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Zoning, Development Timing, and Agricultural Land Use at the Suburban Fringe: A Competing Risks Approach

Diane Hite, Brent Sohngen, and Josh Templeton

Competing risks survival analysis is used to investigate tax and zoning policy impacts on residential, commercial, and industrial development timing in a rapidly growing Midwestern county. Industrial development appears both to precede and occur concurrently with residential development, while commercial development follows other types. Although residences appear to locate away from industrial land, zoning decisions favoring industry may attract rather than deter residential development within a jurisdiction. Regions with higher infrastructure taxes experience development later. Because school taxes fund local public goods important to homeowners, they have little influence on residential timing, but strong influences on industrial and commercial timing.

Key Words: land use change, land use policy, survival models

As economic growth in the 1990s boomed, large areas of agricultural and other undeveloped land converted rapidly to developed uses. While development outside a central city can benefit the local and regional economy (Gordon and Richardson, 2000), many authors argue there are negative impacts of rapid suburbanization, including inefficient use of land or other resources, reduced environmental quality, and congestion, among other impacts (see, for example, Hamilton and Röell, 1982; Kahn, 2000; Brueckner, 2000; Plantinga and Miller, 2001).

Concern with externalities has led policy makers to question whether existing policies inadvertently cause land to change more quickly, and whether alternative policies could slow land use change at the suburban fringe. Given the many policies available—land taxes, zoning restrictions, impact and development fees, direct land use controls, and growth boundaries—it is useful to examine how existing policies have affected land use change, and whether stricter policies could alter the timing of converting agricultural land to developed uses.

Within the literature, many theoretical studies have explored how tax policies are likely to affect the timing of land use change (e.g., Bentick, 1979; Anderson, 1986, 1993; Turnbull, 1988a, b; Capozza and Li, 1994; McFarlane, 1999). Fewer studies have explored the influence of zoning on timing of land use change, although Irwin and Bockstael (2002) show land use change in one parcel can influence the timing of changes in nearby parcels. Thus, zoning policies designed to limit specific types of uses in one location can influence the timing of change on neighboring parcels.

Alternatively, Fujita, Thisse, and Zenou (1997) and Fujita, Krugman, and Venables (1999) argue that industrial and commercial developments outside of cities can spur positive feedbacks, potentially by raising relative real wages, and attracting further residential development. Not only can taxes influence development timing, but the type of development occurring in an area can influence the land around it.

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In this study, we first present a theoretical analysis to assess how property tax millage rate and zoning policies potentially influence timing of land conversions from agricultural to residential use. An empirical analysis is then conducted using competing risks survival analysis to explore the potential effects of a range of factors on the timing of commercial, industrial, and residential developments. The empirical model examines the way certain explanatory variables influence the time to conversion for agricultural land parcels over 10 years within a fast-growing Midwestern county. The model is used to examine changes in development timing of residential, commercial, or industrial land under alternative assumptions about tax millage rates and zoning in homogeneous tax districts.

Only a few studies to date have used parcel-level data to analyze development timing (e.g., Irwin and Bockstael, 2002; Irwin, Bell, and Geoghegan, 2003), although some studies have used aggregate metropolitan-area data to explore the effects of land use regulations on residential development (e.g., Mayer and Somerville, 2000). No studies to our knowledge employ competing risks to assess how the three different land use types interact.

Our study does not specifically examine patterns in land use change, as in Irwin and Bockstael (2002), but by using parcel-level data, we are able to control for spatial factors that influence land values at different locations in the region. Our interest, instead, is to determine how policies like taxes or zoning influence the timing of land use change in contiguous regions where taxes and zoning policies are applied uniformly. While it is difficult to identify the specific influence of one type of development on another (e.g., Irwin and Bockstael, 2002), our results do provide information about how the development process occurred in the region under investigation, and potentially how zoning and taxes may influence future development.

Theoretical Model

The theoretical model focuses on the timing of residential land use conversions because this emphasis encompasses most of the change that occurred in our study region. The model only examines the timing decision, without considering the decision addressing how intensively to develop a particular parcel (as in McFarlane, 1999). Development decisions are assumed to be made within homogeneous tax districts, where the tax structure for all the developed properties is the same—i.e., all developed properties are taxed at the same marginal rate per $1,000 of value.

Because agricultural properties in the study region typically have tax advantages bestowed upon them by special agricultural land use valuation programs, the model allows for different valuations among agricultural and developed land uses. The per acre rental rate for developed residential land at time u is given as $R(u; q(\tau, I), \mathbf{X})$, where $q(\tau, I)$ is the quality of public services provided (i.e., schools, infrastructure). The quality of public services (i.e., school quality, fire protection, environmental quality) is assumed to be a function of the tax millage rate, τ, and the intensity of industrial development near the parcel, I. $\mathbf{X}$ is a vector of additional locational factors affecting land rents for any parcel of land. The focus of this study is on how tax millage rate policies and zoning decisions over the intensity of industrial (or commercial) development in taxing districts affect timing of land use decisions. It is assumed $R_q \$ 0$, and $R_{qq} \# 0$; however, the underlying relationships between taxes and industrial infrastructure are more complicated.

First, we assume $q_\tau \$ 0$, and $q_{\tau\tau} \# 0$. Higher tax rates on existing properties should increase public services provided to residents in a given region, although tax increases likely have their largest effects for regions with relatively low initial tax rates.[1] Second, the relationship between public services and industrial development density could be positive or negative, $q_I \$ \text{ or } \# 0$. We assume $q_{II} \# 0$, regardless of the first-order effect. For low levels of industrial development density, an increase in development can improve public services by increasing overall tax revenues for the taxing district. Industrial developments can often benefit residential uses because they have high infrastructure value per acre of land developed. However, if industrial development is too dense, it could cause pollution or congestion, or otherwise reduce local environmental amenities.

