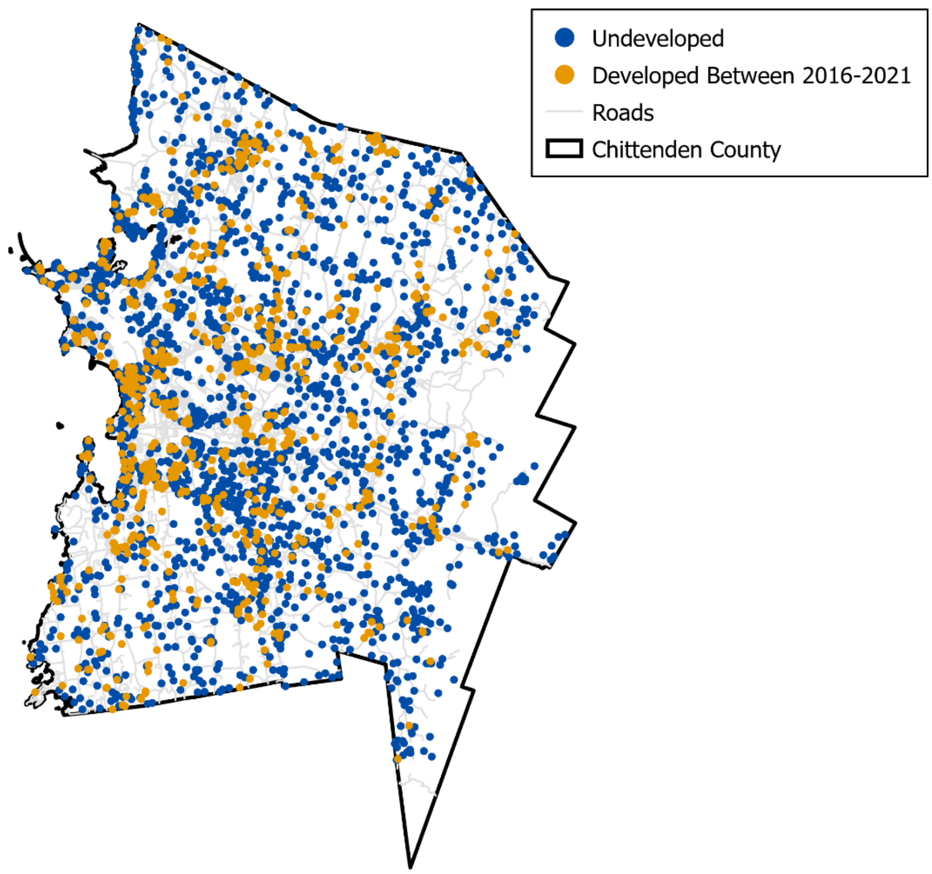
Vehicle Miles Traveled (VMT)	Average weekday vehicle miles traveled for census block group	2020 ACS 5-Year Estimates. DP03 Selected Economic Characteristics (U.S. Census Bureau)
Smart Location Score (SLD score)	Estimated value of the EPA's Smart Location Index (0-100)	Smart Location Database v3 2021 (EPA)
Burlington Distance	Driving distance to downtown Burlington (km)	n/a
Lake Distance Under 5km	Euclidean distance to Lake Champlain (km) for data points within 5km from lake	n/a
Lake Distance Over 5km	Euclidean distance to Lake Champlain (km) for data points beyond 5km from lake	n/a
Park Distance	Euclidean distance to nearest protected forest (km)	Vermont Protected Lands Database (VCGI)
Trail Distance	Euclidean distance to nearest hiking trail (km)	E911 Trails (VCGI) & Trails (Vermont Agency of Natural Resources) (combined)
Ag Land Distance	Euclidean distance to nearest agricultural land (km)	2016 Agriculture Land Cover (VCGI)
Road Distance	Driving distance to nearest Primary or Secondary Road (km)	Vermont, Primary and Secondary Roads (U.S. Census Bureau)
Highway Distance	Driving distance to nearest highway on-ramp (km).	n/a
School Distance	Driving distance to nearest K-12 school (km).	School Locations: K-12 (VCGI)
Town Distance	Euclidean distance to nearest town center (km)	n/a
Town	In which municipality the parcel is located	2021 Vermont State Grand List
Spatial Lag: Neighborhood Development	Average development status of nearest neighbors	Housing 2021, Chittenden County (CCRPC), 2021 Vermont State Grand List

The complete dataset (n=4,451) was then cleaned to remove certain development types, visually-undevelopable parcels, tax-exempt parcels, missing data, and outliers. Among developed parcels, duplicates were removed as were housing units listed as "accessory dwelling units" or "mobile home" as we assume these development types feature a different means of decision-making. Furthermore, many developments were representative of suburban tract homes which resulted from a single developer choice. Therefore, a total of 456 “developed” observations were condensed into 20 observations, the acreage of which was either the sum of each condensed development or (where possible) that of the parent parcel’s recorded acreage in the tax records. Among undeveloped parcels, those that are listed as “tax exempt” and those owned by land trusts were also removed. For a number of observations, land value was not included in the property tax assessment. For instance, the town of Williston did not provide land value assessments separate from improvement value. Vermont property tax assessments also do not assess land value for condominiums. However, land value per acre is highly spatially autocorrelated (e.g. Larson & Shui, 2022) and therefore we used spatial interpolation to estimate LVT per acre for those parcels. We used an inverse-distance weighting based on parcels with known land value per acre. For Williston data points, we included the assessed value per acre of parcels known to be devoid of any improvements. Furthermore, some observations’ tax data did not include acreage. In most cases, we used the shape area of the parcel polygon in ArcGIS. For others, we interpolated acreage using the average lot size of the corresponding census block group.

After data cleaning was complete, 3,285 parcels remained in the dataset, 1,133 developed, and 2,152 undeveloped (Figure 1). Many of the predictor variables yielded long-tail distributions, for which data transformations were implemented for the spatial probit model. Table 2 lists summary statistics for each predictor variable as well as any transformations that were done to improve the normality of their frequency distributions.

Figure 1:

Spatial Distribution of Observations After Data Cleaning



Note. Developed parcel points were placed overtop and therefore cover underlying undeveloped points.

Table 2:

Continuous Predictor Variables and Associated Summary Statistics

Predictor Variables	**Mean**	**Standard Deviation**
ln(Slope)	2.013	0.919
ln(Acres)	1.334	2.097
ln(LVT per Acre)	6.360	2.088
Tree area	0.423	0.186
ln(Residential Density)	4.354	1.574
ln(Housing Unit Density)	-9.998	1.459
ln(Unemployment)	-3.747	0.613
ln(Poverty Rate)	-3.707	1.632

ln(No Car Rate)	-3.704	0.928
ln(Rate of 15min Work Commute)	-1.712	0.663
sqrt(Walkability Score)	2.718	0.562
cube(Vehicle Miles Traveled)	12919.332	5763.863
ln(SLD Score)	3.341	0.631
Burlington Distance	17.538	9.091
Lake Distance Under 5km	0.735	1.326
Sqrt(Lake Distance Over 5km)	2.194	1.881
Cbrt(Park Distance)	0.895	0.379
Cbrt(Trail Distance)	0.874	0.295
Ln(Ag Land Distance)	-1.338	1.105
Cbrt(Road Distance)	1.200	0.482
Sqrt(Highway Distance)	3.005	0.997
Sqrt(School Distance)	1.823	0.700
Sqrt(Town Distance)	1.784	0.602

3.5. Model Implementation & Analysis

3.5.1. Spatial Probit Model

The spatial probit model was estimated using the R package "spatialprobit" (Wilhelm & Matos, 2013). Spatial weights were specified based on a K-nearest neighbor contiguity matrix in which each data point is connected to a specified number (k) of data points closest to it. We found k=1 to be the most suitable model using Akaike Information Criterion for cross validation.

Marginal effects for the mean value of significant variables can be calculated to estimate the change in likelihood of the dependent variable being equal to one given a marginal change in one variable at the mean, holding others constant. For models with spatial autocorrelation, marginal effects must be calculated with consideration of both the direct effects of a change in x_i on that same parcel (y_i) as well as the indirect effects of that same change on neighboring parcels (y_j) (Franzese & Hays, 2008). We used the built-in marginal effects function in the R package "spatialprobit" to calculate indirect, direct, and total effects for each variable.

3.5.2. Random Forest Model

The random forest model was estimated using Python's Scikit Learn package (Pedregosa et al., 2011). We first utilized recursive feature elimination with cross validation (RFECV) to determine which variables should be used in the random forest model. The weighted F1 score, representing a balanced trade-off between precision and recall, was used to cross validate models. We then optimized hyperparameters using GridSearchCV which searches over all combinations of given hyperparameter ranges, again cross validated using the weighted F1 score. Subsequent tuning of hyperparameters was necessary to mitigate model overfit.

Model validation was conducted by randomly subsetting data into a training and testing set with 75% and 25% of the data, respectively. Model predictions were compared to observed outcomes to validate the model's goodness-of-fit, as measured by prediction accuracy and F1 score. With successful validation of the model, we then re-estimated the model using all observed data prior to model interpretation or predictions.

Finally, we conducted *ex-ante* comparisons of predicted likelihood of development under different tax regimes. We first predicted future development with the X matrix of undeveloped parcels as currently specified. We then doubled each town's land value tax rate and re-specified the land value tax per acre column with the new tax rate for the 2x LVT scenario and likewise for the 4x LVT scenario. Predicted future developments for each scenario were then mapped to allow for spatial analysis of their relative contribution to urban sprawl. Here we defined sprawl with two indicators: the parcel's distance to an urban or village core as defined in CCRPC's Future Land Use Plan (CCRPC, 2019), and the location's residential density, based on raster data at the scale of 30m provided by VCGI (VCGI, 2020).

3.6. Results

3.6.1. Spatial Probit Model

Significant spatial autocorrelation in development outcomes was confirmed using Moran's I with 1 nearest neighbor (Moran's I = 0.404, $p<0.0001$). The spatial probit model was found to correctly predict 73% of development decisions between 2016 and 2021 with a log likelihood of - 1692.709. Table 3 summarizes posterior mean and standard deviation of model coefficients as well as marginal effects for significant variables at the 0.05 level.

Table 3:

Estimated Coefficients and Standard Deviation of Spatial Probit Model

	Coefficients		**Total Marginal Effects**	
Predictor Variables	**Mean**	**Std. Dev.**	**Mean**	**95% CI (+/-)**
Intercept	-6.622***	1.929	–	–
ln(Slope)	-0.113***	0.033	-0.041	0.019
ln(Acres)	0.049*	0.022	0.018	0.013
ln(LVT per Acre)	0.324***	0.026	0.117	0.014
Tree area	0.250	0.217		
ln(Residential Density)	0.173***	0.034	0.062	0.020
ln(Housing Unit Density)	0.178**	0.058	0.064	0.034
ln(Unemployment)	0.064	0.048		
Occupied Housing Rate Over 97%	-0.123	0.073		
ln(Poverty Rate)	-0.026	0.019		
ln(No Car Rate)	-0.098*	0.041	-0.035	0.025
ln(Rate of 15min Work Commute)	-0.226***	0.068	-0.081	0.040
sqrt(Walkability Score)	-4 e-04	0.083		
cube(Vehicle Miles Traveled)	1E-04**	4E-05	4.1E-05	6.7E-05
ln(SLD Score)	0.827*	0.385	0.298	0.230
Burlington Distance	0.005	0.012		
Lake Distance Under 5km	0.155***	0.031	0.056	0.018
Sqrt(Lake Distance Over 5km)	0.121	0.053		

Cbrt(Park Distance)	0.057	0.078		
Cbrt(Trail Distance)	0.125	0.101		
ln(Ag Land Distance)	-0.161***	0.030	-0.058	0.018
Cbrt(Road Distance)	0.264***	0.078	0.095	0.046
Sqrt(Highway Distance)	0.035	0.067		
Sqrt(School Distance)	-0.047	0.066		
Sqrt(Town Distance)	-0.064	0.060		
Bolton	-0.682*	0.348	-0.246	0.205
Burlington	-1.205***	0.330	-0.435	0.197
Charlotte	-0.740*	0.313	-0.267	0.187
Colchester	-0.835**	0.305	-0.301	0.181
Essex	-0.293	0.279		
Hinesburg	-0.627*	0.287	-0.226	0.172
Huntington	-1.362***	0.352	-0.492	0.209
Jericho	-0.816**	0.300	-0.294	0.178
Milton	-0.79**	0.301	-0.285	0.178
Richmond	-0.682*	0.317	-0.246	0.184
Shelburne	-0.365	0.304		
South Burlington	-0.789*	0.307	-0.285	0.183
Underhill	-0.619	0.327		
Westford	-0.469	0.311		
Williston	-0.612*	0.287	-0.221	0.169
Winooski	-0.841*	0.369	-0.303	0.222
Spatial Lag	0.227***	0.024	–	–

Note. * p<0.05, ** p<0.01, *** p<0.001

The marginal effects allow for interpretation of each predictor variable in terms of their association with development likelihood. For example, a one unit increase in log-transformed land value tax per acre (corresponding to a $993 increase in land value tax per acre from a plot with average log-transformed LVT per acre) was associated with an 11.7% higher development likelihood on average. A one unit increase in log-transformed distance to farmland (corresponding to a 451m increase in distance from a plot with the average log-transformed distance from farmland) was found to decrease development likelihood by 5.8%. A one unit increase in the log-transformed rate of population with a 15 minute or less commute time (corresponding to a 31 percentage point increase from a plot with average log-transformed rate of 15 minute work commute) was found to decrease the probability of development by 8.1%. Furthermore, all marginal effects associated with the location of a parcel in a particular town were found to be negative, with the two strongest being Huntington (49% lower probability of development) and Burlington (43% lower probability of development). We believe this to be the result of the class imbalance between developed and undeveloped parcel counts which may incline the model toward lower probability estimates.

