Exploring Spatially Heterogeneous Effect of a Property Tax Scheme on Land Development

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A land value tax, a property tax assessed either on land value only or at a higher rate on land than on improvements, has been well scrutinized as a potential tool in mitigating urban sprawl (Bails 1973; Cho *et al.* 2006; Cho, Lambert, and Roberts 2011; Cho *et al.* 2009; Cho *et al.* 2007; Cho and Roberts 2007; Emison 2004; England 2003; Lim 1992; Maxwell and Vigor 2005; Pollock and Shoup 1977; Rawson 1961; Scheftel 2009). Theoretically, the higher tax gives landowners the incentive to fully develop high-rent parcels to generate more rent and help defray the higher tax. Previous research suggests that switching from a property tax that weighs land values and improvement values equally to a tax that places greater weight on land value encourages more intense development on parcels with higher rent than parcels with lower rent. Concentrating development on higher rent land suggests that a land value tax discourages urban sprawl because these parcels are more likely to be located closer to the city center than in areas further away from the city center (Brueckner 1986; Brueckner and Kim 2003; Case and Grant 1991; Mills 1998; Nechyba and Strauss 1998; Skaburskis 1995).

While previous studies confirm that a land value tax can affect development patterns on vacant land, the empirical models did not fully account for the effect of the land value tax on land fragmentation. Land fragmentation ("parcel fragmentation" can be used interchangeably in the context of this study) occurs when a chunk of land is divided into multiple pieces or parcels to be sold or developed. Examining land fragmentation is important because it should be observed where urban sprawl occurs even though land fragmentation itself may not necessarily lead to urban sprawl. When a land tax value is introduced, landowners have an incentive to develop high-rent land by building on vacant land (which has been considered in previous studies) or adding structures on pre-occupied parcels (which has not been previously considered). The overall impact of a land value tax on land fragmentation may be just as important as the effect on development of new parcels because it may affect the overall picture of land development spatial patterns (Irwin and Bockstael 2002).

Much of the previous research on residential development has also ignored the possibility of building residential structures on parcels that are already partially developed. In many cases, the existence of pre-occupied structures does not preclude the possibility of additional development although the existence of pre-occupied structures lower the demand for new structures. To the best of our knowledge, however, pre-occupied parcels have been excluded from many previous studies by treating them as developed parcels. Some previous researchers have also developed separate models to look at (1) development of vacant parcels and (2) adding structures to partially developed parcels, implicitly treating these as different development processes (Geoghegan 2002; Irwin and Bockstael 2002).

Land Development Process Revisited

A parcel has often been defined as developed for residential use if it has a residential structure on it (Cho, Kim, and Roberts 2011; Cho and Newman 2005; Cunningham 2006). The probability of converting a vacant parcel to a developed parcel is estimated as a function of parcel-level attributes and neighborhood variables using a discrete choice model. However, these studies ignore the possibility of further development on pre-occupied parcels, classifying them as pre-developed. This may not be a severe problem since it can be viewed as merely structural improvement, so that it is less likely to have huge impact on overall land-use change.

Another problem arises when a new structure is built on a vacant parcel within an existing subdivision. These observations are treated equally with other development outside subdivisions even though the decision to develop the parcel was made before the study period. To address this issue, researchers have focused on subdivision development while disregarding individual parcel development within a subdivision, effectively treating each subdivision as one parcel (Irwin and Bockstael 2002; Zhou and Kockelman 2008). This strategy captured major land-use change, but did not accommodate individual parcel development without fragmentation . Kim (2011) tried to mitigate this issue by considering only large parcels that are either developed or undeveloped prior to subdivision development, but used an arbitrary minimum parcel size to select major land development.

The aforementioned issues associated with identifying the development status of a parcel can be resolved by examining the land development process closely. The land development process involves two different major decisions: 1) development decision (i.e., building/adding structure on parcel) and 2) parcel fragmentation decision for subdivision development. Even though structure placement is the result of the land development decision, parcels that have structures from a previous decision process are not necessarily excluded from the land development process since these parcels can add additional buildings or can be fragmented for the subdivision development. In other words, development decisions are a recursive process. All parcels can be considered for land development regardless of the status of structure placement because pre-developed parcels can add an additional structure or a new structure after existing structure demolition or parcel fragmentation.