Given these assumptions, we further assume

$$R_I \ ' \ \frac{dR}{dq}\frac{dq}{dI} \ \$ \text{ or } \# 0.$$

That is, the relationship between rental rates and industrial development density is ambiguous. Both of these impacts are tied to the presence of industrial development. The landowner's objective is to

[1] We suspect, in most cases, higher taxes will result in greater levels of public services. However, as noted in the empirical section below, different types of taxes can map differently into public service quality and the resulting rental values for developed land.

maximize the value of land at time 0 by choosing the date of development, T. The value function for an agricultural landowner is given as:

$$(1)\quad V(0,T) = \max_{T}\left(\int_{0}^{T}\left[A(u) - \tau V_F(u)\right]e^{-ru}\,du + e^{-rT}\left\{ \int_{T}^{\infty} R\big(u; q(\tau, I), \mathbf{X}\big)e^{-(r+\tau)(u-T)}\,du - c\right\}\right),$$

where $A(u)$ is the annual rental value of agricultural land at time u, $V_F(u)$ is the value of agricultural land, and c is the cost of developing a parcel of land for residential use. The developer chooses T to maximize land value. As a result of the assumption of exogenous capital intensity, rental rates are assumed to be exogenous to the landowner's decision, and policy makers are assumed to choose tax rates so that all revenues collected are spent locally on public goods. Further, zoning decisions are made such that tax revenues equal public goods expenditures.

The first-order condition for optimal development timing is given as $V_T = 0$. Specifically,

$$(2)\quad A(T) + rc + \tau \int_{T}^{\infty} R\big(u; q(\tau, I), \mathbf{X}\big)e^{-(r+\tau)(u-T)}\,du + \int_{T}^{\infty} R_T\big(u; q(\tau, I), \mathbf{X}\big)e^{-(r+\tau)(u-T)}\,du = R\big(T; q(\tau, I), \mathbf{X}\big) + \tau V_F(T).$$

The left-hand side of equation (2) is the marginal benefit of waiting a moment to develop a parcel of land. This is the sum of the benefits of an additional period of agricultural rent, the opportunity cost of capital for developing, the avoided taxes on the developed land, and the benefit that waiting a period to develop could have on rental rates (i.e., if rental rates are growing over time, then postponing development could bring a higher stream of rents in the future).

The right-hand side of (2) is the lost opportunity of waiting to develop, including foregone rent on developed property and the taxes paid on agricultural land. Anything raising rental rates increases the marginal opportunity costs of waiting to develop, and should increase the rate of development. However, raising rental rates increases future tax burdens, which also raises the marginal benefits of waiting to develop.[2] Thus, the effects of raising tax rates or changing industrial density are likely to be uncertain, as they depend on the relative strengths of changes in $R(T; q(\tau, I), \mathbf{X})$ and

$$\tau \int_{T}^{\infty} R\big(u; q(\tau, I), \mathbf{X}\big)e^{-(r+\tau)(u-T)}\,du.$$

Here, we explore more closely the influence of the industrial density variable on development timing. Results on taxes are uncertain, as in other studies (Anderson, 1986; McFarlane, 1999). To measure the effect of a change in industrial density on development timing, we assess the sign of $(-V_{TI}/V_{TT})$. Note, because V_{TT} is negative at the optimal development time, we need to sign V_{TI}:

$$(3)\quad V_{TI} = \tau \int_{T}^{\infty} R_I\big(u; q(\tau, I), \mathbf{X}\big)e^{-(r+\tau)(u-T)}\,du + \int_{T}^{\infty} R_{TI}\big(u; q(\tau, I), \mathbf{X}\big)e^{-(r+\tau)(u-T)}\,du - R_I.$$

If V_{TI} is positive, additional industrial land will slow development, while if it is negative, additional industrial land will speed development. As noted above, increasing industrial land density could have positive or negative effects on land rental rates. Assuming small amounts of industrial land provide improved public services so that $R_I \geq 0$, an increase in industrial development would speed up development if:

$$(4)\quad R_I \geq \tau \int_{T}^{\infty} R_I\big(u; q(\tau, I), \mathbf{X}\big)e^{-(r+\tau)(u-T)}\,du + \int_{T}^{\infty} R_{TI}\big(u; q(\tau, I), \mathbf{X}\big)e^{-(r+\tau)(u-T)}\,du.$$

Thus, if the increase in rental rates in a region outweighs the additional taxes raised on residences due to higher land valuations, more industrial land will speed up development. In contrast, if the density of industrial development is high initially, or if properties are located too close to industrial land, and $R_I \leq 0$, then additional industrial land could slow development.

The Data

To explore the potential effects of changing tax rates and zoning policies on land conversion timing, we use parcel-level data on land conversions in Delaware County, Ohio, over the period 1988–1998. Delaware County is one of the fastest growing counties in Ohio and the United States. Although the county remains predominately agricultural in terms of land use, the population grew rapidly during the study period. The study region is adjacent to

[2] For undeveloped land, we assume developed rental rates grow smoothly from a level lower than agricultural rental rates initially. Industrial development, however, can have both positive and negative effects on residential development values. We therefore assume residential development occurs at the first point at which the condition in equation (2) is met, and development is irreversible.

