A Race to Develop: A Competing Risk Examination of the Pattern and Timing of Land Development in an Exurban County

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Abstract: Rural-urban fringe counties (i.e. counties adjacent to other counties with large and growing urban centers) often experience intense development pressure as a result of urban growth and expansion. While growth-initiated development can take many forms, the majority of the development that occurs in these exurban counties is in the form of single-family residential dwellings. Moreover, it is in the form of subdivision developments that range in size from very small two and three lot minor subdivisions to massive multi-phase major subdivisions with hundreds of lots and numerous amenities. In this paper, we focus on the land development patterns in Carroll County, MD, an urban-fringe county in the Baltimore-Washington D.C. metro region. The purpose of this paper is to explore whether a basic set of factors, both constant and time-dependent and acting at different spatial scales, can explain the timing and location of major versus minor subdivision developments in Carroll County. Using a micro-level panel of land parcel conversion, historical land records for subdivision development and ArcGIS software a new dataset was created that traces the entire history of the subdivision process in the county. Datasets were also created that trace the history of land preservation so that we could control for official open space and its interaction with the decision to subdivide through time. Using these data and a number of land use variables created from them from 1993-2007, we apply a competing risks duration model to analyze which factors affect major versus minor subdivision development. Visual inspection as well as a descriptive analysis of a series of landscape metrics based on distance from the metropolitan center reveals a different pattern outcome for small versus large subdivisions with larger developments following more closely to the predictions of the urban economic model. Empirically, we find further evidence that the factors affecting the timing of minor versus major subdivision developments are indeed different. Distance and access to road networks have less of an effect on minor over major developments, while surrounding preservation and the option to preserve have less of an effect on major subdivisions. To make the risk comparison relevant and to focus on areas that have experienced the most fragmentation as a result of residential land conversion as well as the most policy attention, we restrict our analysis to parcels located in minimum density zoning districts.

1. Introduction

As urban areas throughout the U.S. have grown, large tracts of undeveloped lands located at the urban fringe and beyond have been rapidly converted to different developed uses. Most land use development patterns within growing urban-rural fringe areas in the U.S. are, to some extent, characterized by low-density, non-contiguous development patterns called "sprawl" (Brown et al. 2005, Burchfield et al. 2006). Recent empirical support has shown that the areas in the US designated as exurban are now larger than both the suburban and urban areas combined (Heimlich and Anderson 2001). This evidence, combined with the fact that the majority of the US population lives in either an urban or suburban area and that land use conversions in exurban areas far exceed the rate of population growth, indicate that exurban expansion and the resultant landscape change may be the result of a limited number of decisions by individuals choosing to live in those areas (Nechyba and Walsh 2004)[1].

While numerous theories have been proposed to explain the processes leading to urban expansion and the ensuing patterns at the urban fringe (Anas et al. 1998), there is still much debate among economists and policy makers about the most important factors (market forces and policy) influencing the land use patterns observed beyond the urban fringe. The answers become even more ambiguous and difficult to establish when land owners in these areas face more than one development option. In this latter case, a comprehensive examination of exurban pattern requires understanding not only the factors affecting the optimal time for an individual land owner to convert their undeveloped parcel, but also understanding what type of development they choose in the presence of multiple options. Moreover, if these options have been imposed by policy, it is important for local officials to understand not only how the traditional market forces of preference and profit maximization have influenced the resultant land use patterns, but also how the policies put in place to address urban expansion have interacted with these market forces to influence the timing, type and pattern of development.

While owners of undeveloped rural land parcels often face a number of different development options (commercial, residential and preservation), in most exurban areas the dominant land conversion type is residential. Moreover, the residential development category often subsumes a number of additional conversion types. One of the most popular policy-lead development options is the choice between major and minor subdivision development[2]. Given this distinction, it is clear that the relevant question is no longer just one of optimal timing of development, but also includes the type of residential subdivision development chosen by the land owner. If the option to preserve a parcel exists as well, then this provides yet another conversion decision[3].

If researchers and policy makers are going to fully understand observed rural land use patterns, it is imperative that they account for all available development options open to the land owner at

[1] Since 1950 the U.S. has seen the pull of the central city diminish with urban populations falling from 65% in 1950 to around 35% in 1990 with corresponding gains for suburban areas (Nechyba and Walsh 2004).