Figure 1 illustrates the recursive land development process. The first decision (hereafter "D1") refers to the decision regarding whether to develop a parcel or not for residential land use. Once the choice is made to develop a parcel, the other decision (hereafter "D2") is whether parcel fragmentation is necessary for this development. In the case of the choice of no development in D1, D2 is not applicable. After one set of decisions (i.e., D1 and D2) is made for each parcel, these parcels will be located in the iterative set of decisions. Because of the circulative property of the development process, the order of D1 and D2 is not important, but D1 took the first place to conceptualize the decision process of the initial land development decision from the beginning of one parcel. Thus, all types of residential development during a particular study period can be diagrammed as Figure 1. Thus, the objective of this research is to empirically adopt this land development decision, which is essentially involved with sample selection modeling, in order to precisely examine the impact of a land value tax on land fragmentation. To implement the objective, it is hypothesized that 1) a higher property tax on land value increases parcel fragmentation and 2) its marginal effect (i.e., property tax on land value) on parcel fragmentation varies spatially.

Methods

Discrete-Choice Model for Parcel Fragmentation Decision

A maximum-likelihood probit model with sample selection is applied to measure the effect of a land value tax on parcel-level fragmented development. Sample selection bias could occur because the parcel fragmentation decision (D2) is made only for parcels where the decisions to develop (D1) has already been made.

We observe only the binary outcome (i.e., $y = 1$ if fragmented, 0 otherwise) but assume that there is a latent variable model underlying these decisions:

$$(1) \qquad y_i^{Frag} = (y_i^* > 0),$$

where $y_i^* = \mathbf{X}_i\beta + u_{1i}$, **X** is a vector of explanatory variables, β is its conformable parameter vector, $u_{1i} \sim Normal(0,1)$, $i = 1, \dots,$ N, and N is the number of observations. y_i^{Frag} is observable only if a positive decision of land development (i.e., $y_i^{Develop} = 1$) is made

$$(2) \qquad y_i^{Develop} = (\mathbf{Z}_i\alpha + \ u_{2i} > 0),$$

where **Z** is a vector of explanatory variables, α is its conformable parameter vector, $u_{2i} \sim Normal(0,1)$, and $corr(u_{1i}, u_{2i}) = \rho$.

If ρ is not significantly different from 0, the standard porbit model in equation (1) yields unbiased estimates. If u_{1i} and u_{2i} are correlated, the log likelihood is stated as:

$$(3) \quad \ln L = \sum_{\substack{i \in S \\ y_i \neq 0}} \ln\{\Phi_2(\mathbf{X}_i\beta, \mathbf{Z}_i\alpha, \rho)\} + \sum_{\substack{i \in S \\ y_i = 0}} \ln\{\Phi_2(-\mathbf{X}_i\beta, \mathbf{Z}_i\alpha, -\rho)\} \qquad + \sum_{i \notin S} \ln\{1 - \Phi(- \mathbf{Z}_i\alpha)\},$$

where S is the set of observation for which y_i^{Frag} is observed, Φ is the standard cumulative normal distribution function, $\Phi_2(.,.,.)$ denotes the probability of a joint event from the cumulative bivariate normal distribution function. In theory, the same explanatory variables can be used for **X** and **Z**. For identification, however, **Z** should include at least one variable that is not in **X.** To address this issue, a dummy variable indicating a previously existing structure is added to **Z**. Because of potential mulitcollinearity between the the dummy variable and property tax on structure value, the total property tax variable is replaced with separate variables for property taxes on structures and property taxes on land.