Table 1. Land Conversion, Delaware County, Ohio (1988–1998)

Change from Agricultural to:	No. of Parcels	Mean Days to Conversion	Std. Error Days	Total Acres	Mean Lot Size (acres)
Industrial	93	2,434.87	1,044.91	841	9.04
Commercial	209	2,690.67	1,303.96	1,324	6.33
Residential	8,843	2,759.67	979.42	18,006	2.03
No Change	5,843	—	—	167,876	28.76

and north of the metropolitan area of Columbus, Ohio, and the Columbus outerbelt skirts the southern boundary of the county. For the most part, the county is relatively flat, but has a number of interesting human and natural geological and environmental features which likely affect development patterns. The City of Delaware is the largest population center in the county, centrally situated and approximately 12 miles from the county's southern boundary. There are four large water supply reservoirs in the county that service residents in the entire central Ohio region, and a large state park surrounds the northernmost reservoir. In addition, two major interstates and two major rivers run north-to-south through the county.

The data for this analysis consist of 14,988 parcels strictly classified as being in agricultural use in June 1988, as recorded by the Delaware County Auditor. Additional information on any parcels that transacted between June 1998 and July 1998 was also obtained from the auditor's data and was used to track changes in land use classification. For our survival analysis, a variable was included to measure the number of days from the beginning of 1988 until either the time of the transaction in which the land use changed or the end of the observation period.

A difficulty with using survival analysis for land development is that each data point starts out with large plots of agricultural land under one owner, subsequently dividing into many smaller lots under different owners. One strategy for addressing this problem is to define the unit of observation prospectively so that when a large plot changes into many smaller ones, it is considered to be the loss of one lot. However, anecdotal evidence suggests farmers may sell part of an agricultural plot for residential or other nonagricultural use, while retaining some portion of the land in agriculture. Consequently, a retrospective treatment of the data may be applicable. Specifically, each plot that moves to nonagricultural use is counted as an individual loss, resulting in a larger number of conversions than would be obtained using the prospective method. The retrospective method is used in this analysis.

From the data, 167,876 acres of land were in agricultural use in 1988—predominantly row crops such as corn and soybeans. Of these, 20,171 acres had been converted to other uses by 1998. Significantly more land converted to residential than to other uses (table 1), and the average sizes of lots converting to industrial and commercial uses were over three times the size of lots converting to residential use. In terms of mean conversion time, average industrial conversion precedes residential conversion in the county by nearly a year (324.8 days), and precedes commercial conversion by about 8.5 months on average. Without taking into account spatial factors, this pattern of change shows industrial development precedes both commercial and residential development in Delaware County.

Distances of each parcel to a range of environmental, neighborhood, and infrastructure characteristics were measured using Geographic Information Systems (GIS). Given the wide range of factors likely to influence development patterns, we include a large number of control variables in the analysis, namely: proximity to infrastructure (roads, highways, exit ramps, sewer lines, transmission lines, etc.), proximity to the central city and fringe job centers, and land quality (slope). Table 2 presents the variables used in the analysis, and reports their corresponding means and standard errors.

To assess the impacts of property tax rates and zoning policies on land use change timing, we focus on regions within the county having the same marginal tax rates and public services for each resident. There are two primary types of property taxes: those funding local infrastructure (police, fire, streets, etc.), and those funding schools. In the study region, school districts cross over township and municipal boundaries, resulting in 49 districts with separate tax rates for schools or infrastructure. Tax rates for each of these districts are determined for the 1984–1998 period, allowing us to assess lagged tax impacts. The number of parcels in each

Table 2. Variables Used in the Analysis

Variable Name	Description	Mean [b]	Standard Error
SouthBnd$M	Log miles distance to Delaware County southern boundary	1.139	0.904
Delaware$M	Log miles distance to Delaware City center	2.090	0.616
Road$M	Log miles distance to nearest road	!3.005	1.101
Highway$M	Log miles distance to nearest major highway	0.815	0.974
TransLine$M	Log miles distance to nearest transmission line	!0.254	1.253
Water$M	Log miles distance to nearest water body	!1.883	1.305
Stream$M	Log miles distance to nearest stream	!0.808	1.042
School$M	Log miles distance to nearest school	0.471	0.884
Comm$M	Log miles distance to nearest commercial plot	!1.104	1.165
Industry$M	Log miles distance to nearest industrial plot	!0.002	1.005
Sewer$M	Log miles distance to nearest sewer line	0.257	1.825
RingMuni	Within one mile radius of city limits	0.303	0.460
SchoolQ	School quality as measured by test scores	75.318	6.273
Slope	Slope length of property	3.501	4.713
SchoolTax [a]	All school taxes within a tax district, lagged one year	38.506	9.661
InfraTax [a]	All taxes within a tax district except school, lagged one year	16.665	4.030
SchoolTax×Slope [a]	Lagged school taxes interacted with slope	134.918	198.158
AgLeftK [a]	Acres of agricultural land left per year, lagged one year	88.498	83.498
CapInt [a]	Per district total structure size divided by lot size, lagged one year	0.072	0.091
%CnvRes [a]	Per district annual % agricultural land converted to residential, lagged one year	0.892	0.218
%CnvCom [a]	Per district annual % agricultural land converted to commercial, lagged one year	0.072	0.170
%CnvInd [a]	Per district annual % agricultural land converted to industrial, lagged one year	0.031	0.130
%Ind88	Percentage of industrial land per district in 1988	0.027	0.041
%Com88	Percentage of commercial land per district in 1988	0.045	0.044
%Res88	Percentage of residential land per district in 1988	0.175	0.134

[a] Denotes time-varying variable.
[b] Mean values are based on $N = 14{,}988$ parcels in the Delaware County, Ohio, study area.

tax district ranges from 10 to 7,997, comprised of 25 to 18,900 acres each. Annual millage rates range from 0.82 to 64.16 for schools, and 10.40 to 79.88 for infrastructure.