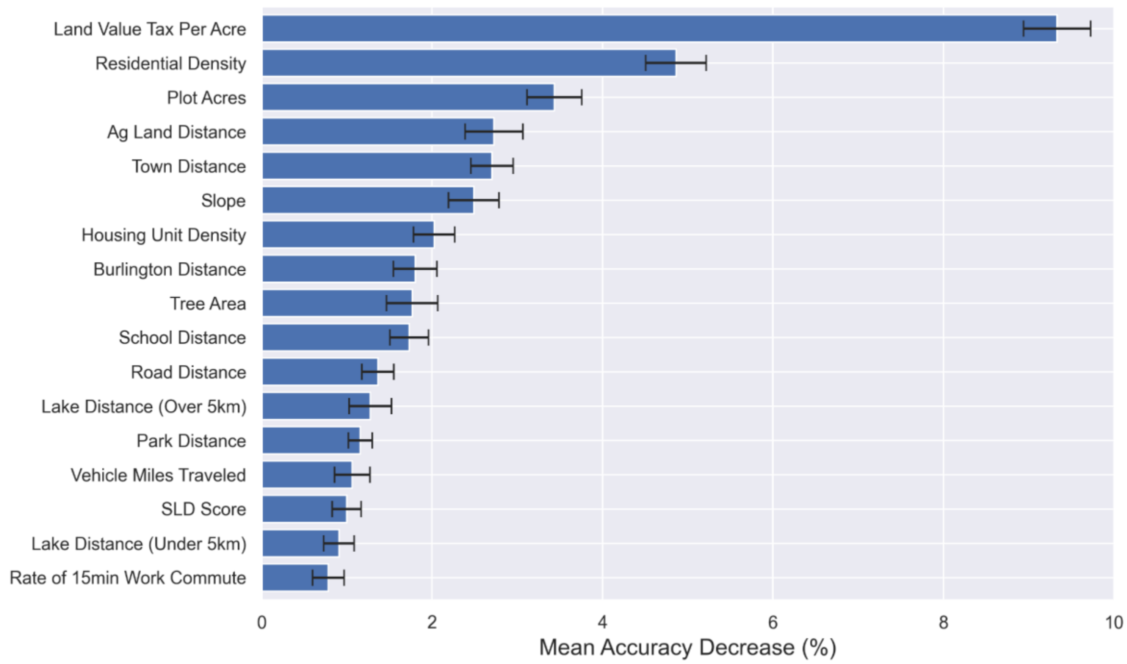
3.6.2. Random Forest Classifier Model

RFECV yielded a total of 17 variables that maximized model performance with regard to the model's F1 weighted score. The random forest classifier was comprised of 400 decision trees with a max depth of 9, a minimum leaf size of 10. While less constraining hyperparameters were found to increase training and test accuracy, their gap was large enough to imply overfitting.

The random forest classifier model, with given parameters, had a training data accuracy of 85% while the accuracy with testing data was 77%. Having then fit all the data, the model was able to correctly predict 84% of parcel classifications. **Error! Not a valid bookmark self-reference.** shows the random forest's permutation feature importance which measures the average decrease in prediction accuracy that results from permuting a variable (Molnar, 2023). Land value tax per acre was the most important feature in the model with a mean impurity decrease value more than double that of the next highest feature.

Figure 2:

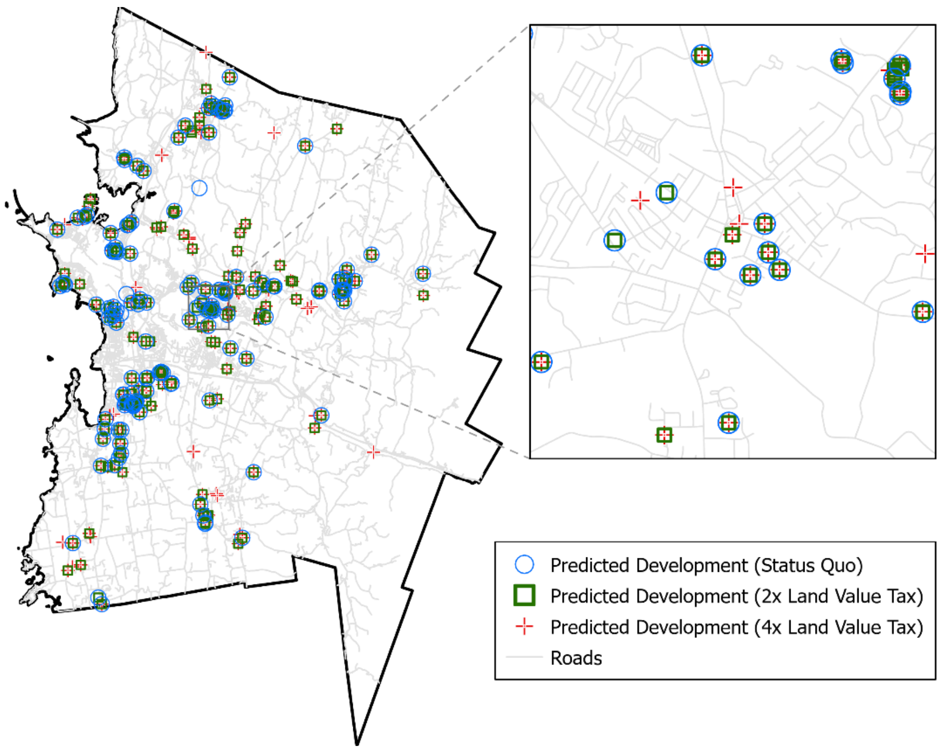
Permutation Feature Importance in the Random Forest Model Using Mean Decrease in Accuracy



The random forest model was then used to predict future development as defined by undeveloped parcels that were classified as developed. Given the stochasticity inherent in random forests, we fit the data across five runs and conduct ex-ante analysis on the aggregation of the five runs. The predicted future development for each of the three tax scenarios for one run is shown in Figure 3. Predicted future development given a status-quo property tax tended toward mid-density, ex-urban locations. Only 7.5% of predicted developments were located in Burlington. Furthermore, 49% of developments were located outside central regions (corresponding to CCRPC planning designations of “center”, “village”, or “metro”).

Figure 3:

Single Run Predicted Future Development Under Three Tax Scenarios



Note. Inset image highlights Essex Junction, one of four “city” municipalities in Chittenden County

As compared to the status quo tax scenario, both land value tax interventions greatly increased predicted development rates. The average number of parcels predicted to be developed increased from 139 for the status quo tax scenario, to 202 and 242 for the 2x LVT and 4x LVT tax scenarios, respectively. However, neither land value tax scenario reduced suburban sprawl projections as hypothesized. The average log-transformed residential density of predicted development decreased from 5.54 with the status quo scenario to 5.40 and 5.33 with the 2x LVT and 4x LVT, respectively. Furthermore, the average distance (meters) to a central region increased from the status quo scenario of 504 to 609 and 643 with 2x LVT and 4x LVT, respectively. The full distribution of residential density (log-transformed) and distance to a central region are shown in Figure 4 and Figure 5, respectively.

Figure 4:

Probability Density Distribution of Predicted Future Development's Residential Density (Log-Transformed) Under Three Tax Scenarios

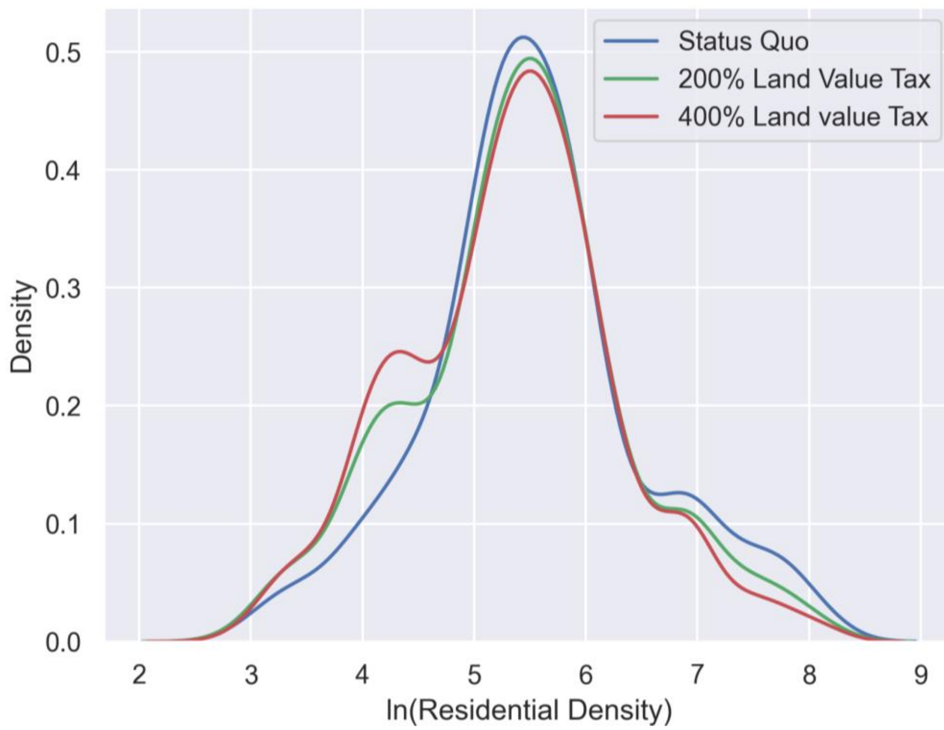
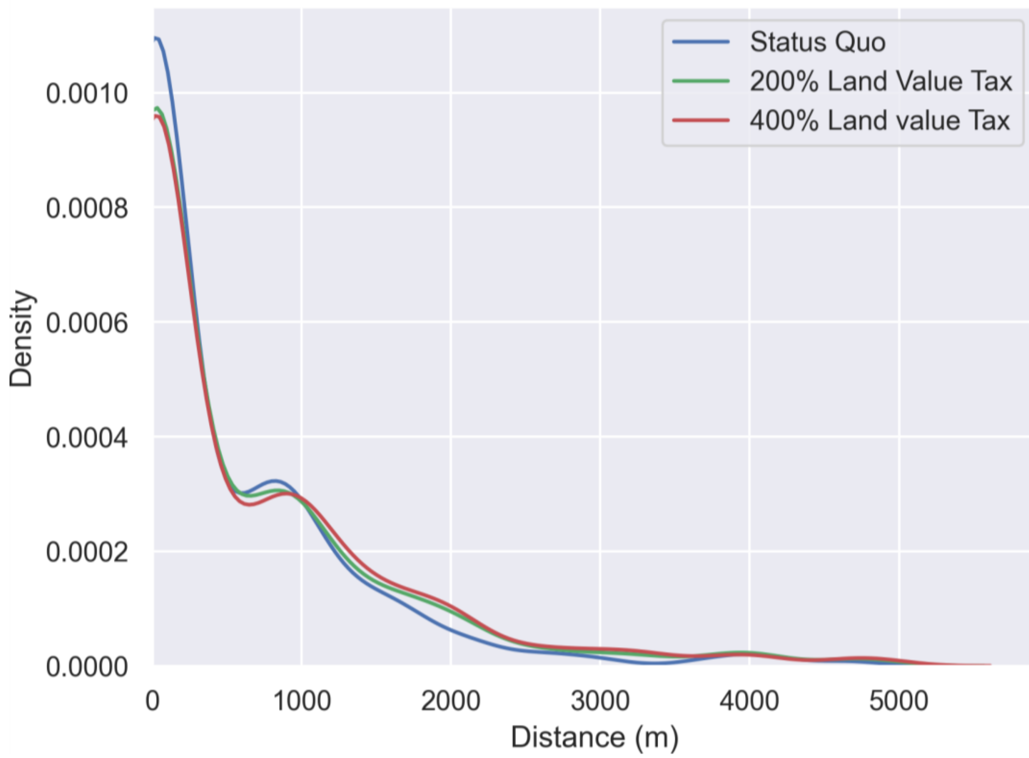


Figure 5:

Probability Density Distribution of Predicted Future Development's Distance to "Center", "Village" or "Metro" Planning Areas Under Three Tax Scenarios



3.7. Discussion

Our findings suggest developers preferred several parcel attributes associated with suburban sprawl for housing development. More specifically, developers preferred locations with higher lot sizes, car ownership rate, work commute time, and distance to a primary or secondary road. Furthermore, their preference for land in close proximity to farms suggests a heightened risk of future farmland conversion. Findings also suggest that developers preferred locations with higher residential density and land value tax burden suggest clustering (spatial autocorrelation) of developments. Taken together with our finding that predicted future development most frequently targeted mid-level residential density, results may signify the occurrence of leap-frog development strategies which target locations just outside city centers to capitalize on expected future land price appreciation.

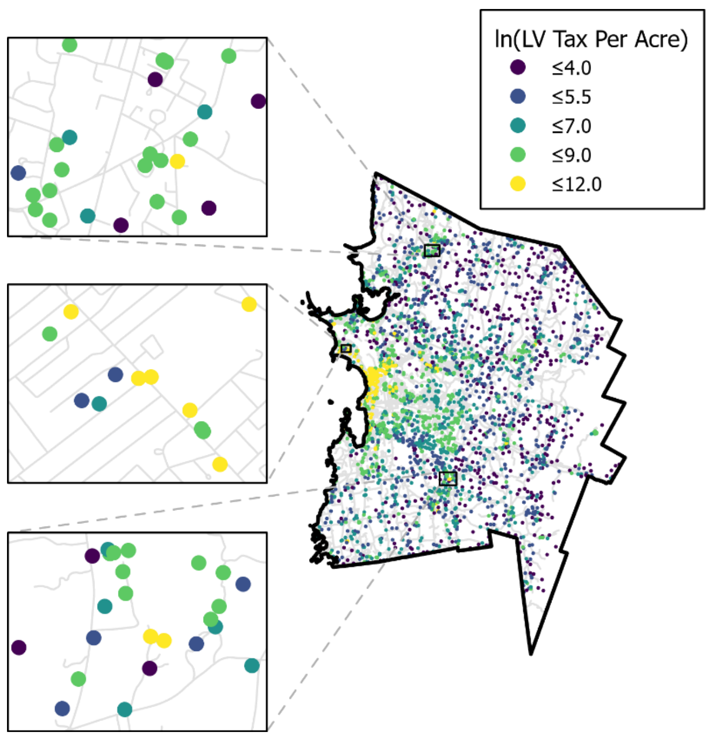
We found evidence to reject our null hypothesis that land value taxation has no effect on developer choices regarding where to construct housing. Both models demonstrate the significant, positive impact of land value tax burden on a parcel's development likelihood and provide further evidence for the effectiveness of land value taxation toward bolstering a region's housing supply. This finding aligns with the substantial body of existing literature which has shown land value tax to increase housing development rates (e.g. Choi & Sjoquist, 2015; Junge & Levinson, 2012; Oates & Schwab, 1997).