Measuring Spatially Heterogeneous Effect of Land Value Tax on Fragmented Development using Marginal Effect at a Point

In general, parameter estimates from nonlinear models should be interpreted through marginal effects since coefficients provide the direction only, not the magnitude of the effect. In nonlinear models, the marginal effect can be computed two ways: 1) Marginal Effects at the Means (MEMs) and 2) Average Marginal Effects (AMEs), which can differ significantly. The MEM is calculated using average values of X variables, $\frac{\partial \mathrm{y}}{\partial \mathbf{X}}|\mathbf{X} = \frac{1}{\mathrm{N}}\sum_{i=1}^{\mathrm{N}} \mathbf{X}_i$, by while the AME is calculated as $\frac{1}{\mathrm{N}}\sum_{i=1}^{\mathrm{N}} \frac{\partial \mathrm{y}_i}{\partial \mathbf{x}_i}$. Since every observation has its own marginal effect (i.e., $\frac{\partial \mathrm{y}_i}{\partial \mathbf{x}_i}$), they can be mapped. Mapping marginal effects can reveal spatial heterogeneity in the effect of the land value tax on fragmented development. Additionally, spatial interpolation will help examine overall spatial heterogeneity of marginal effects. Standard errors for AMEs and MEMs are calculated using Delta method.

Study Area and Data

The Knoxville Metropolitan Statistical Area (MSA) was ranked 8th in overall sprawl among 83 U.S. metropolitan regions based on street connectivity, centeredness, mixed use, and density scores (Ewing, Pendall, and Chen 2002). The high volume of traffic associated with sprawl has made Knoxville 11th in per capita carbon emissions out of 100 U.S. metro areas (Brookings

Institution 2008). Because of sprawl in Knox County, which contains the city of Knoxville and the town of Farragut, the land value tax has been examined as a potential policy tool for reducing urban sprawl (Cho *et al.* 2006; Cho, Lambert, and Roberts 2011; Cho *et al.* 2009; Cho *et al.* 2007; Cho and Roberts 2007; Emison 2004).

The data set used in this analysis includes GIS data on: individual parcels (sales price, lot size, residential space, structural information), census–block groups (income, housing density, travel time to work, unemployment rate, and vacancy rate), boundaries (high school district and jurisdiction boundaries), and environmental features (municipal parks, railroad, and elevation). Means and standard deviations are presented in Table 1.

The development status of individual parcels in Knox County was collected for 1996 - 2009. At the end of 1995, 18,520 parcels were identified as developable for residential houses. During the study period, 1,330 parcels (i.e., $y_i^{Develop} = 1$) out of 18,520 developable parcels (i.e., $y_i^{Develop} = 1 \cup\ y_i^{Develop} = 0$) were developed. Of these 1,330 parcels, 539 (i.e., $y_i^{Develop} = 1\ \cap y_i^{Frag} = 1$) were developed with parcel fragmentation while the other 791 parcels (i.e., $y_i^{Develop} = 1\ \cap y_i^{Frag} = 0$) were developed without fragmentation. Ninety-five percent (1,270 parcels) of the developed parcels had at least one pre-existing structure (i.e., pre-existing structure = 1). This high rate of pre-existing structures shows that previously developed parcels should not be excluded from the data. The fact that 538 of 539 parcels developed with parcel fragmentation had at least one pre-existing structure also shows that previously developed parcels with structures should be considered in the analysis of parcel fragmentation.

Distance and environmental variables were collected to capture the environmental neighborhood effect on land development decisions. Seven newly built municipal parks in Knox

County during the study period were updated to measure distance to parks based on the their built years and the years of parcel development while proximity to the nearest municipal park for undeveloped parcels was measured without these 7 new parks, assuming it as a lagged variable. Because other environmental features were largely unchanged during the study period, 1996 data from the Environmental Systems Research Institute (ESRI) Data and Maps (ESRI 2008) was used. Census-block data for 2000 was used to create proxies for socioeconomic characteristics.

Empirical Result

Parameter estimates are presented in Table 2. The log-likelihood converged at -2,833.216 and the Wald test that all the parameters in the regression equation are zero was rejected at any conventional significance level ($p = 0.000$). The estimated selectivity variable coefficient was -0.774 and the null hypothesis of $\rho = 0$ was rejected at the 1% significance level (likelihood ratio (LR) statistic of 10.28, $p = 0.001$, Chi-square distributed with 1 degree of freedom), confirming that a model of parcel fragmentation decisions (D2) estimate without considering parcel development decision (D1) could be biased.