Because it is difficult, if not impossible, to introduce every zoning decision into our model, we assume that the land use proportions which emerge in each taxing district reflect zoning decisions. For example, the decision to allow more land to be zoned industrial in a given region will result in larger proportions of industrial uses in that region. To control for zoning decisions made before 1988, we calculate the percentage of land per tax district in agricultural, residential, commercial, and industrial uses in effect in 1988 (*%Ag88*, *%Res88*, *%Com88*, and *%Ind88*, respectively). To control for decisions made throughout the analysis period, annual agricultural land converted to residential, commercial, and industrial acres is calculated as a percentage of available land in a district (*%CnvRes*, *%CnvCom*, and *%CnvInd*, respectively), lagged by one year.

Note that zoning decisions are made by municipalities or the county. Because of the way we model the tax districts, each tax district has a single entity in charge of zoning, so that zoning decisions are consistent within the tax district. Zoning decisions, of course, can also be similar across different tax districts if they fall under the same zoning authority.

Zoning laws can also affect the density of development. As above, density regulations are only observed after land use decisions have been made. That is, we do not observe whether zoning boards have required developers to increase or decrease their building density relative to their initial proposals. However, we do observe different densities across the county, which likely reflect zoning decisions. These densities may also reflect economic decisions, as argued by McFarlane (1999). To control for both of these important factors, we have included lagged capital intensity (*CapInt*) per district, the total size of structures divided by total of lot sizes per district.

Survival Model Analysis

Survival models are a standard approach for modeling the distribution of survival times until a particular event occurs (Lawless, 1982). The competing risks method employed here recognizes that once a given event takes place, it will preclude other events from taking place, capturing the irreversibility of land use change decisions. For example, once a change has occurred from agricultural to industrial use, that particular piece of land can no longer change from agricultural to commercial use. This causes a specific type of censoring which is characteristic of competing risks.

Starting at time 0, we are interested in the length of time a parcel remains in agriculture. We employ both a nonparametric model and a parametric accelerated failure time (AFT) survival model to investigate the timing of a land conversion. AFT is applicable for the land use situation where covariates are likely to accelerate or deccelerate survival time. For the AFT analysis, we assume conversion decisions relate to land rental values, which are explained by zoning (type of land use and capital intensity in a taxing district), local school and infrastructure taxes, and other spatial factors, such as existing infrastructure and public goods.

In survival analysis, the time at which an event occurs is a random variable, denoted by T, and estimating the distribution of T is the goal of the statistical modeling. The cumulative distribution function of the random variable is denoted by $F(t) = \Pr(T \le t)$, where $F(t)$ is the probability an event T occurs on or before time t. The survivor function models survival time, given by $S(t) = \Pr(T > t) = 1 - F(t)$, which is interpreted as being the unconditional probability of survival beyond time t. In this analysis, $S(t)$ is interpreted as the probability that agricultural land can survive forces which would cause its change to other uses.

Nonparametric analysis of the data can be informative. Of particular interest here is the hazard function, $\lambda(t)$, which quantifies the instantaneous probability of an event taking place at time t, conditioned on the probability of survival through time t. The hazard function is defined by

$$\lambda(t) = \lim_{\Delta t \to 0} \frac{\Pr(t \le T < t + \Delta t)}{\Delta t} \text{ or } \frac{F'(t)}{S(t)}.$$

The importance of the hazard function in this analysis is that it recognizes conversion risk only for those properties which have not yet converted at a given point in time.

Nonparametric hazard functions generated using the actuarial, or life table method,[3] are presented graphically in figure 1. As shown by figure 1, agricultural land was at risk from industrial development earlier in the period, and residential development risk increased dramatically near the end of the period (at about 3,250 days). The industrial hazard curve shows a spike between 1,000 and 2,000 days, suggesting industrial development peaked early and was followed by more intensive residential and commercial development. Wilcoxen and log-rank test statistics indicate there is a significant (at the 99%+ level) difference in the hazard rates for the three types of development.

To estimate the parametric model, we adopt a multivariate Weibull AFT model. The Weibull distribution is a variant of the exponential distribution in which $T_i = \exp(\mathbf{Z}_i'\boldsymbol{\beta}) \times \sigma g_i$. When the above model is linearized by taking logarithms, it is written as $\ln(T_i) = \mathbf{Z}_i'\boldsymbol{\beta} + \eta_i$, where $\eta_i = \ln(\sigma g_i)$ and follows a Gumbel or extreme value distribution. That is, $\eta_i \sim G(0, \sigma)$ with $f(\eta_i) = \exp[\eta_i - \exp(\eta_i)]$ and survivor function $S(\eta_i) = \exp[-\exp(\eta_i)]$. The corresponding expressions for η_i as a function of failure time (T_i), the covariates ($\mathbf{Z}_i$), and the parameters ($\boldsymbol{\beta}$) are therefore written as:

$$(5) \quad f\big(\ln(T_i), \boldsymbol{\beta}, \mathbf{Z}_i\big) = \exp\left[\left(\frac{\big(\ln(T_i) - \mathbf{Z}_i'\boldsymbol{\beta}\big)}{\sigma}\right) - \exp\left(\frac{\big(\ln(T_i) - \mathbf{Z}_i'\boldsymbol{\beta}\big)}{\sigma}\right)\right]$$

and

$$(6) \quad S\big(\ln(T_i), \boldsymbol{\beta}, \mathbf{Z}_i\big) = \exp\left[-\exp\left(\frac{\big(\ln(T_i) - \mathbf{Z}_i'\boldsymbol{\beta}\big)}{\sigma}\right)\right].$$

One model is estimated for each category of land conversion, while accounting for censored observations.