We did not find sufficient evidence to reject our null hypothesis that a land value taxation scheme would increase pressure to develop in suburban or rural areas. Both land value taxation scenarios show approximately the same trend of development location with regard to residential density and distance to an urban or village center, however with a slight increase in development of lower residential density locations relative to the status quo property tax scenario. We speculate that this finding stems from two limitations of the study. First, the model assumes no interaction between a change in land value taxation and the other revealed preferences of developers. On the contrary, the higher cost of owning a land inefficient home and the lower cost of urban living would likely affect aggregate homeowner and subsequent developer preferences. Second, land value assessments in

Vermont were highly variable and likely inaccurate (Figure 6). Given the county's current property tax system, assessors have little incentive to accurately separate land and improvement value. With regard to our model, the effect of an increase in the land value tax rate on over-assessed suburban or rural parcels could have led to a disproportionate increase in development probability relative to more accurately assessed parcels.

Figure 6:

Variability in Land Value Assessment as Shown by Land Value Tax Per Acre (Log-Transformed)



Furthermore, our research procedure and model implementations presented several simplifications that may have limited the scope and accuracy of the study. First, development was regarded as a binary category, while in the real world, a significant portion of the decision regards how much to develop. A future study might look at the outcome variable as a continuous variable corresponding to development capital intensity.

Secondly, development was assumed to be unconstrained across Chittenden County, while in reality zoning and community oversight present spatially heterogenous development constraints that can be incorporated into the model. Lastly, as stated above, variability of land value per acre created a significant amount of noise and potentially inaccurate predictions in our model. A technique for smoothing such variability may improve model performance.

CHAPTER 4: LAND STEWARDSHIP AND DEVELOPMENT BEHAVIORS UNDER AN ECOLOGICAL-IMPACT WEIGHTED LAND VALUE TAX SCHEME: A PROOF-OF-CONCEPT AGENT-BASED MODEL

4.1. Abstract

Sprawling land development patterns have exacerbated ecological degradation, social fragmentation and public health deterioration. Many have argued that perverse land use incentives stem from two sources: (1) the ability to privately appropriate the collectively created social value of settlements as economic rent, and (2) the inability to recognize ecological opportunity costs of natural land conversion in land use decisions. Land value taxation (LVT) has been shown to encourage urban infill development by reducing or eliminating rent-seeking behavior in land markets. However, despite its purported benefits, the tax reform is value monistic in its definition of optimal land use and therefore does little to address the lack of non-market information to inform land-use decisions. We propose an expanded land value taxation policy (ELVT) which incorporates the ecological footprint of land use into one's land value tax burden. We test both land value taxation and our proposed expanded policy, relative to a "status quo" (SQ) property tax scheme, utilizing a conceptual spatially-explicit agent-based model of land-use behaviors and housing development. Findings suggest both tax interventions can increase capital intensity and decrease land intensity of housing development. Furthermore, both tax interventions led to net profit loss for speculators and a decrease in the average housing unit price. The ELVT scheme was shown to significantly increase urban nature provisions and dampen the loss of ecological value across the region.

4.2. Introduction

Suburban sprawl has dominated the modern landscape in the U.S. and other countries. As of 2017, over half of U.S. citizens were estimated to live in suburban areas (Bucholtz et al., 2020). Characterized by dispersed, low-density residential buildings reliant on automobile travel for access to amenity- or commercial-areas, suburban sprawl presents a robust hindrance to a low resource reliant future (Rafferty, n.d.). So, too, does the associated cultural norm around open-space cultivation. Turf grass is estimated to take up three times the surface area of any other irrigated crop in the U.S. and requires as much as 900 liters of water per person per day, not to mention its associated fertilizer and carbon demand (Milesi et al., 2005).

Such patterns of land use have far-reaching impacts on higher-order social and ecological realities, including ecological deterioration (Simkin et al., 2022), social fragmentation (Mazumdar et al., 2018), and public health degradation (Zhao & Kaestner, 2010). Yet one cannot say the same thing in reverse; patterns of development have largely been driven by myopic individual actions unaware of or ambivalent to their contribution to broader social dilemmas.

Many have pointed to the rent-generating potential of land and subsequent financialization of land markets as embedding perverse incentives in land use decision-making (e.g. Clawson, 1962; Foldvary & Minola, 2017). Rent capture in land markets undermines collective welfare through private appropriation of the public and nature-derived values of place. Consequently, land's exchange value has usurped its fundamental use as a basic human and non-human necessity. Furthermore, as Henry George emphatically argued in the late 19th century, land rents perpetuate poverty by allowing a rentier class to increase land costs in proportion to any increase in productivity (George, 1879).

The implications for ecological economics are momentous. Economic rent makes up an increasing share of national income and continues to be argued as a root cause of growing inequality (Kasliwal, 2016). The persistence of 'rentier capitalism' can also distort the outcomes of environmental protections, contributing to increased inequality and instability (Stratford, 2020). As just one example, the benefits of urban greenspace have been shown to capitalize into property prices and result in displacement of existing communities and market-based exclusivity of the subsequent benefits of greenspace (Bockarjova et al., 2020; Yazar et al., 2020)[1]. Consequently, many argue that the elimination of rent-capture is a crucial prerequisite for broader economic reforms toward a steady-state economy (e.g. Batt, 2012; Stratford, 2020).

The Land Value Tax (LVT) is a fitting policy tool for redistributing the benefits of land stewardship toward the community at large, rather than the neighboring parcels via price appreciation (Batt, 2012; George, 1879). Researchers have demonstrated its effectiveness in promoting urban infill over urban sprawl (Cho et al., 2011), preserving exurban land for nature (Kalkuhl et al., 2018), and reducing housing costs (Choi & Sjoquist, 2015).

[1] For a broader discussion on the unequal distribution of the benefits of urban greenspace, see Juntti and Ozsezer-Kurnuc (2023).

However, despite its improvements both to equity and land-use efficiency by buffering the exploitation of land rents, the taxation scheme remains reliant on markets to define the “optimal use” for land and therefore lacks the ability to relay non-market information to landowners in order to, for example, safeguard ecological thresholds (Wyatt, 2022). Originally proposed by George as a more palatable alternative to socializing land, the sustained reliance on markets and their associated value monism presents a fundamental contrast between land value taxation and land socialization, and a shortcoming of the applicability of land value taxation to ecologically-sound land stewardship.

Moreover, conventional land value taxation falls short of directly incentivizing private urban or suburban land stewardship due to the non-discriminate distribution of the social welfare created. While a landowner would bear the full cost of land regeneration (including the direct cost and potentially increased tax burden from land value appreciation), she would receive a negligible portion of any monetary benefits (via broad distribution of new tax revenue).

Although a slew of public action has focused on conservation or incentivizing private land stewardship, such endeavors typically engage in large-scale conversions in rural regions (Miller & Hobbs, 2002). Urban and suburban areas, where the majority of Americans live, present an unutilized opportunity for broader adoption of ecological-stewardship (Beatley & Brown, 2021; Miller & Hobbs, 2002; Tallamy, 2020). It embodies a paradigm not of human settlements as sacrifice zones countervailed by far off conserved nature, but of one that recognizes the potential for human-nature relationships to be mutually enhancing (Berry, 1988; Leopold, 1966). Urban ecological stewardship also directs the benefits of ecosystem services to within urban and suburban centers, with co-benefits including food-access (Garcia et al., 2018), cultural transformation via crowding-in pro-environmental behavior (Soga & Gaston, 2016), urban resilience (Staddon et al., 2018), and the variety of other benefits associated with proximity to greenspace (Hunter et al., 2019).

4.2.1. Policy Proposal

This research seeks to introduce and justify a theoretical expansion of a land value taxation scheme aimed at encouraging broader adoption of land stewardship practices within and outside urban centers. We propose an ecologically-weighted land value tax scheme (ELVT) which penalizes land degradation and subsidizes ecological stewardship in high-ecological-importance areas. Under an ELVT scheme, a conventional LVT rate is first applied and then scaled up or down according to non-market information and landowner decision-making. The ecological weighting considers two factors: the value that a particular parcel would have to collective ecological health and service provisions (deemed "ecological potential") and the degree to which the parcel, in its current state, is meeting that potential (deemed "ecological value"). For example, a parking lot or industrial site directly abutting unfragmented natural land may have a high ecological potential and low ecological value. So too might a parking lot that is far from any greenspace. Ultimately, such designations of ecological potential and ecological value would be at the discretion of the enacting municipality.

Under ELVT, ecological value would have an inverse relationship with tax burden, the magnitude of which is mediated by ecological potential. Those who live in a high ecological potential location and have converted their lawn to a garden or native habitat (for example) would face a lower tax rate which is subsidized by the higher tax rate of those who maintain ecologically-degrading land use practices but still benefit from ES provision around them. For parcels with a low ecological potential, the tax would mirror that of a conventional LVT.

ELVT provides a means to align individual action with collective value creation. It coheres with the original justification for land value taxation, namely re-socializing collective values, but allows for a broader definition of such values. The policy also aligns with broader policy suggestions such as common asset trusts which builds an institutional capacity to manage common goods toward collective benefit (Weston & Bollier, 2014), and has received some recent attention in political spheres (see Farley et al., 2015). Finally, ELVT could provide a passive means of agglomeration incentives in which land stewardship increases the land value and benefits of restoration among neighboring parcels, thus incentivizing their restoration and bolstering the contiguity of intact land.

While the effects of LVT have had a long history of examination, to the authors' knowledge, researchers have yet to explore the outcomes associated with the particular mechanisms of the proposed ELVT scheme. Nevertheless, limited research on similar proposals supports further examination. Lafuite et al. (2018) showed that a natural land depletion tax has the effect of internalizing the value of biodiversity, resulting in more diversity preserved at equilibrium through more labor-intensive agricultural practices that reduce natural land conversion. The tax was also predicted to mitigate the vulnerability of the economy to overshoot and collapse given time-delayed externalities of biodiversity-loss (Lafuite et al., 2018). Along a similar vein, Xiong and Li (2019) proposed an ecological-deficit tax which compensates the difference between land's ecological carrying capacity and its current ecological footprint. Using a computable general equilibrium model, the authors found that the ecological-deficit tax had the effect of reducing the region's ecological footprint in the long run.

4.2.2. Study Overview

In this study, we utilize a spatially-explicit agent-based model of land use behaviors and housing development as a proof of concept exploration of the emergent outcomes associated with a LVT and ELVT policy. We employ boundedly-rational decision-making among homeowners, developers, and speculators operating within a regional land and housing market. Our analysis focuses on four experiments in which the model is tested under different parameter settings. In experiment 1, we model the three tax schemes (with approximate revenue neutrality) under three different configurations of homeowner preference which influence the resulting development patterns toward suburban sprawl, compact urban infill, and something in between. In experiment 2, we perform a sweep of the percentage of speculator agents in the model to explore their role in mediating spatial and socio-economic outcomes. In experiment 3, we perform a sweep of the magnitude of divergence between LVT and ELVT tax rates to explore the effect of ELVT under increasingly extreme operationalizations. In experiment 4, we relax the assumption of revenue neutrality and perform a sweep of the LVT rates to assess the spatial and economic effects of more aggressive rent-socialization tax policies. Our key finding is that both LVT and ELVT tax interventions increase housing density and decrease land intensive housing, while ELVT further densifies the urban core by moderating the loss of natural beauty which can otherwise drive prospective homeowners away from the urban core.

4.3. Methods

Urban development is an inherently complex process; emergence results from non-linear interactions between strongly coupled social, environmental and economic systems, featuring spatial and multi-scale interactions and context-adaptive decision-making amongst a heterogenous population of land-use decision-makers (Heckbert et al., 2010). Such complexity precludes the use of traditional economic or statistical models (Dosi & Roventini, 2019). Instead, researchers have increasingly turned to agent-based models (ABM) (Crooks et al., 2021). ABMs take a micro-lens of analysis, controlling only individual decisions-making rules and system context, and therefore facilitate the examination of how complex emergent macrophenomenon can result from individual action as well as the outcomes associated with intervening at the individual level (Bonabeau, 2002).

This research takes inspiration from a robust foundation of academic study using spatially-explicit ABMs to understand residential locational choices and urban sprawl. Magliocca et al. (2015) incorporated endogenous, spatially-heterogenous land and housing price formation to demonstrate the occurrence of urban sprawl and leap-frog development driven by consumer preferences and various economic influences on the profitability of farmland conversion. Brown and Robinson (2006) utilized empirical residential locational preferences and show how more realistic heterogeneity in preferences led to greater urban sprawl in location choice. Jackson et al. (2008) demonstrated the emergence of gentrification as mediated by residential migration and resulting changes in land rents. Still others have shown the important dynamics that exist between land use activity, ecological services and resilience (e.g. Guzy et al., 2008; Tsai et al., 2015).

Researchers have also utilized ABMs to explore the effectiveness of tax interventions associated with land value on urban sprawl. Hosseinali et al. (2013) found that a policy which increases the land cost by 50% (presumably by way of a tax) in areas planned for growth was most successful tested policy in encouraging denser development patterns. Furthermore, Chen (2020) demonstrated the effect of differential bargaining power on the effect of land taxes. He found that increasing exurban land costs through a development tax was ineffective in a “thinly-traded” land market because it increases buyer bargaining power such that they can capture greater surplus from the exchange and are thus encouraged to purchase exurban land.

Our ABM simulates a regional housing market and resulting land use patterns to the extent necessary to explore the effect of property taxes on developer, speculator, and homeowner decision-making. A cellular automata structure is used to represent a hypothetical geographic region as a grid of cells (parcels) with land use states and underlying environmental characteristics. Spatially-heterogenous cell characteristics provide information from which agents choose actions that fulfill their motivations and maximize their utility, constrained by imperfect information and bounded rationality.