Parcel Development Decision

In equation (2) coefficient estimates were significantly different from zero for median household income, housing density, travel time to work, vacancy rate, ACT score, distance to parks, distance to railroads, elevation, slope, lot size, total property taxes, and pre-existing structures. Among socioeconomic variables, lower median household income, lower housing density, higher travel time to work, lower vacancy rate, and lower ACT score are associated with a higher likelihood of land development. The positive effect of undesirable socioeconomic characteristics on parcel development (i.e., low income, and low ACT score) may capture the fact that preferred areas were already developed. Among distance and environmental variables, longer distance to parks, shorter distance to railroads, higher elevation, and a higher degree of slope are associated with a higher likelihood of parcel development. Like socioeconomic variables, positive signs for undesirable environmental characteristics may also indicate that more desirable land is already developed. Among property variables, smaller lot size, parcel vacancy, and higher total property tax are associated with a higher likelihood of parcel development. The magnitudes of AMEs and MEMs were similar to each other, but MEMs were relatively smaller than AMEs.

Parcel Fragmentation Decision

In equation (1) coefficient estimates were significantly different from zero for median household income, housing density, vacancy rate, distance to highway, distance to CBD, slope, lot size, property tax on property value, and property tax on land value. Among socioeconomic variables, lower median household income, higher housing density, and higher vacancy rates are associated with a higher likelihood of parcel fragmentation. Coefficient signs for housing density and vacancy rates are reversed when compared to coefficients in the parcel development equation. Interestingly, socioeconomic conditions may have different impacts on parcel development and parcel fragmentation decisions. Among distance and environmental variables, shorter distance to railroad, longer distance to highways, and lower degree of slope are associated with a higher likelihood of parcel fragmentation. Parcel fragmentation may be expected to occur more frequently in remote areas with good access to highway. Unlike the parcel development decision, a flatter parcel was found to be preferred in the parcel fragmentation decision. Among property variables, smaller lot size, higher property taxes on structure value, and higher property taxes on land value are associated with a higher likelihood of parcel fragmentation. Surprisingly enough, none of MEMs were significant at the 5% level, which may mean that the MEM is not a good indicator for this type of analysis. Among AMEs, only property tax variables (i.e., lot size, property taxes on structure value, and property taxes on land value) were significant at the 5% level.

Marginal Effect of Property Tax on Land Value

The MEM of ln(property tax on land value) was not significant at the 5% level, but significant at the 10% level ($p = 0.087$). In this case, the marginal effect of 0.123 is interpreted as a percentage point change, i.e., that probability of parcel fragmentation increases by 12.3 % point when property tax on land value increases by 1% (i.e., $2.22) for a particular parcel with ln(property tax on land valu) of 5.401 (i.e., property tax on land value of $221.57). The AME of ln(property tax on land value) (0.144) can be interpreted in the same way. The probability of parcel fragmentation increases by 14.4 % point when property tax on land value increases by 1 %. Figure 2 shows that the marginal effect for each observation varies according to its current property tax on land value and the marginal effect was significant at the 5% level only if it is greater than 0.165. Two constant MEM and AME are added for the purpose of comparison.

To examine spatially different patterns of marginal effects, we interpolated spatially across individual marginal effects then put the resulting values in one of three classes (i.e., white for insignificant ME, grey for significant ME at the 5% level, and black for significant ME at the 1% level) in Figure 3. It is difficult to find a spatial pattern since it is scattered all over Knox

County, but clusters of higher marginal effects were found between the City of Knoxville and the Town of Farragut. Thus, if the tax rate is increased on property tax on land value, those areas may have a higher probability of parcel fragmentation.