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[3] In the actuarial method, $\lambda(t)$ is given by $2\hat{q}_i/[(t_i - t_{i-1})(1 + \hat{p})_i]$, where $\hat{p}_i$ is the probability of surviving through the ith time period, and $\hat{q}_i$ is $1 - \hat{p}_i$. Further, censoring during a time interval is assumed to take place at the interval's midpoint (see Lawless, 1982).

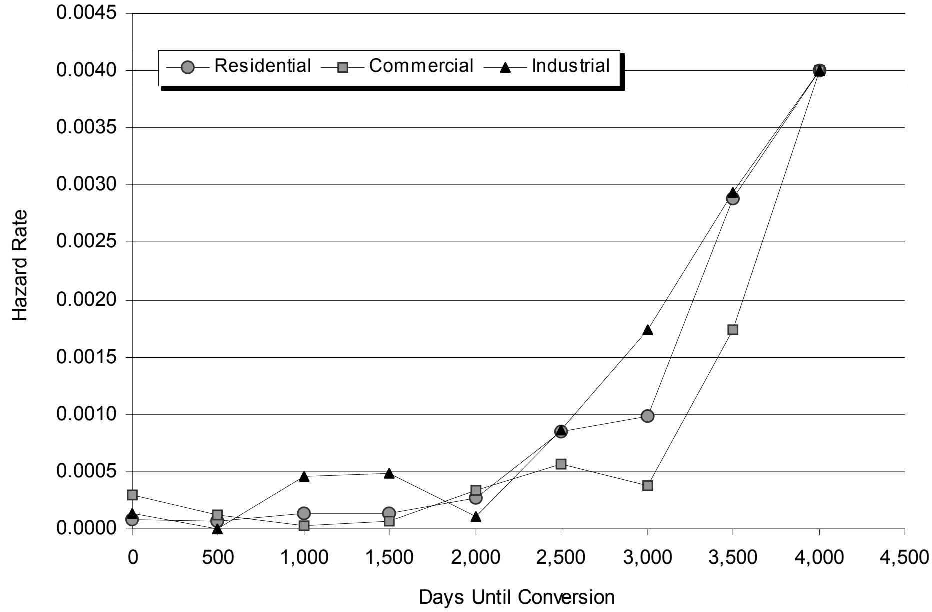

Figure 1. Nonparametric hazard functions

For example, the residential model estimates time to residential use conversion, while accounting for observations censored because of land converting to commercial and industrial use during the observation period, or because the land remained in agriculture throughout. Thus, for the residential conversion category, a log-likelihood function of the following form is estimated:

$$(7)\qquad \ln L(\boldsymbol{\beta}) = \sum_{i \in D} \ln\left[f\left(\ln(T_i), \boldsymbol{\beta}, \mathbf{Z}_i\right)\right] + \sum_{i \in C} \ln\left[S\left(\ln(T_i), \boldsymbol{\beta}, \mathbf{Z}_i\right)\right],$$

where D denotes the set of properties converting to residential use during the time period, and C represents the set of properties remaining in agriculture or converted to industrial and commercial use during the observation period. Analogous likelihood functions are estimated for the industrial and commercial conversion models.

Parametric AFT Model Results

The residential, commercial, and industrial changes are estimated using Weibull econometric models, where each plot is weighted by acre (reported in table 3). Negative coefficients represent factors correlated with earlier conversion times in our sample, while positive coefficients are variables correlated with later conversion times.

Of the policy variables (school or infrastructure tax rates and zoning), only the lagged values of school (*SchoolTax*) and infrastructure tax rates (*InfraTax*) consistently lengthen development timing in all three land uses (residential, commercial, and industrial). Although the theoretical model provides no guidance for tax effects, the empirical analysis for our region suggests high-tax districts developed later than low-tax districts. School taxes have the effect of slowing commercial and industrial conversion relative to infrastructure taxes. Higher school tax rates slow residential conversion, even more so on hillier land, as indicated by the sign of *SchoolTax* × *Slope*. This finding suggests higher tax rates have less effect on slowing residential development on flatter land which is more susceptible to development into large subdivisions. The fact that school taxes are fairly ineffective in slowing residential development may indicate higher school taxes improve school quality—raising residential rental values, and thus partly offsetting the tendency of taxes to slow development.

To assess the influence of zoning, variables reflecting the outcomes of past zoning decisions are considered, namely the variables indicating the percentage of land in different uses for the tax districts. In the residential equation, the *%Ind88* coefficient is larger than that of *%Res88* in absolute terms, suggesting residential development occurred earlier in regions with higher initial industrial density.

