Research Paper

Bayesian methods to estimate urban growth potential☆

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HIGHLIGHTS

- We estimate forest landowners' intent to sell under different development scenarios.
- Changes in property value and distance to new development are important factors.
- The willingness to sell model is fit with a hierarchical Bayesian specification.
- Bayesian methods allows parameters to be used in assessing development potential.
- Using informative priors reveals more heterogeneity in urban development potential.

ARTICLE INFO

ABSTRACT

Urban growth often influences the production of ecosystem services. The impacts of urbanization on landscapes can subsequently affect landowners' perceptions, values and decisions regarding their land. Within land-use and land-change research, very few models of dynamic landscape-scale processes like urbanization incorporate empirically-grounded landowner decision-making processes. Very little attention has focused on the heterogeneous decision-making processes that aggregate to influence broader-scale patterns of urbanization. We examine the land-use tradeoffs faced by individual landowners in one of the United States' most rapidly urbanizing regions – the urban area surrounding Charlotte, North Carolina. We focus on the land-use decisions of non-industrial private forest owners located across the region's development gradient. A discrete choice experiment is used to determine the critical factors influencing individual forest owners' intent to sell their undeveloped properties across a series of experimentally varied scenarios of urban growth. Data are analyzed using a hierarchical Bayesian approach. The estimates derived from the survey data are used to modify a spatially-explicit trend-based urban development potential model, derived from remotely-sensed imagery and observed changes in the region's socioeconomic and infrastructural characteristics between 2000 and 2011. This modeling approach combines the theoretical underpinnings of behavioral economics with spatiotemporal data describing a region's historical development patterns. By integrating empirical social preference data into spatially-explicit urban growth models, we begin to more realistically capture processes as well as patterns that drive the location, magnitude and rates of urban growth.

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1. Introduction

Across the globe, rapid urban expansion is impacting both the productivity of natural systems and the health of human populations. Globally, recent projections suggest that by 2030 urban land area will be 3 times larger than the extent observed in 2000 (Seto, Güneralp, & Hutyra, 2012). Urbanization results in the loss of productive agricultural lands, fragmentation of critical habitats that support biodiversity and a reduction in the amount of carbon the biosphere can sequester from the atmosphere (Seto, Fragkias, Güneralp, & Reilly, 2011). In the United States, recent research has

demonstrated that the conversion of forests and farmlands to low-density built environments has compromised local ecosystems and the life-sustaining benefits these ecosystems provide (Alig, Kline, & Lichtenstein, 2004; Brown, Johnson, Loveland, & Theobald, 2005; Hansen et al., 2005; Maestas, Knight, & Gilgert, 2003; Munn, Barlow, Evans, & Cleaves, 2002; Radeloff, Hammer, & Stewart, 2005). These environmental consequences will become increasingly salient as the global population continues to grow and as greater proportions of the population choose to live in urban areas (Angel, Parent, Civco, Blei, & Potere, 2011).

Despite growing concerns over the environmental consequences of rapidly growing urban areas, very little research has attempted to understand how the decisions of individual landowners affect aggregate urbanization processes. Numerous studies of urban growth have used observational data of historical development patterns (e.g., remote sensing data, property ownership records, etc.) to describe, quantify and project the location, magnitude and rates of urban growth (Seto et al., 2011; Verburg et al., 2016). Historical development trends are frequently used to measure and model urban growth patterns (Brown, Verburg, Pontius Jr, & Lange, 2013; National Research Council, 2013). However, urbanization at its most fundamental level is the result of individual landowners' decisions to sell or develop their farm- and (or) forestland. Urbanization is an emergent process resulting from the aggregate land-use decisions of hundreds or thousands of individual landowners and their interactions with their environments (Alberti, 2010; Verburg et al., 2015).