[2] While size restrictions vary, in most cases minor developments restrict the number of buildable lots to 3, 4 or 5 with major developments being anything larger than this. In addition, minor developments also have a less rigorous planning and approval process.

[3] Farmland preservation programs give owners of large agriculture parcels the option to forego their development rights in exchange for a per acre payment. Once the parcel is sold to the preservation program, the parcel is no longer available for residential development.

the time of development. In this paper, we are interested in the choice, by a land owner, to convert their undeveloped parcel to either a major or minor development and more specifically whether these two development options compete for residential development space, if the observed patterns are more scattered for one type of development choice versus the other and finally, if the factors influencing the type of conversion at the time of development are different between the two types of development. We also account for whether a parcel owner chooses to preserve their parcel but we do not specifically investigate this conversion decision in the present paper.

To test these hypotheses, we constructed a unique parcel-level panel dataset on major and minor subdivision development from Carroll County, Maryland, a rural-urban in the Baltimore-Washington, D.C. metro region. This dataset allowed us to determine not only the timing of the conversion event, but also the choice of development type. The primary distinction between the two types of subdivisions is the number of buildable lots allowed with majors comprising four or more buildable lots and minors less than four. There is a further distinction in that minor subdivisions do not require any roads or on-site infrastructure to be built and they can be approved by the Chairman of the Zoning Commission [without the formal hearing and platting process that is required of major subdivisions] (Carroll County Planning Commission).

Subdivision development has played a major role is land use conversion in Carroll county and in the observed patterns of development over the landscape. Since 1990 Carroll County has had close to 18,000 parcel conversions on a total of 36,000 acres of land. Out of these, 95% where in some form of residential development and 85% were located in either a major or minor subdivision development. Subdivision development accounted for close to 16,000 acres of this development with minor subdivisions, although they account for a much smaller portion of the buildable lots, making up close to 3,500 acres. The average size for major developments during our study period was 80 acres and for minor developments it was 30 acres. Given the significant contribution of both types of subdivisions developments to land conversion, another important question is whether they follow the predictions of traditional urban growth models.

One of the main features of the urban monocentric model is a negative distance gradient from the city center. In order to compare our data with the predictions of urban bid-rent model, we created a series of historical land use maps using the dates of land conversion from the dataset. The maps were generated at five-year increments starting in 1980 and going through 2005. We then gridded up the landscape of the county in 2km by 2km windows, created raster maps for each period and calculated the percentage of each land use type in each window[4]. We also calculated the travel time from the centroid for each square to the two closet central business districts (CBD), Washington D.C and Baltimore Maryland. We then regressed the value for the

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[4] The metric for the percentage of landscape in each window is as follows: $P_i = \frac{\sum_{j=1}^{n} a_{ij}}{A} * 100$, where a_{ij} is the total area for one all patches of type i. For each window a similar metric was calculated for all land use types. The final dataset consisted of 1064 windows for 10 land use types but because we are only interested in the patterns as it relates to subdivision types and preservation we only report the output for these land use types. A number of other landscape metrics (mean patch size, number of patches, total edge contrast index and a clumpiness index) were conducted in addition to the percentage of land, but given the amount of data generated it was not feasible to include all of them in this paper. This exercise is merely descriptive in the present context and so we limit our presentation to percentage of the landscape metrics.

landscape percentage metric for each window on the window's value of the travel times. The results of this analysis are given in Table 1 and the scatter plots are in the appendix, Figure A1.

For the minor subdivision developments, the relationship with distance is quite weak although it does grow some over time. In addition, the distance to Baltimore City is negative; suggesting a negative gradient but the sign for Washington, D.C. is positive and only significant in the last two periods. For the major subdivision development, both distances show a negative distance gradient with a strong relationship, especially in the final two periods. The metric for the preservation has a positive relationship with Baltimore City and a negative one relative to D.C. with the relationship growing over the three periods. This is likely the result of the fact that the majority of the preservation that has taken place in the county over the last 25 years has been concentrated in the north-west and western portion of the county. These results provide some descriptive evidence that the factors affecting the minor development process may not be the same as those affecting the majors. The metric results for the percentage of major developments display a monocentric pattern, while the minor developments show some of the same signs but have a much weaker and even non-monocentric pattern in some years. Our empirical results confirm this descriptive result.