Table 3. Residential, Commercial, and Industrial Change Models, Weighted by Acres

	Residential Change		Commercial Change		Industrial Change	
Variable	Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error
Intercept	4.957***	0.189	3.635***	0.473	8.288***	0.691
Stream$M	0.081***	0.005	—	—	—	—
Delaware$M	0.521***	0.017	0.104**	0.041	0.233***	0.037
Road$M	0.267***	0.005	—	—	—	—
Highway$M	—	—	0.342***	0.016	0.150***	0.017
SouthBnd$M	—	—	0.251***	0.031	!0.030	0.064
TransLine$M	!0.037**	0.005	0.070***	0.013	0.031*	0.016
Water$M	0.154***	0.005	0.017	0.018	0.058***	0.018
School$M	!0.075**	0.010	!0.135***	0.036	—	—
Comm$M	0.107***	0.006	0.527***	0.017	!0.155***	0.018
Industry$M	!0.251***	0.010	0.278***	0.018	0.458***	0.026
Sewer$M	0.156***	0.006	0.077***	0.016	0.137***	0.023
RingMuni	0.041***	0.014	0.339***	0.047	0.235***	0.047
InfraTax	0.369***	0.004	0.080***	0.005	0.044***	0.005
SchoolTax	0.040***	0.001	0.107***	0.004	0.076***	0.005
SchoolQ	!0.018***	0.002	0.032***	0.006	0.249	0.012
Slope	!0.028***	0.005	0.072***	0.028	0.045	0.031
SchoolTax×Slope	0.000***	0.000	!0.002***	0.001	!0.000	0.001
AgLeftK	!0.003***	0.000	!0.003***	0.000	0.000	0.000
CapInt	!3.414***	0.059	!2.524***	0.267	!2.993***	0.204
%Ind88	!9.428***	0.375	!3.403***	0.785	!6.808***	1.436
%Com88	22.992***	0.441	!1.761*	0.980	!3.792**	1.622
%Res88	!6.679***	0.085	!2.805***	0.245	0.991*	0.510
%CnvRes	!0.802***	0.112	0.816***	0.131	!1.098***	0.190
%CnvCom	0.140	0.121	!0.363***	0.138	—	—
%CnvInd	!0.655***	0.129	1.786***	0.208	!0.760***	0.199
Scale	0.689***	0.005	0.536***	0.013	0.249***	0.012
Weibull Shape	1.451***	0.010	2.120***	0.131	4.991***	0.704
	LnL = !55,415, χ^2 = 42,385		LnL = !3,502, χ^2 = 11,411		LnL = !633, χ^2 = 11,088	

Notes: *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively; *N* = 14,988 parcels. Negative coefficients represent factors correlated with earlier conversion times in the sample, while variables with positive coefficients are correlated with later conversion times.

Over the 1988–1998 time period studied here, the impact of these two variables changes—i.e., the absolute value of the *%CnvRes* coefficient is greater than that of *%CnvInd*. Industrial development during the time period is still correlated with earlier conversion to residential use, but too much industrial development may ultimately cause negative externalities. This is supported by the negative sign on *Industry$M*, which indicates there could be negative externalities associated with living too close to industrial developments.

Given the theoretical results, it is of interest to assess the relationship between industrial density and residential development timing more closely. In particular, we find that a 1% increase in industrial development density (*%Ind88*) would have its maximum effect on residential development timing when approximately 10% of the land is in industrial uses. Thus, for all tax districts with less than 1% of land in industrial uses, a 1% increase in industrial development reduces the survival probability of remaining agricultural land by 0.40%. For tax districts with 1% to 10% of land in industrial uses, the survival probability is reduced by 0.51%, and for tax districts with more than 10% of land in industrial uses, the survival probability is reduced by 0.43%.

Initial commercial development density, *%Com88*, is positive and strongly significant in the residential equation, revealing that residential development during the period initially occurred away from areas of heaviest commercial development. The variable *%CnvCom* is also positive in the residential equation, but insignificant, suggesting this relationship weakens. Commercial development, at least in our study region, appears to follow industrial and residential development. In the commercial equation, the signs on all three initial land use variables are negative, with *%Ind88* being the largest in absolute terms, followed by *%Res88* and *%Com88*. Thus, the earliest commercial developments occurred where industrial or residential development were already greatest. Commercial development occurred later in regions where residential and industrial development during the period of analysis were strongest, as indicated by the positive signs of *%CnvRes* and *%CnvInd* in the commercial equation. From the analysis of marginal survival probabilities, a 1% increase in residential development within a tax district does not begin to speed commercial development until residential uses rise above 32% of local land uses.

At least initially, it appears industrial development occurred away from the most heavily developed residential regions in the county. The negative sign on *%CnvRes* in the industrial equation, however, suggests conversion to industrial use during the study period occurred earlier in regions experiencing relatively larger losses of land to residential uses. This finding is surprising, although it potentially reflects the long time lags associated with industrial development projects. It also indicates that regions experiencing relatively larger losses of land to residential uses were likewise prone to relatively larger losses of land to industrial uses.

Turning to the control variables (table 3), the slope of a lot (*Slope*) speeds residential development, slows commercial development, and has no impact on the rate of industrial development. Commercial development occurred earlier on better agricultural land, while residential development occurred earlier on sloped land less suitable for agricultural uses. Land further from electrical transmission lines developed into residential uses earlier, while land closer to transmission lines developed into commercial or industrial uses sooner. Distance from water bodies had the opposite effect on development timing for all three uses (although insignificant for commercial), suggesting residential land nearer to lakes and streams is more desirable for residential development.