Conclusion

Two hypotheses were tested: 1) higher property tax on land value increases parcel fragmentation and 2) its marginal effect on parcel fragmentation varies spatially. To test the hypotheses, a two stage land development decision process was examined to accommodate iterative decisions on land development. We also found that a parcel development decision should be incorporated even if we are only interested in examining the factors which affect parcel fragmentation because of potential sample selection bias.

This case study using Knox County's data showed that a higher property tax rate on land value could promote parcel fragmentation and this relationship would be stronger in the area between the city's and town's boundaries. Since many residential subdivisions were developed recently in the Town of Farragut, which is known as a luxurious bedroom community for those commuting to the City of Knoxville, land prices around the town boundaries are relatively high. Thus, a higher property tax rate on land value may promote parcel fragmentation in these areas. This finding does not necessarily imply urban sprawl would be increased by a land value tax, but it may capture the potential side effect of a land value tax on urban sprawl, possibly caused by higher propensity of parcel fragmentation. This effect would be clearer if a more objective measurement of urban sprawling at the micro level could be possible.

One of the obvious caveats in this research is that no explicit spatial modeling was used to address spatial interdependence or spatial spillover. However, spatial interactions are not constant over time because of different market conditions for different periods (Kim, 2011) and the indirect marginal effect (e.g., calculated through spatial lag) is negligibly small comparing to the direct marginal effect even if the aspatial estimation in this study may be a biased estimator.

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Table 1. Variables and Definition

Variables (Unit)	Definition	Development	Fragmentation
		Mean (Std. Dev.)	Mean (Std. Dev.)
Dependent variable			
Development	Dummy variable indicating development status of parcel (1 if a parcel was developed between 1996 and 2009, 0 otherwise)	0.072 (0.258)	1.000 (0.000)
Fragmentation		0.029 (0.168)	0.405 (0.491)
Socioeconomic variables			
Median household income ($)	Median household income for census-block group in 2000	43,345.970 (14,481.421)	49,138.910 (18,906.922)
Housing density (houses/acre)	Housing density for census-block group in 2000	0.353 (0.458)	0.504 (0.576)
Travel time to work (Minutes)	Average travel time to work for census-block group in 2000	12.540 (2.037)	12.274 (1.935)
Unemployment rate	Unemployment rate for census-block group in 2000 (ratio of unemployed to the labor force, age 16 or older)	0.037 (0.023)	0.035 (0.024)
Vacancy rate	Vacancy rate for census-block group in 2000 (ratio of vacant housing units to total housing units of any type)	0.068 (0.023)	0.064 (0.024)
ACT score	Mean value of average composite scores each year of American College Test (ACT) by high school district from 2000 to 2009	20.575 (0.784)	20.912 (0.987)
Distance and environmental variables			
Distance to park (feet)	Euclidean distance from the centroid of a parcel to the centroid of the nearest park	14,208.934 (8,387.458)	13,270.133 (7,904.076)
Distance to railroad (feet)	Euclidean distance from the centroid of a parcel to the nearest railroad	12,214.145 (8,755.824)	10,283.701 (8,021.775)

Distance to highway (feet)	Euclidean distance from the centroid of a parcel to the nearest interstate highway	19,507.754 (12,953.787)	16,910.629 (11,798.039)
Distance to CBD	Euclidean distance from the centroid of a parcel to the centroid of the central business district (CBD)	52,575.677 (17,680.932)	53,250.064 (17,784.853)
Elevation	Average elevation of a parcel	1,034.426 (117.102)	1,038.759 (114.358)
Slope (°)	Degree of slope at the parcel location	9.459 (4.846)	7.359 (4.183)
Property variables			
Lot Size (Acre)	Size of parcel	5.686 (13.420)	12.460 (22.101)
Pre-existing structure	Dummy variable indicating existence of pre-developed structure	0.747 (0.435)	0.955 (0.208)
Total property tax	Total property tax	2,843.526 (17,277.533)	29,205.625 (57,167.028)
Property tax on structure value	Property tax on structure value	2,023.159 (13,287.978)	22,260.163 (43,706.097)
Property tax on land value	Property tax on land value	820.367 (4,924.933)	6,945.458 (16,940.359)
Number of observation		18,520	1,330

Note: The numbers in grey are the mean and standard deviation of variables which are not used in the equations.