Table 1: Descriptive Metric Regressions

Year	Land Use	Intercept	Wash. D.C.	Balt. Cty	R-sqrd
1985					
	Percentage of Landscape				
	*Minor**	0.92**	0.52	-0.82**	0.004
		(0.26)	(0.35)	(0.37)	
	Major	32.00**	-6.56**	-23.33**	0.207
		(1.77)	(2.36)	(2.52)	
	Preserved	2.51**	-0.76	7.72**	0.006
		(2.42)	(3.22)	(3.44)	
1995					
	Percentage of Landscape				
	Minor	1.53**	1.64**	-2.12**	0.01
		(0.38)	(0.51)	(0.54)	
	Major	56.22**	-9.28**	-45.17**	0.34
		(2.28)	(3.03)	(3.24)	
	Preserved	-6.33**	-5.97	34.01**	0.08
		(3.04)	(4.04)	(4.32)	
2005					
	Percentage of Landscape				
	Minor	2.03**	2.47**	-3.15**	0.02
		(0.47)	(0.63)	(0.67)	
	Major	68.15**	-15.44**	-49.71**	0.37
		(2.57)	(3.42)	(3.65)	
	Preserved	-24.23**	-13.91**	80.96**	0.24
		(3.94)	(5.25)	(5.61)	

*These values were obtained by OLS by regressing percentage of landscape metrics on the distances to both Washington, D.C. and Baltimore City. The standard errors are given in parentheses.

Because the main focus of this paper is on the choice of development type at the time of conversion and whether the two types of development compete with one another, an empirical analysis is conducted using a competing risk survival analysis. This model allows us to investigate the timing of the development decision as well as the type of development and whether the two types of development decision respond to the same set of factors or whether they are driven by a different set of influences. A number of studies have used hazard models to study the timing of subdivision development (Irwin and Bockstael 2002, 2004; Town et al. 2008). Another used a competing risks framework to study the timing and type of zoning decision among residential, commercial and industrial development (Hite et al. 2003). To our knowledge, no studies have applied the competing risks framework to look at how major and minor subdivision choices interact.

Because we are most interested in explaining the non-contiguous patterns often observed outside of suburban areas, we restrict our analysis to subdivision events in either of the two most restrictive zoning regions – Conservation and Agriculture Districts[5]. In addition, this restriction allows for a better comparison of the risk of one type of development over the other as well as controlling for these decisions in presence of policies, such as preservation programs, that were designed to combat them.

The results from the competing risk model confirm the outcome of our descriptive metric analysis and provide at least some evidence that the factors influencing the decision to develop a major subdivision are different than those for a minor. Major developments follow much more closely the predictions of the monocentric model with distance from the CBD decreasing the likelihood of development; for the minor developments, the distance gradient is actually positive. In terms of surrounding land use, permanently preserved open space has a positive influence on the timing of minor development but has no effect on the timing of major development. While the two types of developments share some common traits, there appears to be a statistically significant difference between the two in a number of ways.

The paper is structured as follows. Section 2 gives a review of the literature, section 3 gives the basic theory, section 4 gives the empirical framework, section 5 explains the data construction and variables, section 6 gives the results and section 7 concludes.

2. Review of the Land Development Literature

2.1 Theory of Land Development

Much of the theoretical research on urban and rural form has focused on improving upon the basic urban monocentric model. Within the context of the monocentric, bid-rent model (Alonso, 1964; Muth, 1969; and Mills, 1967) increasing incomes, given that the income elasticity of land is large relative to the income elasticity of demand for transportation, induces households to substitute more land for proximity to the central business district (CBD). This leads to a declining density gradient and larger lot sizes as we move outward from the city center. When we combine this with a decline in transportation costs over time the result is that the bid-rent

[5] Current minimum-lot zoning has been in place since 1989 for Carroll. Thus, we take the zoning in these two districts as exogenous for our study period.

gradient declines along with the agglomerative effect of the CBD and the city expands[6]. The problem with this specification is that it fails to account for the durability of the structures being built, the irreversibility of the decision and consequently the dynamic aspects of the decision; the static model essentially assumes that the city is rebuilt in each period. Neither the history of the development process up to that point nor the expectations about the future play any role and so it cannot accurately capture much of the pattern we observe at the urban-rural fringe.