Total agricultural land in a district during the previous year (*AgLeftK*) has a small, negative effect on the timing of residential and commercial development, but does not have an impact upon speed of conversion to industrial use. This result is consistent with development patterns for land within one mile of municipal boundaries (*RingMuni*). Land close to municipalities is found to develop more slowly than other land in the sample, indicating land is held speculatively in agricultural use at the urban-rural fringe. Interestingly, this effect is largest for commercial and industrial developments, i.e., they are shifting away from incorporated areas, as found by Fujita, Thisse, and Zenou (1997).

Finally, lagged capital intensity (*CapInt*) within a tax district is shown to significantly increase the rate of conversion to all three types of land use, with the largest impact on rate of conversion to residential use. Note that this variable is highly correlated with the value of developed land, and thus should have a negative sign as predicted by our theoretical model.

Policy Analysis

An unweighted residential model of an otherwise identical specification to the acre-weighted model is estimated and used to examine the effects of policy changes on residential conversion time.[4] The unweighted model parameters are similar in sign to those in the weighted model, although the estimates are more highly significant in the weighted model. For the sake of brevity, the unweighted model is not presented here.

Using the unweighted model, seven potential policy actions are examined including tax changes and zoning changes. These policy actions are: (*a*) a 20% increase in school taxes for each taxing district $(\{SchoolTax + SchoolTax \times Slope\}(1.20)$; (*b*) a 20% increase in infrastructure taxes $(InfraTax(1.20)$; (*c*) a 20% increase in all taxes; (*d*) a law that reduces capital intensity by 20% $(CapInt(0.80)$, a proxy for lot size zoning restrictions; (*e*) a 20 % decrease in annual residential growth $(\%CnvRes(0.80)$; (*f*) a 20% decrease in annual industrial growth; and

[4] The reason for using the unweighted model is that interpretation of weighted model predictions is difficult. Further, the type of analysis performed here cannot be used accurately with the industrial and commercial models because the heavy censoring causes inaccurate prediction times (Allison, 1995). Results for the unweighted model are available from the authors upon request.

Table 4. Policy Simulations: Predicted Days to Conversion

A. ALL LAND (N = 14,988 parcels)

Policy Action Scenario		Median Days	Mean Days	Std. Error Mean
	Baseline	***3,847.99***	***6,836.10***	***411.22***
(a)	8 School Tax 0.2	4,274.08	7,300.25	411.96
(b)	8 Infrastructure Tax 0.2	5,216.97	18,370.49	1,969.58
(c)	8 All Tax 0.2	5,838.23	19,040.81	1,973.52
(d)	9 Capital Intensity 0.2	4,172.22	7,280.48	436.23
(e)	9 Residential Development 0.2	3,995.41	7,041.44	413.67
(f)	9 Industrial Development 0.2	3,874.01	6,892.44	419.70
(g)	9 Residential + Industrial Development 0.2	4,025.90	7,097.94	422.12

B. UNCONVERTED AG LAND IN 1998 (N = 5,678 parcels) – Adjusted t_0 = January 1998

Policy Action Scenario		Median Days	Mean Days	Std. Error Mean
	Baseline	***422.00***	***6,061.64***	***982.97***
(a)	8 School Tax 0.2	947.16	6,666.56	984.56
(b)	8 Infrastructure Tax 0.2	2,478.77	28,423.19	4,712.79
(c)	8 All Tax 0.2	3,205.82	29,321.09	4,722.03
(d)	9 Capital Intensity 0.2	477.68	6,261.49	1,014.32
(e)	9 Residential Development 0.2	667.32	6,314.23	983.77
(f)	9 Industrial Development 0.2	430.28	6,188.32	1,005.79
(g)	9 Residential + Industrial Development 0.2	669.68	6,441.10	1,006.62

Note: Arrows (8, 9) denote tax increases and decreases, respectively.

(*g*) a 20% decrease in growth of combined residential and industrial development types.

While we cannot specifically test how zoning decisions affect development, these scenarios can provide an indication about how changes in zoning policies would affect subsequent development. Note, the results show that a policy on commercial development would have little or no effect, because commercial development in our study occurs after residential or industrial development.

Table 4 (panel A) reports the results of policy analyses for all residential plots in the sample, as well as for just those parcels remaining in agricultural use in 1998 (panel B). Predicted survival times for parcels remaining in agricultural use were adjusted to reflect the predicted number of days until conversion after January 1, 1998.

It is difficult to assess the relative effects of all the policies because we have not attempted to measure whether the policies imply similar economic costs on society. The 20% changes in taxes do imply similar changes in tax payments per dollar of investment, however, so the tax policies in scenarios (*a*)–(*c*) can be compared.

As expected, infrastructure tax increases (scenario *b*) have a larger effect on residential development times than school tax increases (scenario *a*). If school taxes were raised by 20% for all districts, the median days to conversion would increase by about 11% or 14 months (4,274.08 versus the 3,847.99 baseline median days) for the full sample, and by about 10% or 17 months for the parcels that had not yet converted in 1998. An increase in infrastructure taxes lengthens residential conversion time more, 3.8 years for the full sample and 5.7 years for the unconverted parcels. A combined increase in school and infrastructure taxes does not result in a proportional increase in days to conversion.

The analysis does not allow for realistic within-sample predictions for capital intensity, because minimum lot size restrictions would be applied differentially throughout the sample (i.e., lot size restrictions would not be applied in percentage terms as in our analysis). Nevertheless, by comparing predicted days to conversion for the policy actions to those predicted by the baseline, such simulations can illustrate relative impacts among the restrictive zoning policies (i.e., capital intensity and growth restrictions). For the full sample, a 20% capital intensity reduction would be the zoning change most effective in slowing growth (4,172.22 median days to conversion) as compared to residential and industrial restrictions (3,995.41 and 3,874.01, respectively) and 3,847.99 baseline median days. Of the 1998 unconverted agriculture land, however, a restriction on all types of development would slow median time to development to about 1.8 years, as opposed to capital intensity restrictions (1.22 years).