Table 2. Parameter Estimates

Variables (Unit)	Development			Fragmentation		
	Coefficient (Std. Error)	MEMs (Std. Error)	AMEs (Std. Error)	Coefficient (Std. Error)	MEMs (Std. Error)	AMEs (Std. Error)
Constant	-9.197* (1.512)			-16.360 (9.152)		
Socioeconomic variables						
ln(Median household income)	-0.176* (0.067)	-0.008* (0.003)	-0.013* (0.005)	-1.080* (0.469)	-0.120 (0.121)	-0.140 (0.088)
Housing density	-0.132* (0.055)	-0.006* (0.003)	-0.010* (0.004)	0.741* (0.287)	0.082 (0.081)	0.096 (0.056)
Travel time to work	0.025* (0.011)	0.001* (0.001)	0.002* (0.001)	-0.002 (0.058)	-0.0002 (0.006)	-0.0002 (0.008)
Unemployment rate	0.102 (0.942)	0.006 (0.047)	0.009 (0.075)	8.014 (5.435)	0.891 (1.000)	1.042 (0.838)
Vacancy rate	-2.578* (0.877)	-0.129* (0.044)	-0.207* (0.070)	9.252* (4.519)	1.028 (1.117)	1.203 (0.852)
ACT score	-0.135* (0.032)	-0.007* (0.002)	-0.011* (0.003)	0.001 (0.163)	0.0001 (0.018)	0.0001 (0.021)
Distance and environmental variables						
ln(Distance to park)	0.097* (0.032)	0.005* (0.002)	0.008* (0.003)	-0.154 (0.172)	-0.017 (0.025)	-0.020 (0.024)
ln(Distance to railroad)	-0.080* (0.021)	-0.004* (0.001)	-0.006* (0.002)	0.123 (0.101)	0.014 (0.017)	0.016 (0.015)
ln(Distance to highway)	0.003 (0.021)	0.0002 (0.001)	0.0003 (0.002)	-0.228* (0.109)	-0.025 (0.025)	-0.030 (0.018)
ln(Distance to CBD)	-0.023 (0.063)	-0.001 (0.003)	-0.002 (0.005)	0.784* (0.351)	0.087 (0.086)	0.102 (0.063)

ln(Elevation)	0.836*	0.041*	0.066*	1.959	0.218	0.255
	(0.191)	(0.010)	(0.015)	(1.083)	(0.205)	(0.157)
ln(Slope)	0.178*	0.009*	0.014*	-0.414*	-0.046	-0.054
	(0.033)	(0.002)	(0.003)	(0.152)	(0.045)	(0.031)
Property variables						
ln(lot size)	-0.251*	-0.012*	-0.020*	-0.519*	-0.058	-0.067*
	(0.021)	(0.001)	(0.002)	(0.161)	(0.047)	(0.026)
Pre-existing structure	-0.218*	-0.010*	-0.017*			
	(0.067)	(0.003)	(0.005)			
ln(Total property tax)	0.958*	0.048*	0.076*			
	(0.023)	(0.002)	(0.002)			
ln(Property tax on structure value)				0.172*	0.123	0.022*
				(0.073)	(0.102)	(0.008)
ln(Property tax on land value)				1.109*	0.019	0.144*
				(0.218)	(0.014)	(0.053)
Rho						
ρ	-0.774*					
	(0.118)					

* Significant at the 5% level ($p<0.05$).