The solution too these issues was addressed with the development of dynamic urban growth models that included the notion of durability of housing [rather than malleability] and that included land owners with either myopic or perfect foresight.[7] By including an intertemporal decision making component, agents were forced to continually trade off the value of the immediate decision against that of all subsequent future decisions. These additions provided a much greater sense of realism in that now the agents could be considered ex ante efficient making the best choice given the information available at the time and their beliefs about all future information. These models helped move theory closer to capturing a number real world scenarios and general urban land use patterns.

In addition to these urban models, several other theoretical models looked specifically at the phenomenon of leapfrogging and mixed land use patterns and under what conditions it is rational and economically efficient to leave areas of land undeveloped (Ohls and Pines 1975; Mills 1981; Wheaton 1982; Turnbull 1988; and Braid 1988 and 1991). Ohls and Pines (1975), using a two-type, two-period model demonstrate how land can be withheld inside an urban area by simply accounting for differences in the way agents discount future costs and benefits. Mills (1981) extends the Ohls and Pines model and demonstrates how intertemporal decisions making on the part of the agent, even under risk neutrality and perfect foresight, can lead to leapfrogged development. Additionally, he includes uncertainty about future demand shocks and demonstrates how uniform uncertainty on the part of the agents can lead to a case where too much land is allocated and negative rents result; when expectations about future shocks are heterogeneous among the agents the result is an annulus with mixed development among different types. The model again shows that a discontinuous pattern of development is *ex ante* efficient.

While the monocentric model and its derivatives provide some evidence that reduced transportation costs and rising incomes are the primary causes of urban sprawl, there is some evidence that other effects also play an important role in explaining land use patterns. One of these hypotheses is based on Tiebout’s 1956 classic article of residential sorting. The article asserts that people sort themselves based on their preferences for the various public goods and amenities. The empirical evidence for Tiebout’s residential location choice model suggests that a person’s choice of residence can be negatively influenced by crime (“flight from blight”),

[6] See Glaeser et al. (2004) for an empirical explanation of how automobiles became the primary catalyst for sprawling cities. Wheaton (1974) gives a good comparative static review of the effect of rising incomes on city expansion and Margo (1992) and Brueckner (2000) give an empirical analysis of the effect of rising incomes on the urban sprawl.

[7] Anas (1978) is one of the first dynamic models with myopic foresight and Fujita (1976) and Arnott (1980) develop some of the first models to include perfect foresight into a dynamic urban framework. Also, Fujita and Ogawa (1982) develop a model of polycentric and multi-centric urban pattern development; Anas, Arnott, and Small (1998) provide an excellent overview of the evolution of all of the monocentric models and their derivatives.

congestion and local tax rates and positively affected by schools, local public amenities, local public policies and coordination failures or competition among local governments.[8]

Another closely-related hypothesis is based on local interactions and spillovers among agents whether they are firms or households. In these models, the observed land use pattern is the result of interdependences among agents. The key underlying mechanism in all of these models is a continuous tradeoff between agglomerative forces that initiate clustering and dispersive forces that generate scattering .[9] For example, localized clustering could result from the location of a local shopping center or public good such as a park, school or university and dispersion could result from desire for more open space – the size and direction of each effect is an empirical question. Empirical work on local interactions has looked at subjects such as human capital and labor market spillovers (Moretti 2002), inter-jurisdictional sorting related to schooling (Epple and Sieg 1999) and racial segregation (Bayer, McMillan, and Rueben 2004). Alternatively, other empirical work has tested and found evidence that local interactions and land use externalities are significant contributors to local non-contiguous development and sprawl patterns of development (Irwin and Bockstael 2002; Irwin and Bockstael 2004). In these papers, the interaction effect among recently developed subdivisions is found to be negative, which leads to the conclusion that a local repelling effect could at least in part explain some of the scatted development patterns we observe.