4.3.1. Environment

The hypothetical geographic region is represented by a 100 x 100 grid of cells with each cell representing a plot of land with underlying locational, economic, and environmental characteristics. Cells take one of four discrete land use states: conserved land that is unavailable for agent purchase or development, undeveloped land that is also un-owned, land that is undeveloped but owned by an agent, and land that was developed with housing. All cells falling into the lattermost state also contain values which describe the number of housing units on the cell, as well as the number of those units currently available for purchase. The environment also characterizes ecological value (*EV*) as discrete states where conserved or undisturbed forest land is equal to 1, disturbed but undeveloped land is equal to 0 and developed land is equal to -1 unless restoration has occurred, in which case *EV* is equal to 0.5.

Four environmental characteristics form the foundation of agent preferences. The natural beauty (*NB*) matrix represents the hedonic value of a plot for environmental, aesthetic, or recreational purposes. Pre-specified forested cells are given the highest NB value of 1. A distance decay function is then used to gradually lower the NB value with increasing distance to a forested cell. *NB* values are also reduced by one sixth of the cell's density value (however with a fixed *NB* min value of 0.3) to represent the typical loss of natural beauty in high-density urban locations. The proximity to the central business district (*CBD*) matrix represents each cell's proximity to the central cell, normalized to between 0 and 1. The housing density (*density*) matrix represents the development intensity of the surrounding cells. It's calculated with the sum of housing units in the surrounding 7x7 cell grid divided by the maximum value of surrounding development, assumed to be an average of 2 units per cell. The lot size (*lot_size*) matrix describes the acreage of each cell which is assumed to increase with distance to the central cell (*dist*) as:

$$lot\_size = 0.075 * (dist + 1) + 0.25 + \varepsilon \quad (4.\ 1)$$

$$\varepsilon = N\left(o, \frac{lot\_size}{4}\right) \quad (4.\ 2)$$

Initial lot sizes are specified then given random variance (ε) with the standard deviation proportional to initial lot size. As such, we assume lot sizes fall between approximately 0.325 acres at the center to approximately 6 acres at the outermost cell. *lot_size* affects agent preferences in two ways: first, it is used to calculate the total land tax burden which directly affects agent willingness to pay; second, it is used to calculate the lot size per housing unit once development occurs which affects homeowner housing preference.

Other environmental characteristics speak to the costs and profitability of land or housing ownership. Per acre land values were specified for each cell representing the cost per acre of purchasing a particular plot of land devoid of improvements. Because our model does not endogenize price formation in the land market, we approximated land values based on homeowner preferences, neighborhood housing density and total regional housing as:

$$LVPA = land\_pref * (nbr\_housing + 1)^{1.4} * total\_housing^{0.9} + LVmin \quad (4.\ 3)$$

where *land_pref* is the average homeowner land preference (0,1) for each cell across 50 randomly sampled homeowners, *nbr_housing* is the sum of occupied housing units in the surrounding 13 x 13 neighborhood, *total_housing* is the sum of all occupied housing units across all cells and *LVmin* is the specified minimum land value per acre. Upon calibrating the LV equation with the specified exponents, the approximation reproduces a characteristic power law distribution of land values across a region as well as the land price appreciation that results from nearby or aggregate development (See Appendix; Albouy et al., 2018).

The environment also includes separate tax rate matrices for improvement value (*IVT_rt*) and land value (*LVT_rt*). For the SQ tax scheme, both tax rate matrices are equal and uniform across space. For the LVT tax scheme, *LVT_rt* is spatially uniform while *IVT_rt* is homogenously equal to zero. So, too for the ELVT scheme, however with *LVT_rt* varying across space according to *EV* and *EP*. The formula for calculating *LVT_rt* under an ELVT regime is as follows:

$$LVT\_rt = \tau + E_{burden} \tag{4. 4}$$

$$E_{burden} = \frac{EP(-EV)}{eco\_burden\_denom} \tag{4. 5}$$

where τ is the baseline *LVT_rt*, and *eco_burden_denom* is a scalar used to arbitrarily control the magnitude of divergence from the base rate at *EP* and *EV* extremes. Due to the tax rate variation that results from land use changes under ELVT, each cell also includes hypothetical tax rate values if each parcel was restored or developed to allow agents to anticipate taxes associated with their actions.

The *EP* matrix was specified to represent one of the many ways a municipality might communicate the locations in which land stewardship is most important. We used a distance decay function to create a gradient of values from 0 to 3 as a function of distance to any conserved land. In practice, ecological potential could be a far more sophisticated description of ecological integrity, essential habitats, etc., or a more arbitrary description of, for example, neighborhoods in need of better stormwater management.

4.3.2. Agents

Agents represent land users of various types who can buy, sell, develop and restore parcels of land. Agents spend money buying land, developing land, restoring land, and paying taxes. Agents gain money by way of assumed fixed exogenous income (for homeowner agents) and land or housing sales. Agents are heterogeneous in their preferences, wealth, and altruism. They make decisions based on the expected benefits of different actions relative to their own motivations, constrained by their wealth. Decision-making is implemented under imperfect information and bounded rationality, in which agents are given a randomly generated subset of all possible options and choose randomly from a smaller subset of those options that satisfy at least a given threshold of relative benefit. Agents interact indirectly, through sensing and reacting to the environment, which is impacted by other agents as well as through a housing marketplace where purchase price is directed from the buyer to the seller.

"Homeowner" agents seek to buy housing that meets at least a given threshold of utility, constrained by their wealth. The utility a particular homeowner (i) gains from a particular housing unit (j) is calculated from a multiplicative combination of cell characteristics relative to preferences and preference weighting, much like that of Brown et al. (2005).

$$U_{hu_{i,j}} = NB_{\mathrm{j}}^{\,nb_{prefwt_i}} * \; density_{match_{\mathrm{i,j}}}^{\,density_{prefwt_i}}$$

$$* \ CBD_{j}^{cbd\_pref\_wt_i} \ * \ lot\_size\_match_{i,j}^{lot\_size\_pref\_wt_i} \quad (4.\ 6)$$

While *NB* and *CBD* refer directly to cell values, *density_match* and *lot_size_match* represent an agent's interpretation of *density* and *lot_size* matrices, respectively, given their own preferred ideal values (*ideal_density*, *ideal_lot_size*). They are calculated as the absolute value of the difference between a cell's density or lot size and the agent's ideal value. Each preference weight for each agent is randomly sampled within a given min and max value from a uniform probability distribution. Agent preference weights are then normalized to sum to one. Given associated preference values and preference weight values, utility is constrained to between 0 and 1. The utility of agent *i* for a particular housing unit *j* is then multiplied with their wealth (assumed to represent the maximum amount of money they would be willing to spend on a home) to determine their willingness to pay ($WTP_{i,j}$) for the unit. *WTP* is also affected by the present value of the unit's property taxes, given homeowner future discount rate (*future_disc_rt_homeowner*), as well as the neighborhood vacancy rate as:

$$WTP_{i,j} = \ U\_hu_{i,j} * wealth * (1 + vacancy\_multiplier) - present\_value\_tax \quad (4.\ 7)$$

$$vacancy\_multiplier = (0.25 - vacancy\_rt) * 0.25 \quad (4.\ 8)$$

Because the vacancy rate is fixed at between 0 and 0.5, *vacancy_multiplier* can reduce or increase WTP by as much as 6.25%.

Under the ELVT scheme, Homeowners that already own a home have the option to restore their land. Restoring land refers to the act of investing a pre-determined sum (*restoration_cost*) per acre to change land use attributes of a cell such that it then provides greater ecosystem services (*EV* changes from -1 to 0.5). The probability of choosing to restore (*p_restore*) for homeowner (*i*) and owned parcel (*j*) is as follows:

$$P\_restore_{i,j} = altruism_i * economic\ benefit_{i,j} * neighborhood\ adoption_j \quad (4.9)$$

in which *altruism* (0,1) reflects their own devotion to providing collective goods, *economic benefit* is the expected present value of savings on tax payments divided by their income, and *neighborhood adoption* represents the percentage of plots in the surrounding 7x7 cell grid that have restored their land. The homeowner chooses to restore if their *P_restore* value is greater than a random number between 0 and 1 drawn from a uniform distribution.

Homeowners also have the option to sell their current home if they become overburdened by the cost of ownership or if the associated utility of other housing units on the market at or below their willingness to pay exceeds the utility they derive from their current home by at least a given threshold (*pref_dif_to_sell*).

"Developer" agents seek to supply homeowners with housing by buying and developing land. They make decisions about where to buy land for development based on expected profit, represented by the percent difference between the 75^{th} percentile of the aggregate willingness to pay across a random sample of homeowners and the expected cost of developing. Costs include the present value of the tax burden after development, given developers' future discount rate (*future_disc_rt_developer*). Potential development sites are constrained to a random subset of plots (*rnd_off_limits*), to invoke imperfect information, as well as to locations in which the cost of development would not exceed their wealth and where the vacancy rate is less than 0.25. Upon calculating the expected profit for each potential development site, developers then choose randomly between the top x% (*rnd_choice_pct*) of plots with regard to their associated expected profit, invoking bounded rationality.

Upon buying land, developers determine how many units to build. Developers are each given unique values for square footage per unit, building costs per square foot, and desired improvement value to land value ratio by drawing randomly with uniform probability from given parameter ranges (*unit_sf_range*, *build_cost_psf_*range and *desired_IV_LV_ratio_range*, respectively). The agent (*i*) can then calculate how many units to build (*N_units*) on a plot (*j*) as follows:

$$N\_units_{i,j} = \frac{LC_{i,j}}{IC\_per\_unit_{i,j}} * desired\_IV\_LV\_ratio_i \tag{4. 10}$$

$$LC_{i,j} = LV_j * \left(1 + \frac{LVT\_rt\_developed_j}{future\_disc\_rt_i}\right) \tag{4. 11}$$

$$IC\ per\ unit_{i,j} = unit\_sf_i * build\_cost\_psf_i * \left(1 + \frac{IVT\_rt_j}{future\_disc\_rt_j}\right) \tag{4. 12}$$

Under the ELVT tax scheme, developers may consider the profitability of building half the units they intended and restoring the other half of the site. They consider the half restoration, first if their personal altruism value is greater than a randomly drawn value between 0 and 1. If so, they estimate the cost per unit of developing half the units, given a reduced tax rate. If the cost per unit plus a profit premium of 15% remains lower than homeowner willingness to pay, they choose to do the half-restoration development.

Developers then estimate willingness to pay per unit by sampling 20 homeowner agents at random. If the cost per unit is less than or equal to the 75th percentile of homeowner willingness to pay, the development occurs. The price per unit is set somewhere between the cost per unit and the estimated willingness to pay with the exact point between the two based on the neighborhood vacancy rate:

$$price = cost\_per\_unit + \frac{WTP - cost\_per\_unit}{2} * (1 + vacancy\_multiplier) \quad (4.\ 13)$$

$$vacancy\_multiplier = (0.25 - vacancy\_rt) * 4 \quad (4.\ 14)$$

Therefore, we assume a vacancy rate of zero would set the price at *WTP* and a vacancy rate of 0.5 would set the price at the *cost_per_unit* which reflects how differential bargaining power between buyers and sellers affect price (Harding et al., 2003). Upon setting a price, the housing units are added to the market and available for homeowners to buy.

"Speculator" agents seek to buy and sell land or housing units in such a way as to capitalize on land value appreciation that results from other agent actions. Their decision-making is based on expected profit of buying, holding, then selling a plot, calculated as:

$$BC\_ratio = \frac{dLV}{LVT\_rt} \quad (4.\ 15)$$

where *dLV* is the average percent change in land value per year over the past 3 timesteps. If the maximum *BC_ratio* across all available plots is greater than 10%, the speculator chooses at random between the plots with the x% (*rnd_choice_pct*) highest *BC_ratio*. Speculators continue buying plots at each timestep so long as the aforementioned profitability condition is met.

At each timestep, speculators sell one of their owned plots either randomly with probability 0.1 or if their wealth is less than or equal to zero. Under the ELVT tax scheme, speculators can also consider land restoration. For all owned unrestored land, they look at the profit potential of restoring the land (as a result of lower taxes):

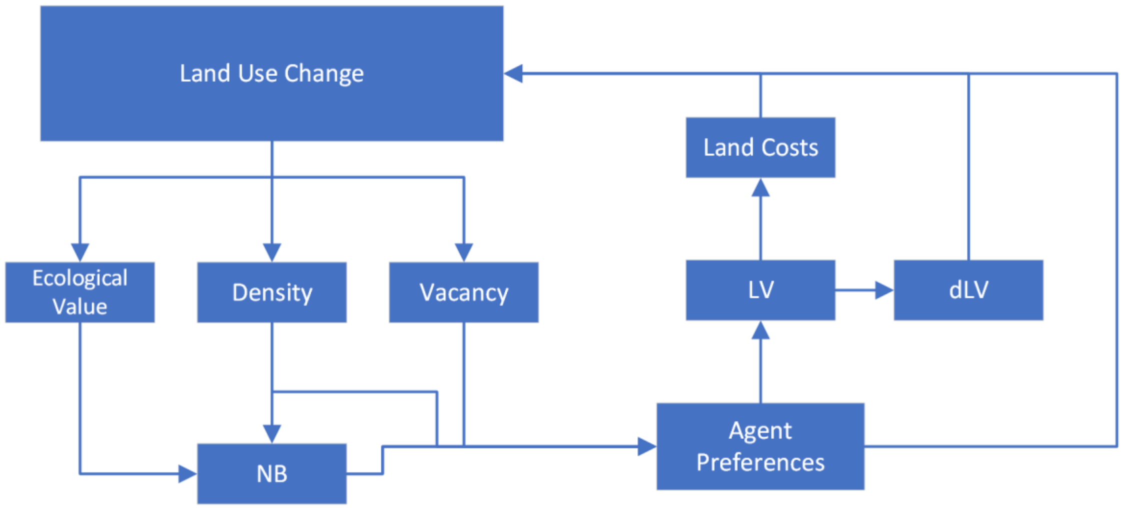
$$P\_restore = \frac{\left(\frac{LV*(LVT\_rt - LVT\_rt\_restored)}{future\_disc\_rt} - restoration\ cost\right)}{restoration\ cost} \quad (4.16)$$

4.3.3. Feedback

Several key feedback loops between agent actions and environment form the basis of recursivity in the model (Figure 7). With regard to preferences, development affects both density (positively) and natural beauty (negatively) which then affects preferred locations at the next timestep. Newly restored cells also affect natural beauty (positively). Changes in development and locational preferences impacts land values and resulting cost of purchasing and developing, tax burden, and returns for existing owners of land or housing. Fast appreciating land value attracts speculators to the area with whom developers must compete for access to desirable land and homeowners must compete for access to housing.