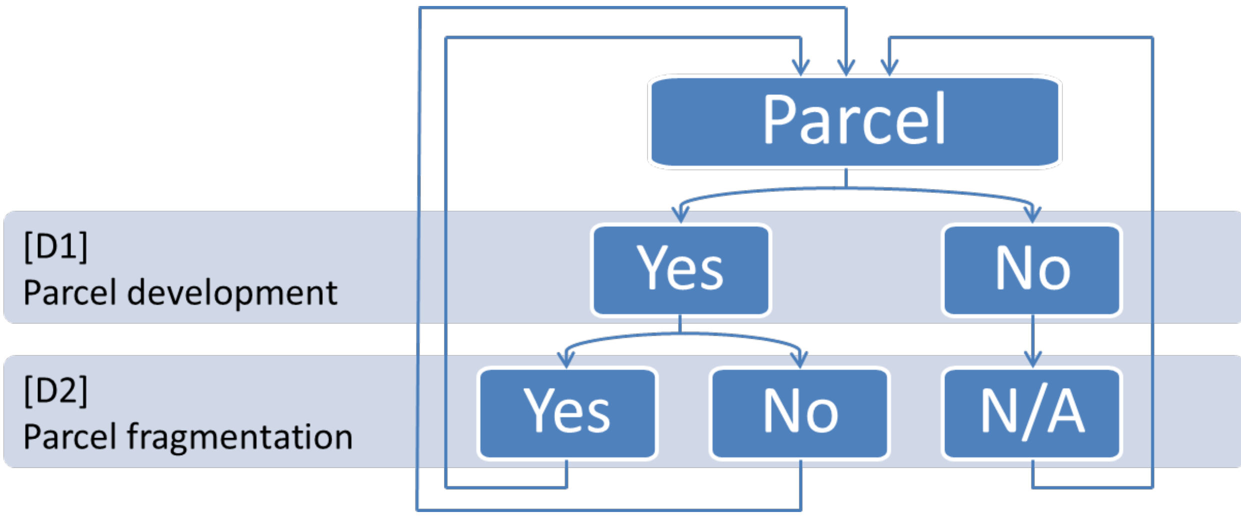

Fig. 1. Recursive land development process

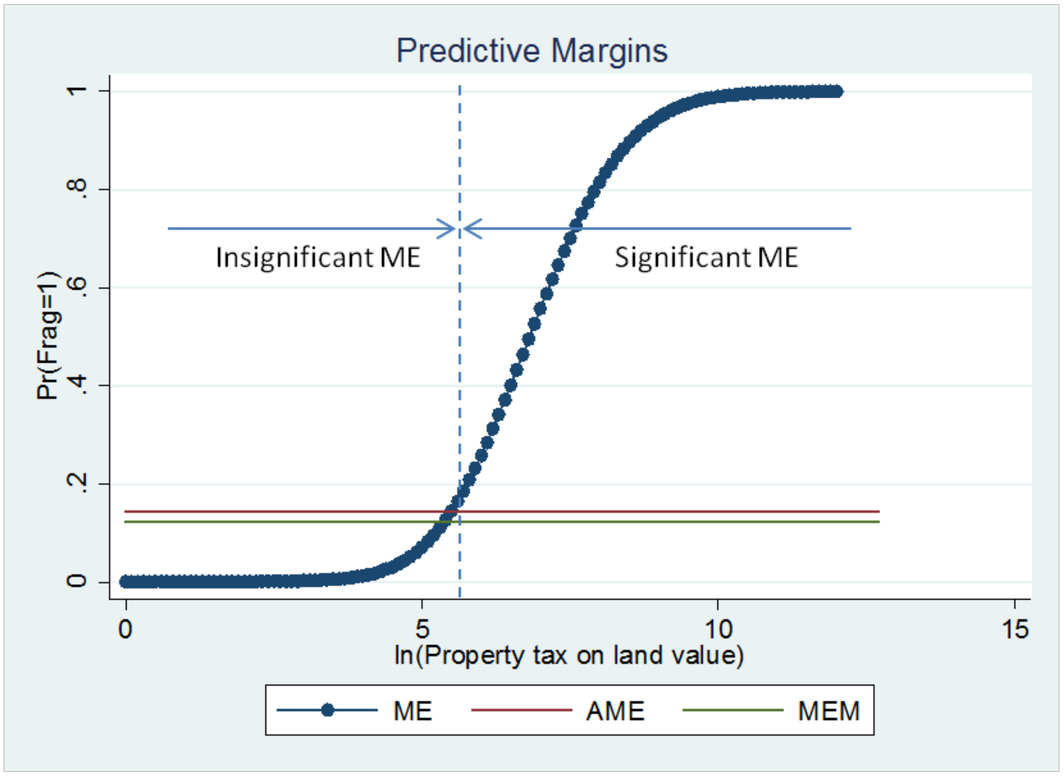

Fig. 2. Marginal effect of ln(property tax on land value)