2.2 Land Use Policy

While researchers continue to debate the specific causes of exurban sprawl and fragmentation, concern among policy makers and residents about the actual occurrence of sprawl has spurned a number of responses. Few people would deny that the rapid expansion of the urban and rural-urban economy is a good thing from a pure economic perspective. And one of most important inputs into that expanse is the conversion of undeveloped land to more productive uses. However, in most instances, land owners fail to internalize the negative externalities imposed during the rapid outward expansion. These include loss of biodiversity, loss of farmland, non-point source water pollution and air pollution and congestion as result of increased travel from more remote locations.

Addressing these issues, however, is not always easy due in part to the property rights movement of the 1970s (Echevarria 2005). The result of this movement was a much more loosely regulated land market, especially in areas beyond the urban fringe. Given this constraint to land use control, policy makers had to develop more creative mechanism and policy-based approaches to regulating farmland development and sprawl. Some of the most popular measures that have been implemented include land use taxes, development fees, zoning restrictions, direct land use controls and purchase of development rights (PDR) (Horowitz et al. 2009). This latter program essentially expands the choice set for land owners giving them an additional conversion option other than development and allows them to continue farming while being compensated for their development rights. According to the American Farmland Trust, over fifty state and local governments have equivalent programs with 1.6 million acres under easement. While these

[8] See Cullen and Levitt (1999) for the effect of crime on urban population and Bradford and Kelejian (1973) for an early econometric model of "flight from blight."

[9] The agglomerative effect of local interactions has been studied extensively with the "new economic geography" literature (Fujita et al. 1999); the latter is a relatively new approach to studying land use pattern.

programs are designed to impede exurban expansion, a number of studies have considered the effect of these programs finding that, while they can slow the growth process, the results vary given location and the type of program (Miller and Nickerson 2003; Lynch and Carpenter 2003).We build upon much of the aforementioned literature and investigate the timing and choice of subdivision development type, while accounting for the preservation option.

3. Theoretical Model

The focus of this paper is on the individual land owner's optimal timing and investment decisions about when and how to convert her parcel from an undeveloped state to one of several other competing land uses. The theoretical basis is derived from previous research on the optimal timing of conversion (investment) (Arnott and Lewis 1979; Capozza and Helsley 1989 and 1990; Dixit and Pindyck 1994; McDonald and Siegal 1986). For the very reasons that we are concerned with the exurban land market in the first place – high growth pressure and rising land values – we can assume that the decision to convert is not a question of if but when. Increasingly scarce land supplies due to conversions and easements as well as growing real income levels will guarantee an upward trend in land and house prices over time and thus an optimum in the conversion timing problem.

To specify the problem formally, we consider an individual owner of parcel i who chooses the optimal time t^* to convert that parcel to one of several competing land uses at location z. The decision making problem for the choice of developing residentially is:

(1) $$V_i^{ag}(t,s,z,X) = max_s\{\int_t^s A(X_i^1,\tau,z)e^{-r(\tau-t)}d\tau + (R(X_i^2,s,z) - C(X_i^3,s,z))e^{-r(s)}\},$$

where A is the constant agriculture rent per unit of land, R is the gross payment for all the units created from a parcel of subdivided land at time t, C is the cost of converting a parcel to residential use, r is the interest rate and X_i^1, X_i^2 and X_i^3 are vectors of constant and time-dependent covariates that affect the value of agricultural land, gross returns and conversion costs, respectively. Because we do not expect the factors affecting the choice of development type, preservation and leaving a parcel undeveloped to be mutually exclusive, there will be a number of factors common to each of the final three vectors. For example, prime soils are hypothesized to decrease the development costs for the land owner. However, these prime soils also increase the returns to agriculture. In many cases, the outcomes for certain factors are ambiguous as they have offsetting effects.

The first-order necessary condition for a maximum of (1), the value of at the optimal development time is:

(2) $$rR(X_i^2,t^*,z) = A(X_i^1,t^*,z) + rC(X_i^3,t^*,z)$$

Condition (1), which is derived by Capozza and Helsley 1990, says that land is developed when the discounted present value of gross returns is equal to discounted costs plus the opportunity costs of development. This equation implicitly defines the boundary or location of the decision.