Figure 7:

Feedback Interactions Among Environmental and Agent Attributes



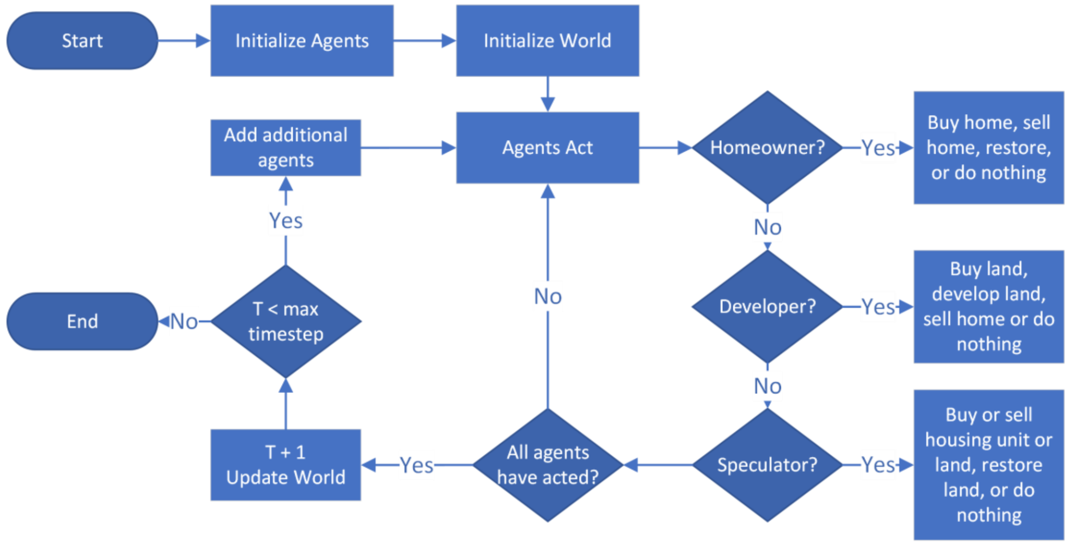
Note. NB = natural beauty, LV = land value, dLV = change in land value.

4.3.4. Scheduling

The model is run by first initializing the starting number of agents as well as the cell grid environment with all corresponding geographic characteristics. At each timestep, agents act by buying, selling, or restoring cells. After all agents act, the ancillary cell characteristics (e.g. density, vacancy) are then updated based on the changed land use or housing ownership. A pre-specified number of new agents are then added to the simulation before the timestep advances and agents act again. The high-level process sequence is visualized in Figure 8.

Figure 8:

High-Level Model Process Sequence



4.3.5. Parameters and Initialization

As a conceptual model primarily for the purpose of exploratory analysis, our model features limited empirical calibration. Like many other conceptual ABMs (e.g. Bell et al., 2016), we hesitate to set some parameter values to empirical data without emulating other aspects of the context in which that empirical data is based. Rather, we sought to employ general rule-of-thumb values, where necessary, to form parameter ranges from which agents draw at random.

Table 4 summarizes parameters and associated values or value ranges used for the model. The model begins by initializing a specified number of agents (*n_init_agents*) whose type is drawn at random from a weighted list (*ag_type_wt*) along with the agent's initial characteristics depending on the agent type. A notable assumption regards development costs and preferred amount of capital investment. We assume a range of unit square footage between 1000 and 2500 and a per square foot cost of between $100 to $200 which represents all project costs except for land costs (Abraham & Tynan, 2023; Lynch, 2023; Theriault, 2023). Therefore, the average cost to build a unit (not including the land cost) is $225,000. We also assume developers seek to build units such that the land cost represent between 12.25-20% of total costs of development on average (*desired_IV_LV_ratio_range* = [4, 7]) (Foo, 2018; Lynch, 2023; Rabinowitz, 1988; Schuetz, 2020).

We then initialized the environment's land use states and ecological values which were randomly generated, but fixed for all simulation runs (Figure 9). From this, we derive ecological potential as a distance decaying value from conserved land, and natural beauty, as a distance decaying value from any forested cell ($EV = 1$) with stronger weighted toward those that are conserved. Finally, tax rates were chosen based on total tax revenue of initial runs of the model such that tax revenue in the final timestep under LVT and ELVT scenarios were roughly revenue neutral in relation to the status quo tax scenario.

Figure 9:

Initial Spatial Distribution of Land Use and Ecological Value as well as Resulting Ecological Potential and Natural Beauty

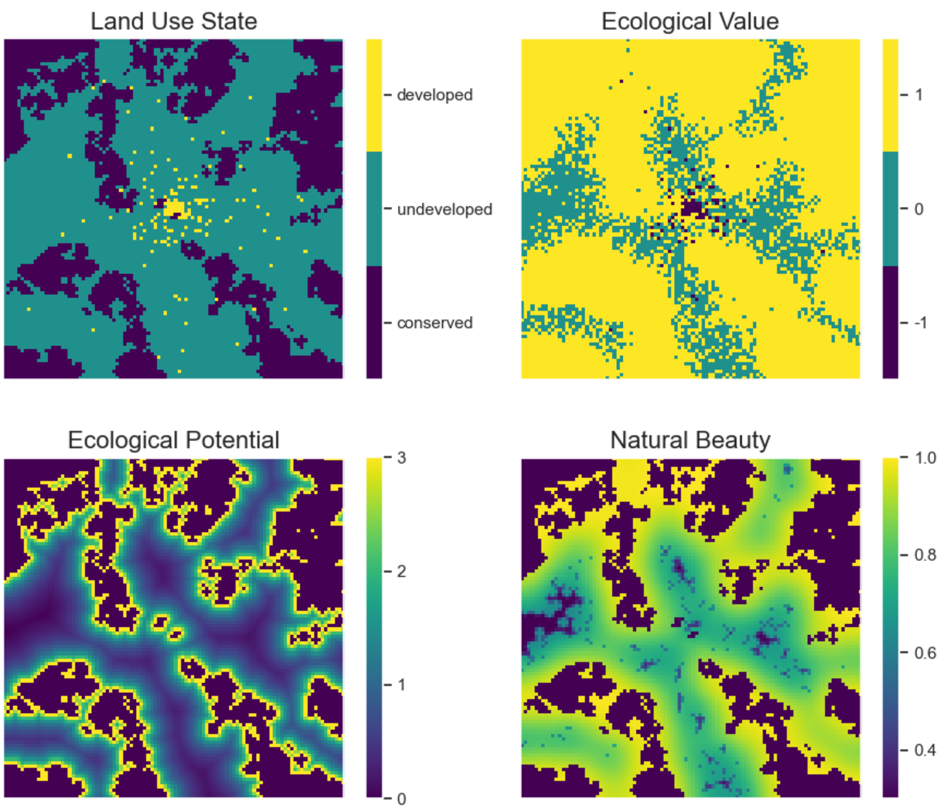


Table 4:

Model Parameters Under "Baseline" Configuration

Parameter	Description	Baseline Configuration
max_timestep	Number of timesteps for which the model runs	20
P_initial_development	Used to scale the randomly generated initial housing development	0.2
N_init_agents	The number of agents initialized into the simulation at timestep 0	300
N_new_agents	The number of agents added to the simulation at each subsequent timestep	30
ag_type_wt	The weights used to condition randomly chosen agent-type when each agent is	[0.15,0.80,0.05]

	initialized. Organized as [developer, homeowner, speculator]	
ln(*starting_wealth_homeowner*)	Mean(std dev.) of the normally distributed values from which homeowner agents draw then exponentiate to derive starting wealth	13.25(0.25)
ln(*starting_wealth_developer*)	Mean(std dev.) of the normally distributed values from which developer agents draw then exponentiate to derive starting wealth	16(0.5)
ln(*starting_wealth_speculator*)	Mean(std dev.) of the normally distributed values from which speculator agents draw then exponentiate to derive starting wealth	15(1)
rnd_off_limits	The probability from which each available land cell draws to determine whether it is not available for purchase (re-drawn at each timestep)	85%
rnd_choice_pct	The top percent of cell location choices from which agents randomly choose	10%
altruism_homeowner_range	Range of uniform probability altruism values from which homeowners draw	[0.2, 1]
altruism_developer_range	Range of uniform probability altruism values from which developers draw	[0.1, 0.5]
future_disc_rt_homeowner	The rate at which homeowners discount potential income in future years	10%
future_disc_rt_developer	The rate at which developers discount potential income in future years	25%
future_disc_rt_speculator	The rate at which speculators discount potential income in future years	33%
pref_dif_to_sell	Minimum difference in utility between the most preferred on-market housing unit and the currently-owned housing unit above which the homeowner sells their current property	0.15
NB_pref_range	The range of values from which homeowners sample uniformly to determine their natural beauty preference weighting	[0.01, 0.4]
CBD_pref_range	The range of values from which homeowners sample uniformly to determine their *CBD* preference weighting	[0.2, 0.6]
density_pref_range	The range of values from which homeowners sample uniformly to determine their *density_match* preference weighting	[0.2, 0.4]
lot_size_pref_range	The range of values from which homeowners sample uniformly to	[0.01, 0.2]

	determine their *lot_size_match* preference weighting	
Ideal_density_range	Range of uniform probability *ideal_density* values from which developers draw	[0.1, 0.7]
Ideal_lot_size_range	Range of uniform probability *ideal_lot_size* values from which developers draw	[0.05, 1]
LVT_rt	The rate at which land value is taxes. Formatted as [SQ rate, LVT rate, ELVT rate] and chosen to approximate revenue neutrality	[0.035, 0.10, 0.10]
IVT_rt	The rate at which improvement value is taxed. Formatted as [SQ rate, LVT rate, ELVT rate]	[0.035, 0, 0]
eco_burden_denom	Denominator of the eco burden calculation. Used to arbitrarily control the magnitude of divergence from the base rate at EP and EV extremes	50
unit_sf_range	Range of uniform probability *unit_sf* values from which developers draw to calculate their *cost_per_unit*	[1000, 2500]
*build_cost*_psf_range	Range of uniform probability *build_cost_psf* values from which developers draw to calculate their *cost_per_unit*	[100, 200]
desired_IV_LV_ratio_range	Range of uniform probability *desired_IV_LV_ratio* values from which developers draw to calculate how many units to build	[4, 7]
restoration_cost	The cost to restore one acre of land	$5,000

4.3.6. Experimental Design

We perform four experiments to assess relative outcomes under different parameter assumptions. Table 5 summarizes parameters used in each experiment, with all other parameters fixed using values specified in Table 4. In experiment 1, we model three land use scenarios via changes in homeowner preferences: a baseline scenario represents middle-of-the-road urban development; a sprawl scenario represents a stronger preference for larger lot sizes, low-density, and high natural beauty plots; and a high-density scenario represents a stronger preference for locations in close proximity to CBD, and with high-density.

In experiment 2, we assessed the impact of a growing speculator population on sprawl and housing availability. We did so via a sweep on the probability of choosing a speculator agent (*ag_type_wt*) when randomly assigning initial and new agents. We also increased the total number of agents so as to keep homeowner and developer counts relatively constant for each iteration. In experiment 3, we assess the impact of ELVT under increasing divergence from LVT rates at the extremes (i.e. the magnitude of the subsidy and penalty) via a sweep of *eco_burden_denom* values. In experiment 4, we assess system outcomes under increasing LVT rates.

Table 5:

Unique Parameter Values Used in Model Experimentation

Experiment 1: Land Use Patterns			
Parameter	Baseline Scenario	Sprawl Scenario	High-Density Scenario
NB_pref_range	[0.01, 0.4]	[0.3, 0.5]	[0.01, 0.2]
CBD_pref_range	[0.2, 0.6]	[0.1, 0.3]	[0.5, 0.7]
density_pref_range	[0.2, 0.4]	[0.2, 0.5]	[0.4, 0.6]
lot_size_pref_range	[0.01, 0.2]	[0.2, 0.4]	[0.05, 0.1]
Ideal_density_range	[0.2, 0.5]	[0.01, 0.3]	[0.3, 0.8]
Ideal_lot_size_range	[0.05, 0.75]	[0.25, 1.0]	[0.05, 0.15]
LVT_rt ([SQ, LVT, ELVT])	[0.035, 0.1, 0.1]	[0.035, 0.135, 0.135]	[0.035, 0.1, 0.1]
IVT_rt ([SQ, LVT, ELVT])	[0.035, 0, 0]	[0.035, 0, 0]	[0.035, 0, 0]

Experiment 2: Speculator Count Sensitivity Sweep			
Parameter	Min	Max	Increment
ag_type_wt_speculator	0.01	0.29	0.07
N_init_agents	300	420	30
N_new_agents	30	42	3

Experiment 3: ELVT Magnitude Sensitivity Sweep			
Parameter	Min	Max	Increment
eco_burden_denom	20	140	30

Experiment 4: LVT Rate Sensitivity Sweep

Parameter	Min	Max	Increment
LVT_rt	0.05	0.25	0.05

Note. All experiments use the baseline parameter settings (Table 1) except where specified under each experiment.

Model stochasticity arises from the various randomly drawn elements of the model (e.g. homeowner preferences, available land at each timestep, agent cell choice) as well as through the path dependence from the effect of prior agent actions on environmental conditions. To account for this, we utilized the Monte Carlo average and standard error over 20 runs of each unique initialization to converge on a robust estimate of each system metric. Therefore, for the multi-land-use tax comparison, a total of nine unique initializations yielded 180 runs. For each sensitivity analysis, a total of 5 unique initializations yielded 100 runs.