Discussion and Conclusions

This paper explores how taxes and zoning affect the timing of land use change decisions at the urban-rural fringe. A theoretical model suggests changes in property tax rates and zoning policies can have positive or negative effects on the timing of land conversion from agricultural to residential, commercial, or industrial uses. While higher property tax rates reduce land values and should slow land use change, they could speed land use change if they increase public services and make some locations more attractive for development, such as with taxes specifically designated for schools.

Zoning in the theoretical model focuses on the decisions communities make to allow industrial or commercial development to occur in specific regions, and what effect this has on the timing of subsequent residential, industrial, or commercial development. The model shows that industrial development density can have positive or negative effects on development timing, depending on how this density influences local public service flows. For example, industrial development can have negative externalities and slow development on nearby properties, but it also may speed residential conversion by raising tax revenues for local jurisdictions and increasing the overall level of public services provided.

A competing risks survival model is developed and estimated to investigate how a number of different variables influenced development timing of residential, commercial, and industrial land in a rapidly growing county of the Midwest (Delaware County, Ohio) from 1988 to 1998. Both nonparametric and parametric results are reported.

Our empirical framework, while informative, has two important limitations. First, the coefficients in the parametric model cannot be specifically identified. The estimated models, however, do show how tax or zoning policies potentially affect development timing within Delaware County. Second, we do not monitor individual zoning decisions for each parcel, but assuming zoning decisions are relatively uniform across different taxing regions, we assess the impact of zoning policies on commercial, industrial, or residential land uses by assuming the development that does occur reflects local public policy on important zoning decisions.

While the theoretical results on the effects of taxes on development timing are unclear, the empirical results reveal higher property tax rates slow development timing. The most important effect of a change in the property tax rate, such as through a referendum, appears to occur through the capitalization of tax rates into land values, rather than through the direct change in annual property taxes paid. Still, not all taxes are created equal, as changes in infrastructure taxes have a stronger effect on residential conversion than changes in school taxes. The opposite results hold for industrial and commercial developments. Localities that raise infrastructure taxes are likely to observe less rapid residential development in the future, although they could experience more rapid conversion to commercial or industrial development.

As for zoning, policies at the urban-rural fringe designed to restrict residential development, such as minimum lot size restrictions, could enhance the likelihood of industrial sitings in the future. Industrial development in our data initially occurred in regions with high proportions of existing industrial and commercial development and low residential development density. There are several explanations for this result. First, regions with a high proportion of residential landowners likely developed zoning restrictions which precluded industrial developments. Second, these regions also tend to have tax policies favoring school taxes, and thus deterring industrial development. Third, following Fujita, Thisse, and Zenou (1997), it is possible that land values become too high in residential areas for industrial development. Finally, residents in rural areas may have less bargaining power in keeping industrial sites from locating nearby.[5]

Alternatively, zoning policies designed to restrict industrial development can have both positive and negative influences on the timing of residential development. While proximity to industrial locations appears to slow residential development timing, within the time frame of this study, residential development timing occurred more quickly in regions with high initial industrial development as well as in regions with large losses to industrial development over time. Based on our findings, the marginal effect of a small increase in industrial development

[5] We thank Stephen Swallow for bringing this point to our attention.

density has its largest effect at approximately 10% industrial density. Thus, regions with less than 10% industrial density that zone for additional industrial development may not only face decreased levels of environmental amenities, but also increasing development pressure.

Unlike industrial development, commercial development follows residential development, a finding that emerges in both the nonparametric and the parametric results. Commercial development becomes most prevalent after the percentage of residential land in a district surpasses about 32%. This makes sense if commercial developments—such as shopping malls, grocery stores, and gas stations—require fairly intense nearby residential development to be profitable.

From our simulations, tax policies are shown to have a stronger influence on development timing than zoning policies. Furthermore, infrastructure taxes have a larger effect on residential timing than school taxes, possibly because school quality is important in many residential location decisions, and higher school taxes could imply better school quality. For the zoning policies, lot size restrictions appear to be more effective at slowing residential development than policies aimed at limiting specific types of development, although this result depends critically on initial capital intensity. For example, when just the remaining agricultural land is considered, lot size restrictions are much less effective because most unconverted parcels are in regions already characterized by low capital intensity.

Clearly, one of the main limitations of this analysis is that our measures of zoning are relatively primitive. Specifically, we do not measure actual zoning decisions, but instead consider how taxing regions set policies across parcels. The results are nonetheless instructive in showing the interactions among industrial, residential, and commercial development. These results may be useful for policy decisions faced by cities at the urban-rural fringe as they grow. For example, not only does industrial development appear to precede residential development, it appears to occur simultaneously with residential development, at least up to a certain density of industrial development (in our model, 10%).

Undeveloped regions that promote industrial development are likely to see future residential development. On the other hand, commercial development follows residential and industrial development, and it appears to peak at about 32% residential density. As residential development occurs, planners need to recognize that commercial development will follow, and they should begin formulating plans for such development far in advance.

Of course, we acknowledge these are fairly coarse results, and that many important zoning decisions (e.g., lot size restrictions, septic systems) are likely to occur at a finer level than explored in this study. Further data collection on changes in zoning laws, variances, and so on, over the time period could provide more detailed information on the spatial effect of zoning.

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