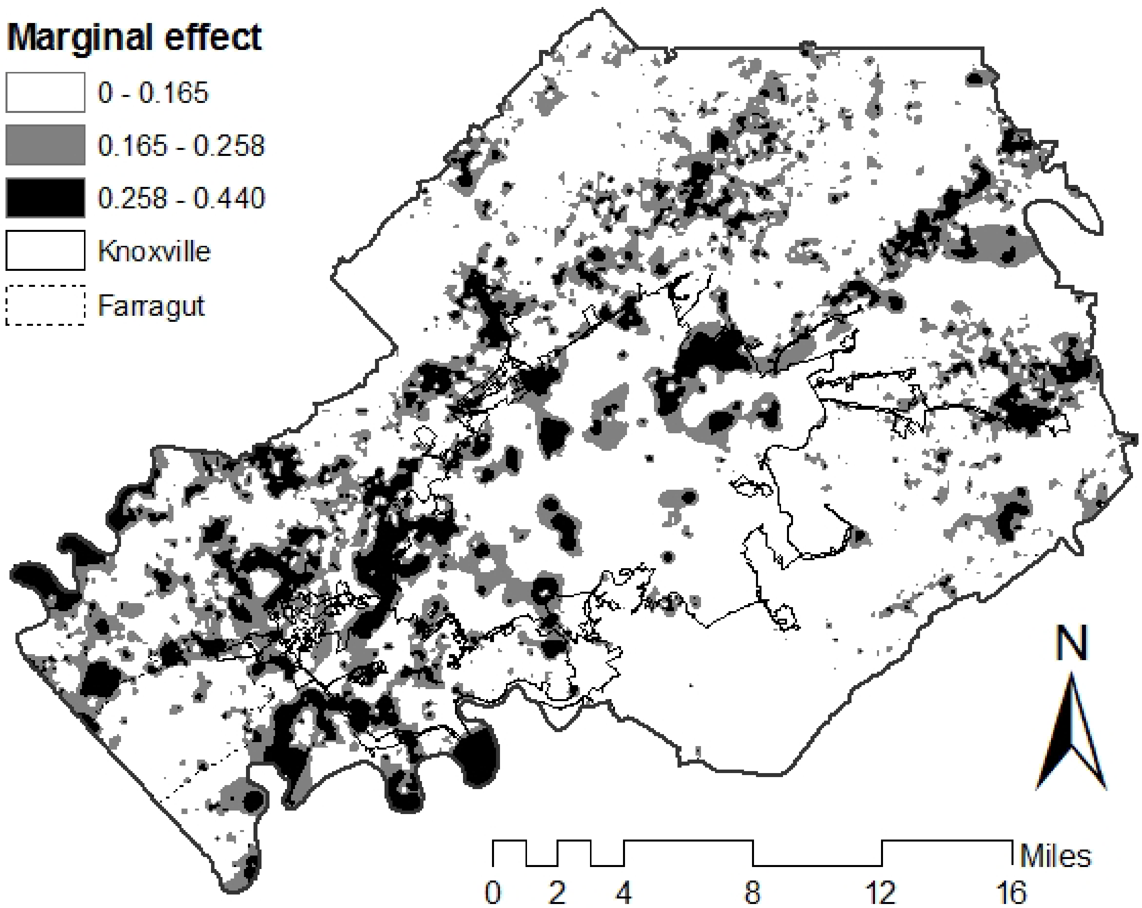

Fig 3. Spatially Varying Significant Marginal Effect of Property Tax on Land Value on Parcel Fragmentation