4.3.7. Analysis

Given the limited calibration and conceptual framing of the model, we adhere to an exploratory analytical approach, focusing on broad system dynamics and emergent patterns to build intuition and inspire future inquiry rather than attempting to forecast specific regional land use outcomes or provide a means of decision-support for policy-makers (Matthews et al., 2007). More specifically, we direct attention to relative changes among both tax interventions (as compared to status quo) pertaining to the following questions: (1) to what degree do changes in homeowner preferences lead to differing land development patterns? (2) can differing tax schemes reinforce or redirect land use patterns and emergent outcomes for three common land use patterns as enacted by changes in homeowner preferences? (3) how does the magnitude of speculator interest affect such emergent patterns and can LVT and ELVT dampen their effect? (4) how does ELVT differ from LVT under various tax scheme operationalizations? Table 5 summarizes the specific metrics used to investigate our research questions pertaining to urban densification, housing availability, ecological integrity and land use incentives.

Table 6:

Measured Land Use, Economic, and Ecological Outcomes

Category	Metric	Description
Urban Densification	Avg HU lot size (acres)	The average lot size per housing unit for housing which is occupied by homeowners
	High-density housing rate	The percentage of homes which occupy cells with a density above 0.4
	Largest patch size	The largest number of contiguous developed cells across the region
	Housing within urban boundary	The percent of housing units that are within 20 cells from the center
Housing Availability	Total Housing	Sum of all housing units in the region
	Avg HU price	Average price for one housing unit
	Avg homeowner without home	Percent of homeowners who either haven't found a home, or have recently sold their home to move
	Avg vacancy rate	The average rate of vacancy across all cells and all timesteps
Ecological Integrity	Ecological value change	The percent change in the sum of ecological value relative to initial ecological value
	Urban ecological value	The sum of regional ecological value
Land Use Incentives	Avg tax burden by home type	The average tax burden for homeowners with high-density housing (housing_unit_lotsize < 0.125), mid-density housing (0.125 < housing_unit_lotsize < 0.25), and low-density housing (housing_unit_lotsize > 0.25)
	Avg tax burden by agent type	The average tax burden of homeowner, developer, and speculator agents

Avg change in wealth	The average change in wealth for each agent type from timestep 0 to the final timestep

Note. *Metric is calculated for values of the final timestep unless otherwise stated in the description.*

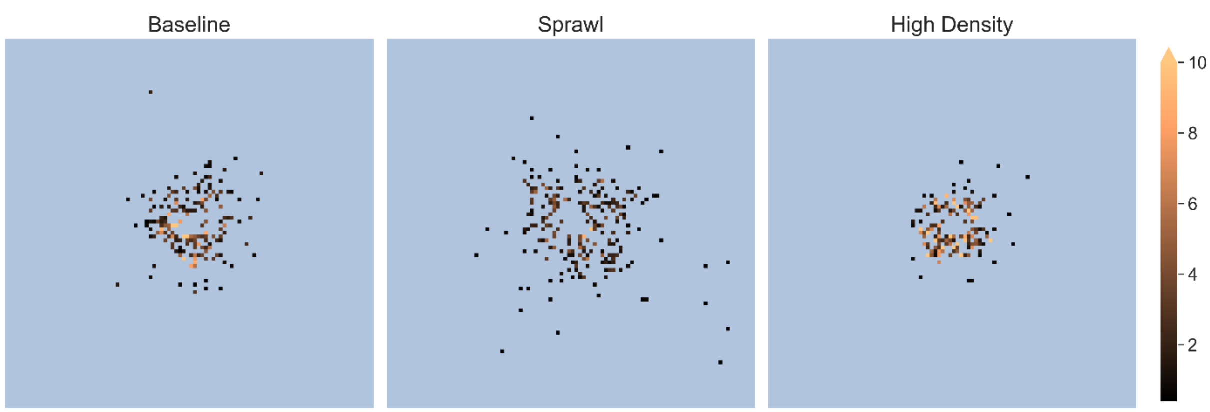
4.4. Results

4.4.1. Experiment 1

Under the conventional SQ tax scheme, our model broadly reproduced archetypal development patterns via changes in agent preferences weightings (Figure 10). The "baseline" land use scenario demonstrated a central urban core with a downward-sloping gradient of housing density out to scattered suburban arms of development. The "sprawl" land use scenario demonstrated low-density decentralized housing clusters with minimal urban core housing. The "high-density" land use scenario demonstrated a tight core of high-density housing with relatively few suburban dwellings beyond it.

Figure 10:

Housing Units Per Acre for Housing Created by "Developer" Agents from Single Simulation Run



Note. Pre-specified initial development (fixed across all land use scenarios) not shown in the figure creates a small urban core and scatter outer development for all simulations.

For the baseline scenario, initial development tended toward the center. The broad ranges of homeowner preferences seemed to reinforce project costs as the primary driver of location. As initial development increased land value in the center, developers moved just outside to capture lower land costs with similar homeowner willingness to pay. However, as land values increased further, developers could increase the number of units built, and therefore profitability again favored the urban core. This dynamic continued until the loss of natural beauty or the increase in density lowered homeowner preference for the urban core, at which point broader exurban development ensued.

In the spawl scenario, development locations heavily favored locations of high natural beauty, initially in close proximity to the urban core. However, such development increased density and reduced natural beauty such that subsequent development moved farther from the center toward higher natural beauty locations.

In the high-density scenario, homeowner preferences steeply declined from distance to initial development because of their high *ideal_density* preference. As the central core was further developed, homeowner preference for these locations increased resulting in a positive feedback loop of tight urban development. Developments moved outward only when all more central land was unavailable.

Figure 11 visualizes the average and standard error for each model outcome under each land use scenario and tax scheme. Relative to the SQ scheme, Both LVT and ELVT significantly increased total housing count and were associated with higher density dwellings on average. Furthermore, exurban housing development was less frequent under both tax interventions (Figure 12). Both tax interventions were also associated with a significant decrease in housing prices on average (Figure 11). In the baseline scenario, the average housing unit price decreased by 27.8% and 30.8% under LVT and ELVT, respectively. In the sprawl scenario, the average housing price decreased by 18.9% and 2.5% under LVT and ELVT, respectively. And in the density scenario, the average housing price decreased by 36.8% and 37.0% under LVT and ELVT, respectively. We attribute this to the increase in development spurred by the tax interventions which not only allowed developers to spread development costs over more units, but also acted to increase the vacancy rate and therefore push prices down. As a result, far more homeowners found houses in the model with an average of 64% of homeowners unhoused in the status quo scenario as compared to an average of 27.5% and 28.1% under LVT and ELVT, respectively, averaged over all land use scenarios.

Figure 11:

Urban Densification, Housing Availability and Ecological Integrity Metrics for Each Land Use Scenario and Tax Scheme

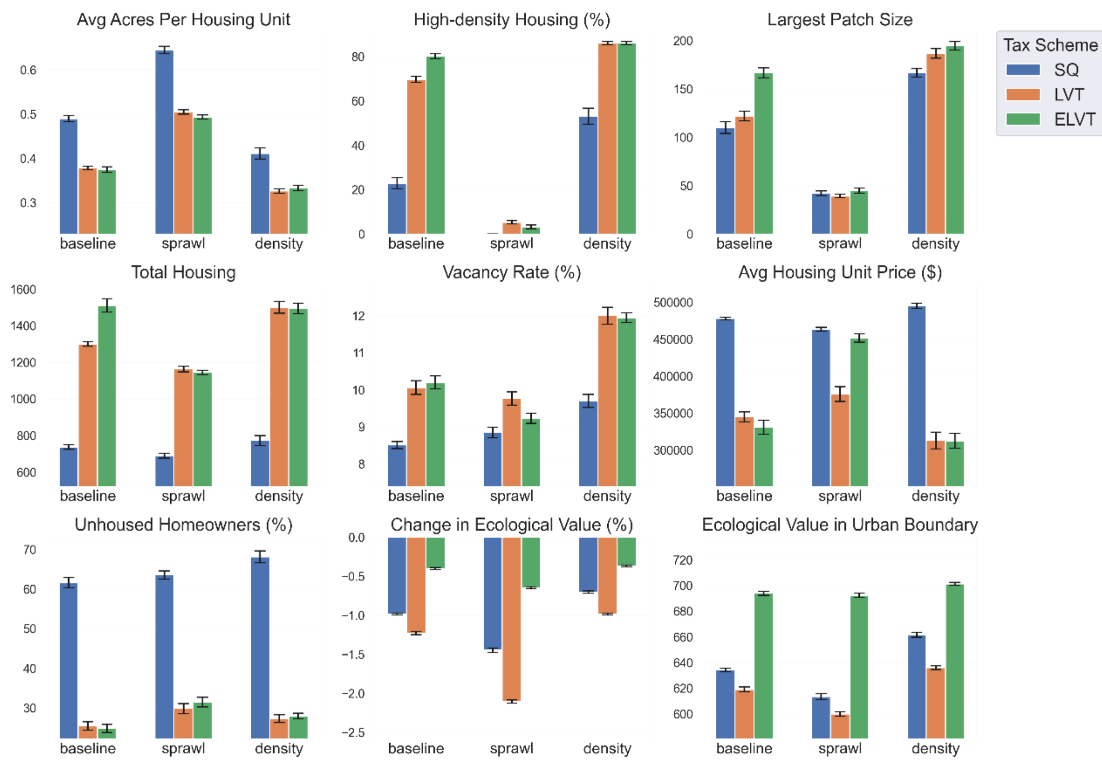
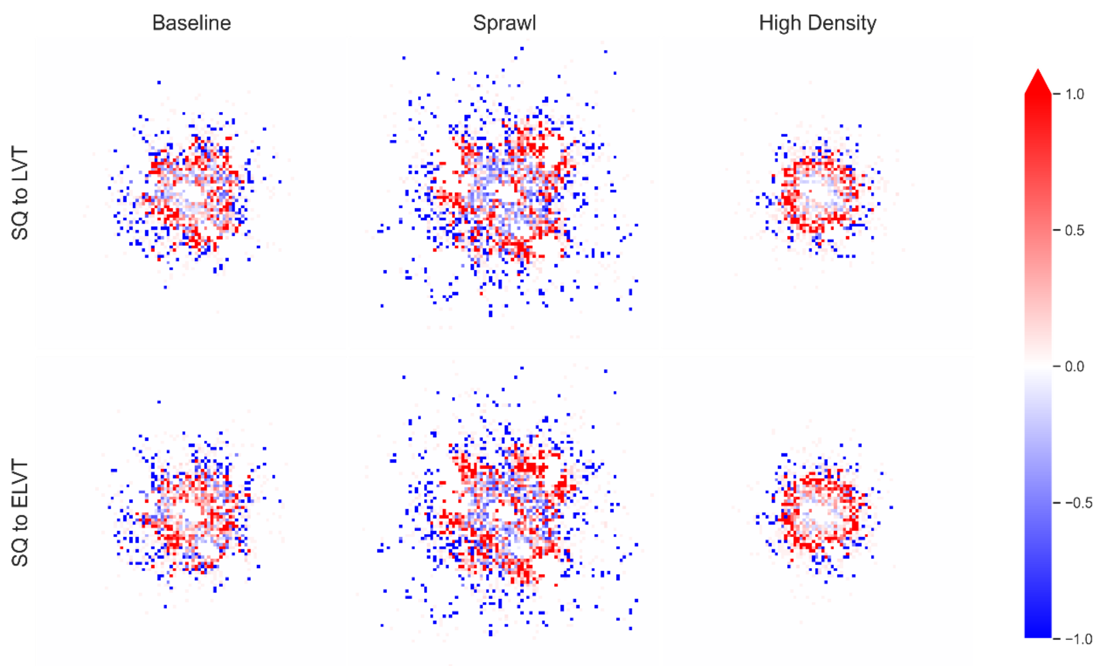


Figure 12:

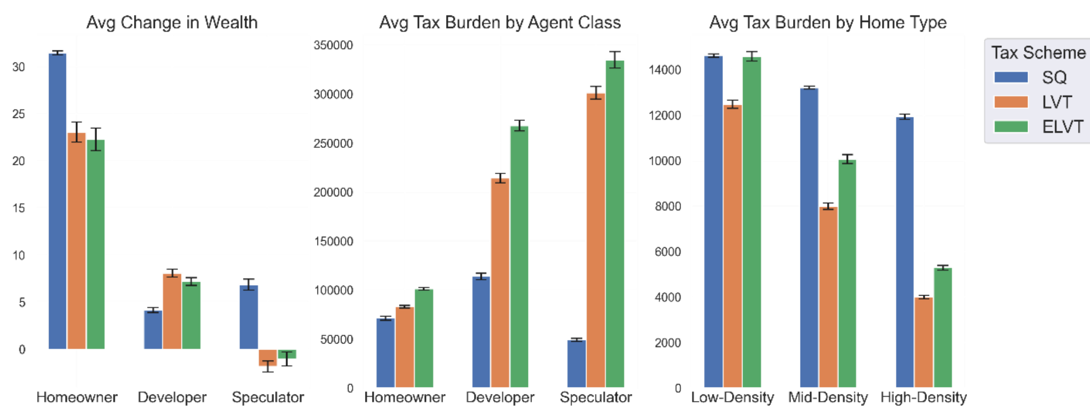
Percent Change in Monte-Carlo Average Likelihood of Development for LVT and ELVT Relative to SQ Tax Scheme



Both tax interventions also had the effect of greatly decreasing the profitability of speculative investment (Figure 13). Relative to SQ, the average tax burden of speculators increased by 512% and 580% under LVT and ELVT, respectively. As a result, the change in speculator wealth on average decreased from 6.7% under SQ to -1.8% and -1.0% under LVT and ELT, respectively. Figure 13 also shows a significant decrease in homeowner wealth, despite a small increase in tax burden. However, coupled with the finding that average housing prices decreased precipitously, this may speak to a broader alignment of housing with use value and therefore less of an investment asset amongst homeowners. Finally, despite a large increase in tax burden, developer's wealth on average increased under both tax interventions. This, too, may encourage developers to favor high-volume, capital-intensive investment in housing above leapfrog development strategies.