The land-use decisions of landowners in urbanizing regions are influenced by multiple, often conflicting, factors. Urban development commonly results in an increase in the market value of nearby agricultural and forest lands (Bastian, McLeod, Germino, Reiners, & Blasko, 2002; Delbecq, Kuethe, & Borchers, 2014; Guiling, Brorsen, & Doye, 2009). Consequently, owners of those agricultural and forest lands may welcome nearby urban development, seeing it as a way to expand the value of their properties. However, most small non-industrial agricultural and forest owners in the United States do not manage their properties for financial reasons. Rather they value the aesthetic, cultural, recreational and social benefits provided by owning a working farm or an unmanaged forest stand (Silver, Leahy, Weiskittel, Noblet, & Kittredge, 2015). Nationwide survey data suggest non-industrial private forest owners tend to rate financial objectives for owning woodlands less important than amenity-related objectives such as desirable landscape aesthetics, providing habitat for wildlife or protecting nature (Butler et al., 2016). If landowners place more value on the non-monetary uses of their properties, it is likely they would perceive encroaching development and rising property values as a burden. Nearby development can directly affect landowners' ability to achieve the aesthetic, cultural, recreational and social benefits, which they value most. As development encroaches and property values rise, property taxes also increase which can create a financial burden on landowners who do not manage their properties for income generation (Butler et al., 2012; Greene et al., 2014; Ma et al., 2014). These are the difficult tradeoffs faced by landowners in rapidly urbanizing regions. These complex and multi-faceted decisions are the most fundamental mechanism of the urbanization process.

It is important to note at this point that not *all* urbanization is driven by the sovereign decisions of landowners. Development can occur through direct State intervention. In the United States for example, eminent domain has allowed city governments to expropriate private property for public use via compensating payments (Epstein, 2013). Similarly, compulsory purchase orders, used in the United Kingdom, Ireland, Taiwan and developing countries are a legal mechanism through which ownership of private property can be transferred if it is deemed to be in the public interest (Adu-

Gyamfi, 2012; Denyer-Green, 2013; Lin & Lin, 2006). With these exceptions, the predominant method through which urbanization occurs is via the aggregation of individual landowners' decision to sell their farmland and(or) forestland.

In this research, we explicitly examine the factors driving individual landowners' land-use decisions in one of the United States' most rapidly urbanizing regions – the urban area surrounding Charlotte, North Carolina. Our investigation focuses on the land-use decisions made by non-industrial private forest owners spread across the region's development gradient. A discrete choice experiment is used to determine the critical factors influencing individual forest owners' intent to sell their properties across a series of experimentally varied development scenarios. Data are modeled with a Bayesian hierarchical model. The *choice experiment* model yields estimated posterior distributions for each of the experiment's attributes. We use these estimated posterior distributions to inform a subsequent hierarchical spatial model, the *development potential model*, which predicts the potential of each parcel within the study area to be developed based upon historical development patterns and parcel-specific attributes which match the attributes presented to forest owners in the choice experiment (current distance to development, property value and qualification for a tax-relief program). The linked modeling approach, enabled through the use of Bayesian estimation techniques, allows us to generate spatially-explicit estimates of development potential that are informed by primary data collected from the forest owners whose future land-use decisions will affect how and where urbanization occurs throughout the study area. We show that urban growth is an aggregate product of human decisions, which are themselves a function of how individuals evaluate competing factors associated with encroaching development. Our research demonstrates that carefully developed and rigorously employed social science research can be used to inform projections of the location, magnitude and rates of urban growth.

2. Related literature

2.1. The effect of urbanization on forest property values

Economic theory suggests the value of land is determined by the net present value of expected future returns (Chavas & Thomas, 1999). For forested properties, expected future returns can be influenced by the proximity to viable timber markets, accessibility to city centers and future rent increases resulting from an increased demand for land (i.e., population growth) (Capozza & Helsley, 1989). Rising property values resulting from the increased demand for land is most notable near or at the boundaries of urban areas (Delbecq et al., 2014). In a national study measuring the determinants of agricultural land values, Plantinga, Lubowski, and Stavins (2002) found that as much as 80% of a property's market value is attributable to expected development rents. This proportion tends to rise as urban areas expand and the total amount of developable lands diminishes (Bastian et al., 2002; Guiling et al., 2009; Wear & Newman, 2004). Consequently, forest owners living near rapidly urbanizing regions are facing difficult decisions regarding whether they retain the current use of their forest lands (e.g., harvesting for timber, recreational and(or) aesthetic enjoyment, etc.) and pay increasing property taxes, or decide to sell to developers (Butler et al., 2012; Greene et al., 2014; Ma et al., 2014).

While there has been a large body of empirical work examining the factors and effects of urbanization on property values, most of this research has focused on agricultural land values and has used hedonic pricing methods. To our knowledge, only one study has used stated choice experiments to examine the factors influencing forest landowners' decision to sell. Stated choice experiments allow