Figure 13:

Changes in Wealth and Tax Burden by Agent and House Type for the Baseline Land Use Scenario



Some notable differences emerge when comparing effects of LVT and ELVT schemes. Broadly, ELVT acted to increase urban infill densities, likely as a result of higher urban natural beauty and subsequent homeowner preference. Also, whereas LVT tended to exacerbate regional ecological value loss relative to SQ, ELVT greatly decreased EV loss to almost neutral levels.

4.4.2. Experiment 2: Speculator Count Sensitivity Analysis

The results of experiment 2 demonstrate the significant sway speculator agents had in the model (Figure 14). As the number of speculators increased, they tended to decrease the availability of high-value land and housing which forced broader, low-density exurban development. Moreover, given the increased competition for available housing, housing prices tended upward as well as the percentage of agents unable to find housing. Even though the LVT and ELVT tax interventions increased the average tax burden of speculators, those tax interventions also led to faster appreciating land values as a result of more development. As such, speculators were still able to profit from the region’s land and housing market.

Figure 14:

Select Urban Densification, Housing Availability and Ecological Integrity Metrics for Sweep of Percent of Agents of Type Speculator

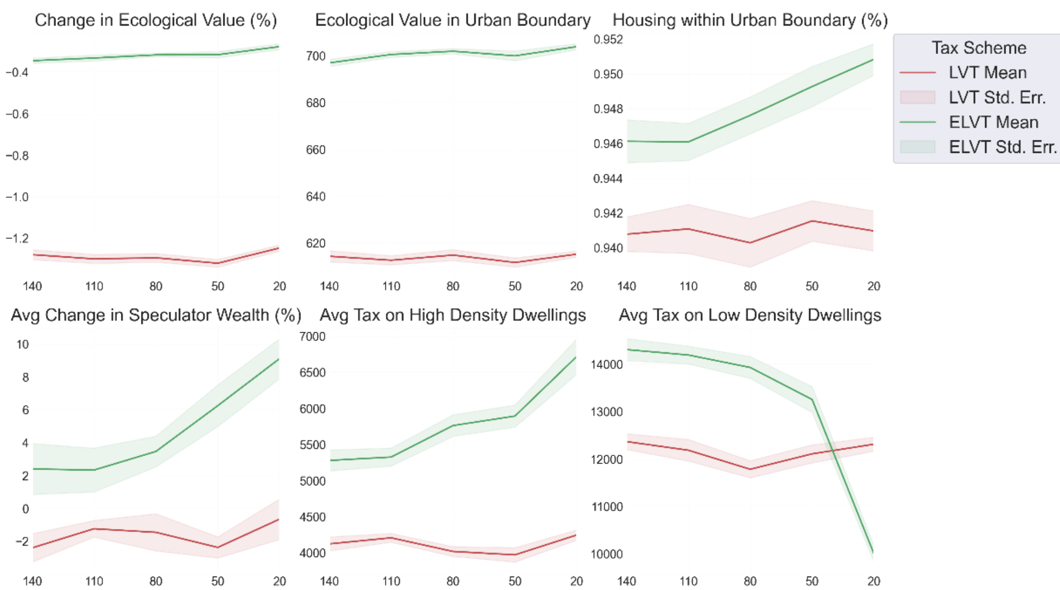
4.4.3. Experiment 3: ELVT Magnitude Sensitivity Sweep

The results of experiment 3 signify the need for greater attention on the decision-making criteria of adopting restoration practices. A decrease in the *eco_burden_denom* value increased the divergence between *ELVT_rt* and *LVT_rt* (i.e. increased the magnitude of increase or decrease of tax burden in high ecological potential areas) which should have led to a larger adoption of land restoration. Yet, Figure 15 shows a slight decrease in the number of restored parcels between the lowest and highest *eco_burden_denom* values. This may be the result of a higher urban density rate which meant less homeowners had the minimum lot size for which restoration was possible. Nonetheless, the higher tax rate on ecologically-important land acted to decrease the average acres per housing unit and increase the percentage of housing with the urban boundary.

Results also show a significant decrease in speculator tax burden that resulted from decreasing *eco_burden_denom* values. Land owning speculators were again able to capture a large portion of land rents so long as they restored the land parcel to receive a lower tax burden. Such restorations would increase the surrounding natural beauty and therefore increase the land value, to the benefit of speculative investment. This, coupled with the finding that the average tax burden on low-density housing decreased and the average tax burden on high-density housing increased suggest that as the *ELVT_*rt diverges further from the *LVT_rt*, some of the beneficial effects of land value taxation may diminish.

Figure 15:

Select Urban Densification, Housing Availability and Ecological Integrity Metrics for Sweep of eco_burden_denom Values

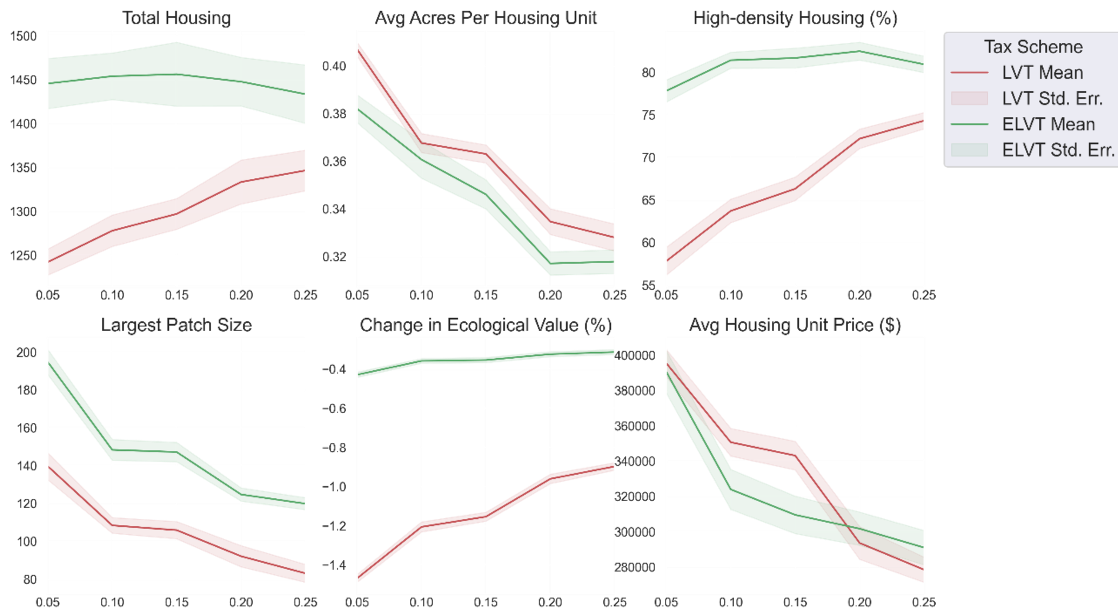


4.4.4. Experiment 4: LVT Rate Sensitivity Sweep

In experiment 1, we set the LVT and ELVT tax rate such that resulting tax revenue in the final timestep was relatively close to revenue neutral as compared to SQ. In experiment 4, we show that land value taxation can further decrease urban sprawl and speculator interest as tax rates increase. We find that as *LVT_rt* increases, many of the beneficial effects of the revenue-neutral tax intervention magnified. As shown in Figure 16, total housing and housing density continues to increase while housing prices continue to fall. Moreover, where the revenue neutral tax intervention did not directly address urban boundary size, a higher *LVT_rt* significantly decreased the largest patch size and increased the percentage of housing within the urban boundary (Figure 16). Taken together, these results suggest that with a high enough rate, land value taxation can lead to dense, walkable cities that exert less pressure on surrounding exurban land.

Figure 16:

Select Urban Densification, Housing Availability and Ecological Integrity Metrics for Sweep of LVT_rt



4.5. Discussion

In this paper we have presented a novel policy tool aimed at buffering the problematic trajectories imparted by rentier capitalism and resulting land use tendencies. The expanded land value tax scheme not only limits the financial viability of land speculation, it also provides a mechanism by which communities can price in the social costs of ecological degradation and subsidize land stewardship. With this conceptual agent-based model we were able to conduct exploratory analysis in order to build understanding on the broad changes in outcomes and land use patterns that result from the LVT and ELVT tax interventions.

Results of this study show general alignment with many of the theoretically- and empirically-demonstrated effects of land-value taxation on land development, including higher housing development rates and urban housing capital density (Choi & Sjoquist, 2015; Plassmann & Tideman, 2000), decreased urban sprawl (Cho et al., 2011; Choi & Sjoquist, 2015), and lower housing unit prices (Choi & Sjoquist, 2015; DiMasi, 1987). Under a revenue neutral tax shift (experiment 1), both LVT and ELVT acted to increase the capital intensity of housing development, thereby increasing density and decreasing housing prices. Furthermore, speculation was taxed heavily and became a profit-losing endeavor. However, under the revenue neutral scenario, the location of developments was still more strongly mediated by household locational preferences than costs. Given a preference for low- or medium-density, urban sprawl persisted. As we increased the rate at which land value is taxed (experiment 4), homeowners favored highly land-efficient developments in the urban core more so than any exurban lands they may have favored at a lower tax rate.

We also show that speculators exert significant sway in land patterns and housing prices (experiment 2). Under the SQ tax scheme, a higher speculator count decreased total housing and the percent of housing within the urban boundary thereby increasing the average acres per housing unit. However, under both LVT and ELVT schemes, all such metrics stayed relatively consistent as the speculator count increased. While at low speculator count, both tax interventions resulted in negative wealth change for speculators, as the count increased, wealth change as well as housing prices trended upward.

Our findings also suggest many beneficial effects of ELVT. The proposed tax intervention broadly acted to increased urban housing densities, increase urban greenspace provisions, and greatly decrease the loss of ecological value across the hypothetical region. However, the decision-making criteria for the adoption of land restoration did not show much response to a growing subsidy for doing so. We partially attribute this to homeowners having less means for restoration as housing densifies. Finally, we find that the disincentive to speculate on land value under LVT was diminished under ELVT as the subsidy of land restoration increased; speculators were again able to profit off land rents so long as they restore the land.

One cautionary result from the model was the faster appreciation of land values under both LVT and ELVT tax scenarios due to the increased development and density it spurred. Despite the expectation that much of this appreciation would be taxed away and therefore attract less price appreciation due to speculative interest, a higher property tax burden can still displace existing residents (Martin & Beck, 2018). This is particularly worrisome under the ELVT scheme given the well documented evidence of green gentrification dynamics (Bockarjova et al., 2020). However, the degree to which gentrification would be dampened were speculation to be eliminated remains a question. Furthermore, the validity of this result remains questionable given our proxy land value estimation; further examination is needed with incorporation of the many drivers of upward or downward pressure on land values, including vacancy, commercial and rental interest, buyer and seller bargaining power, and speculator demand.

By establishing this proof of concept study, we hope to provide direction and inspiration for future empirically-grounded inquiry. Such empirical data might include local consumer preferences, developer decision-making behavior, land stewardship practices and adoption likelihood via survey, locally-calibrated land values and development costs, as well as more detailed estimations of locally-defined ecologically-important land and effects of small-scale land stewardship on ecosystem service provisions.

Furthermore, the inclusion of more realistic land-use decision-criteria and a more comprehensive group of actors could improve the model's realism. For example, the inclusion of existing landowners may help shed light on willingness to sell, tax capitalization in land, and farmland conversion dynamics (Magliocca et al., 2015). A primary feature of land value taxation is to increase the cost of holding urban land idle, and therefore, this study's omission of pressure on existing vacant landowners missed an important aspect of the story. Furthermore, the assumption of one central business district was overly simplistic and may have decreased sprawl potential as compared to when commercial areas and jobs follow suburbanites (Brown et al., 2005). Finally, a comparison of the impacts of the tax scheme vs. other parameter variables (or other policy approaches) can be utilized to shed light on the relative importance of the tax intervention. One example of this is Bell et al. (2016) who used a Random Forest Classifier model to describe the relative importance of various parameters toward particular outcomes.

CHAPTER 5: CONCLUSION

The striking ubiquity of dispersed, sprawling settlements across the U.S. suggests common influences on individual land-use motivations, likely stemming from shared economic conditions and/or state institutions. Such pervasive influences on decision-making represent potential leverage points that, once addressed, can lead to systemic reform in urban development patterns and socio-ecological realities. This research built upon a broad basis of academic thought suggesting that land speculation is one such fundamental culprit (e.g. Clawson, 1962; Foldvary & Minola, 2017). We explored the influence of two hypothesized factors on land development practices; the ability to capture economic rent in land value causes developers to favor leapfrog development patterns; and the inability of markets to account for ecological opportunity costs of natural land conversion misaligns development costs with social impact.

The two studies presented in this thesis explore land value taxation as a means for reorienting land development practices toward the production of abundant, land-efficient dwellings. The tax resocializes (to varying degrees) the value of land created by public investment and the community at large which otherwise embeds a perverse incentive toward speculation-motivated investments in land and housing. Together, these studies demonstrate a strong relationship between land value taxation and the degree to which housing development is prioritized over holding land idle with the expectation of price appreciation (speculation).

In Chapter 3, we took an empirical, top-down analytical approach, examining suburban sprawl dynamics as they relate to the hypothesized influence of land rent capture across Chittenden County, Vermont. Not only is this region suffering from a severe housing affordability crisis and emerging suburbanization (Buki et al., 2017), but it also encapsulates a long history of, and continued preferences for compact, walkable urban centers which make reformed housing development practices a broadly desirable endeavor (CCRPC, 2018). By way of a spatial regression and classification model, we demonstrated overarching trends and relative importance of various parcel, neighborhood, and locational characteristics as they relate to recent housing development choices in the region. Findings suggested that developers tended to prefer suburban housing locations over the past six years, including larger lot sizes, greater car ownership rate, longer work commute time, farther distance to a primary or secondary road, and closer proximity to farmland. Moreover, land rents played a pivotal role in locational decision-making; A parcel's land value tax per acre exhibited a significant positive association with development likelihood and was shown to be the most important characteristic in predicting location. However, in ex-ante analysis, where land value tax burdens were doubled and quadrupled, predicted development locations did not shift toward central village or urban locations as hypothesized.

In Chapter 4, we focus more directly on the theoretical effects of land speculation on regional development and their potential resolution through land value taxation. We also proposed and examined the effects of internalizing the ecological effects of land use by way of an expanded land value taxation scheme. Deemed the "ecologically-weighted land value tax," or ELVT, the proposed policy aims to not only limit the financial viability of land speculation, but also to provide a mechanism by which communities can price in the social costs of ecological degradation and subsidize land stewardship. Using a spatially-explicit, conceptual agent-based model, we demonstrated the adverse effects of speculation-based actors on regional suburbanization and ecological deterioration, irrespective of homeowner preferences. Across several experiments, we showed that both land value tax interventions were associated with urban densification, lower housing prices and reduced profitability of speculation. The ecologically-weighted land value taxation scheme outperformed land value taxation in the relative degree of resulting urban densification, which we attribute to higher urban greenspace provisioning, and thus higher preference for urban living amongst homeowners. On the other hand, results demonstrate how ELVT provides a means by which speculators can recapture a greater share of land rents by improving the ecological value of a plot or by purchasing high ecological-value land which has a lower tax rate. As such, results suggest ELVT can run counter to LVT with regard to housing affordability and deterred rent-seeking behavior under more extreme tax operationalizations.

Taken together, these studies embody a robust research approach which relies on broad regional trends as well as emergent outcomes of controlled individual motivations to elucidate a social phenomenon more thoroughly. At the local level, we bring attention to problematic development trends and what can be done via tax reform. At the theoretical level, we present a critique of land value taxation with regard to unrepresented ecological values and propose an expansion of the tax mechanism to align individual actions with broader social consideration of their impact. Furthermore, while the focus of this research is on geographic development outcomes, we believe the policy alternatives outlines here provide co-benefits to many other socio-economic goals, including just distribution of economic rent and essential need satisfiers, regional self-sufficiency, improved quality of life and social cohesion, as well as more support and connection to those non-human community on which we rely.

5.1. Limitations

Chapter 3 and 4 both presented unique limitations to the scope of analysis and subsequently the conclusions that could be drawn. While Chapter 3 provides important takeaways for recent local housing development trends and the influence of land value tax burdens on residential development choices, the means by which ex-ante tax interventions were modeled provided only a simple representation of the multifaceted effects of land value taxation. For one thing, land value taxation is typically enacted in tandem with a proportional reduction in the taxation rate on improvement value, which reduces capital investment costs. Given that the study simplified development decisions to a binary, capital investment choices as a function of the improvement tax rate, and the subsequent impacts of reducing improvement tax burdens, could not be modeled. Furthermore, the study only demonstrated supply-side responses to a hypothetical land value tax intervention, ignoring important demand-side responses such as, for example, changes in homeowner locational preferences associated with more expensive suburban dwellings, cheaper urban dwellings and a greater abundance of housing options. Finally, while the study shows a definitive relationship between land tax burden and development likelihood, it lacks the appropriate depth to confirm that such a relationship is representative of rent-seeking behavior and leapfrog development. Without a means to prove causation, it’s equally likely that developers may seek locations in close proximity to existing development which tend to have higher land value tax burden rather than reacting to a higher land value tax burden by choosing to develop.

In Chapter 4, we demonstrate a clear relationship between individual motivations around land speculation and suburbanization. However, with little empirical calibration or validation, the degree to which the model represents a real-world case remains questionable. Such omissions include empirically-based local development costs, homeowner preferences, and development constraints (e.g. zoning). Furthermore, conclusions are conditional on the many assumptions of the model which have the effect of simplifying agent motivations, actions, and reactions to changing context around them. For example, the model assumes the existence of one central business district for jobs or recreation which has a centripetal effect in relation to an assumption that service centers follow suburbanites outward. The model also assumed a spatially-homogenous random subset of land for sale at any one timestep. Doing so ignores important dynamics regarding incentives to sell (or not sell) land which is strongly tied to land value taxation (Dye & England, 2010). Finally, the absence of certain key actors in land use decision-making limited the scope of outcomes from which to interpret results. Among the most notable omissions are renters, farmers, and commercial real estate owners. Without those actors, certain issues in housing development, such as rent affordability and gentrification or farm profitability and conversion pressures, could not be explored.

5.2. Future Research

The limitations of Chapter 3 and 4 present abundant avenues for future inquiry. Broadly speaking, further research for Chapter 3 is needed to fill the gap between the local development trends and the hypothesized decision-making motivations, namely rent-seeking behavior. Such research might leverage qualitative methods to prod the subjective rationale of developer choices more directly. Furthermore, expanded quantitative analysis could address some of the aforementioned simplifications of the current model. For example, future models might include development choices as a continuous or ratio variable representative of capital investment or dwelling counts. They also might include residential preferences as a mediating factor for developer choices.

Conversely, in Chapter 4, further research is needed to fill a gap between the demonstrated hypothetical effects of controlled individual motivations and those effects in the context of a particular municipality or region. The acquisition of empirical data needed to contextualize a particular region could be a bountiful source of additional research in and of itself. For example, future studies could explore cultural perceptions and social diffusion of lawn conversion practices, the effect of tax incentives in crowding in or crowding out broader suburban ecological stewardship practices, the aesthetic qualities of perceived natural beauty in suburban settings, and thresholds or tipping points from which cultural norms around suburban lawns can change.

Finally, this thesis as a whole takes as a given that suburbia is fundamentally and uniformly antagonistic to a socio-ecological sustainability transition. The logical conclusion is thus to eliminate it where possible. Others have criticized this simplified description and response to suburbia. They argue instead that certain aspects of suburbia make it a “site and terrain of political ecological action,” and thus one should focus on social transformations in suburbia rather than the elimination of the physical structures in which it is founded (Keil, 2019). Therefore, yet another angle of future research centers on a detailing of the characteristics of suburbia, as influenced by the resulting spatial configuration of a suburbanite’s life, that centers this environmental naivete as well as that which could be fostered to transform suburbia from the inside.

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APPENDIX

Figure 17.

All Spatial Variables a Single Run Under SQ Tax Scheme and "Baseline" LU Configuration

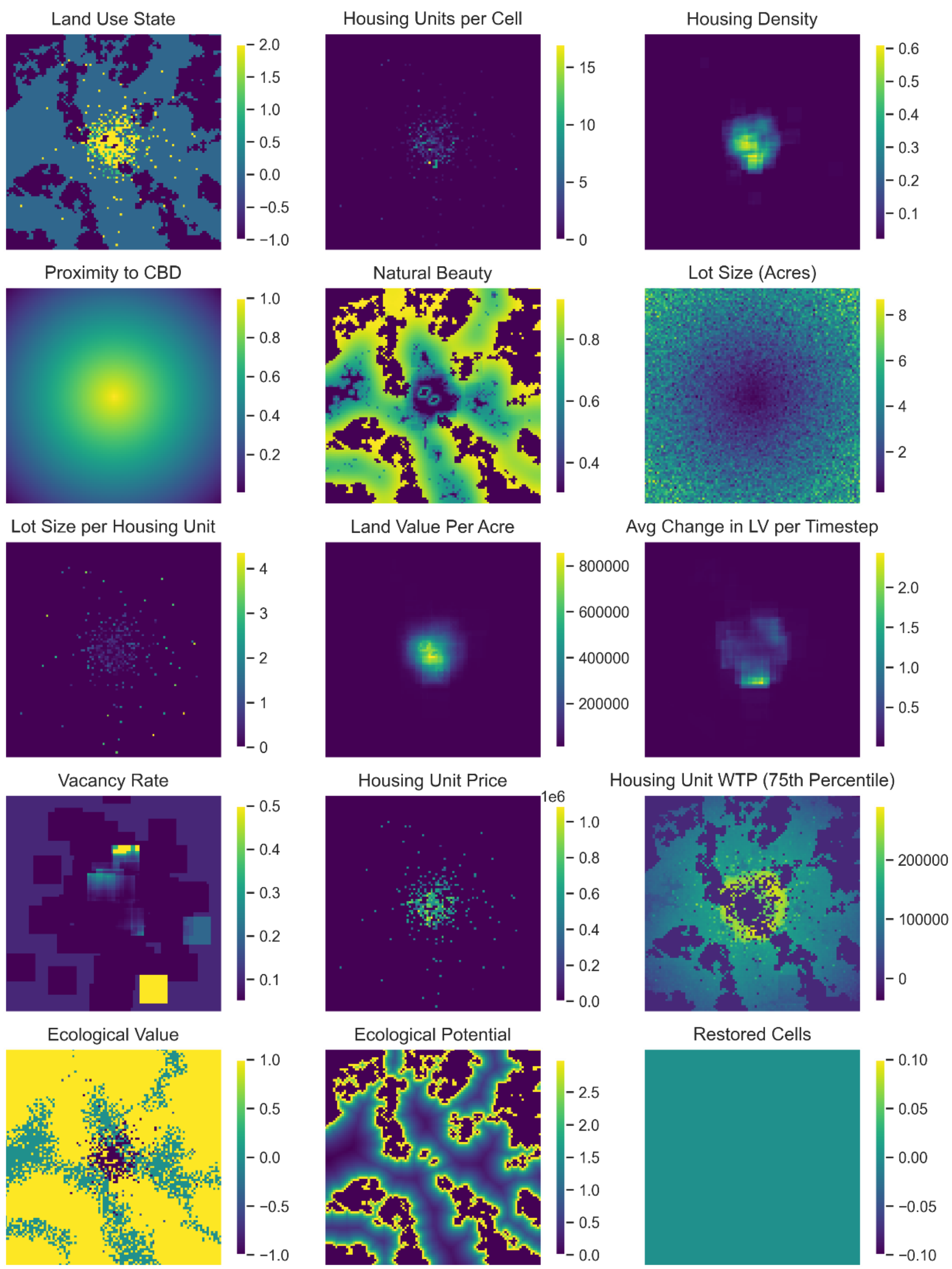

Figure 18.

All Spatial Variables a Single Run Under LVT Tax Scheme and "Baseline" LU Configuration

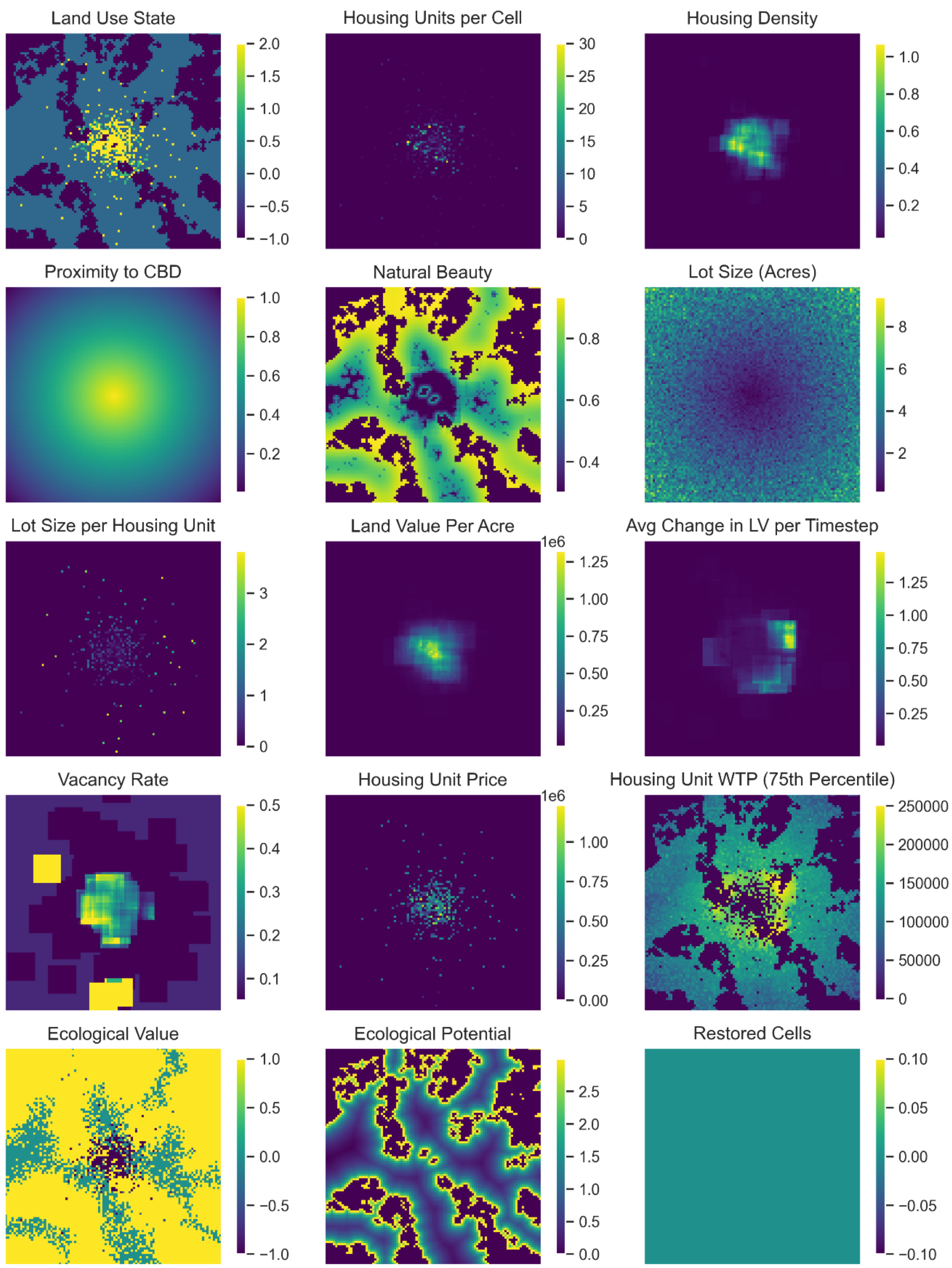

Figure 19.

All Spatial Variables for a Single Run Under ELVT Tax Scheme and "Baseline" LU Configuration