This model assumes a perfectly competitive market for land as well as a fixed lot and thus development size and choice. However, our empirical investigation deals with the more complex problem of timing in the presence of more than one subdivision development option. Many investments in capital involve such a decision – of both timing as well as choice of project and intensity. Capozza and Li (1994) extend the model to include such a case where the decision involves the choice of timing as well as intensity or type of investment. In this problem, the owner of a parcel considers two options that produce cash flows of $R = (R_1, R_2)$ per capacity and capital intensity of $q(k) = (q_1(k_1), q_2(k_2))$, where k is the choice of capital (or capacity) to build on the land. This choice is likely determined partially by the owner of the parcel and his or her profit maximization based on market decisions at the time and partially by the policy restrictions placed on the parcel by local land policies.

The formal problem is similar to condition (1):

(3) $$V_i^{ag}(t, s, z, k, X) =$$

$$max_{s,k_j} \left\{ \int_t^s A\left(X_i^1, \tau, z\right) e^{-r(\tau - t)} d\tau + \left(q_j(k_j) R_j\left(X_i^2, s, z\right) - C\left(X_i^3, s, z\right) k_j\right) e^{-r(s)} \right\}, \quad j = 1, 2.$$

Assuming a simultaneous decision on the part of the land owner, the solution to this problem is the same as (2) with a separate solution indexed by the specific options. In this model, the land owner chooses not only the optimal timing of investment t^* but also the capacity k_j or size of development to build in order to maximize presented discounted returns. Capozza and Li (1994) show that intensity as well as timing interacts in important ways in determining the value of land and the decision to convert. Other theoretical as well empirical works have considered issues related to development timing in the presence of multiple options and found that the presence of multiple options affects the timing and the specific choice (Geltner et al. 1996, Hite et al. 2003, Towe et al. 2008). Because we are interested the question of whether different factors influence the decision to develop a major versus minor subdivision development, we employ the Capozza and Li framework to test this hypothesis for Carroll County.

4. Empirical Framework

To empirically estimate the theoretical model of optimal timing of development in the presence of multiple choices, we employ a reduced-form hazard model. A number of previous empirical studies have analyzed land use conversion decisions using static discrete choice models (Bockstael 1996, Carrion-Flores and Irwin 2004). These studies used the decision to convert as the dependent variable and estimated the relative probability of parcel conversion conditional on a number of different covariates. One of the issues with these models, however, is that they fail to account for the dynamic nature of the development decision. Increasingly, researchers are applying duration models, which are able to account for both the dynamic nature of the decision as well as the transition of important covariates through time. One important extension of this model, the competing risks duration analysis, is able to model the optimal timing decision in presence of multiple failure options.

Duration analysis is a class of statistical models designed to study the occurrence and timing of events where the dependent variable is specified as the waiting time until a specific event occurs.[10] In this paper, we define our dependent random variable as T, which is the time of

[10] See Cox and Oates (1984) for a review of analysis of survival data and Lancaster (1990) for a microeconometric approach.

“failure” or conversion of a specific parcel from an undeveloped state to a developed one. The conditional density or hazard function is specified as:

(4) $$h(t) = \lim_{\Delta t \to 0} \frac{\Pr(t \leq T < t + \Delta t | T \geq t)}{\Delta t}.$$

This is the probability that a particular event or conversion will occur in the period between t and $t + \Delta t$ conditional on the fact that the failure has not occurred before this point. Taking the limit, it is interpreted as the instantaneous rate at which failures occur. The parameterized proportional hazard specification of this model is given by:

(5) $$h_i(t) = h_0(t) \exp(x_i \beta) ,$$

or in its familiar log form:

(6) $$log h_i(t) = \log h_0(t) + \beta_1 x_{i1} + \ldots + \beta_k x_{ik}$$

where i denotes the individual parcel, $h_0(t)$ denotes the baseline hazard function, which is the hazard function common to each individual holding all other variables constant, x_i is a $1 \; x \; k$ vector of covariates and β is k-dimensional vector of coefficients to be estimated. If we further specify a specific distribution for the baseline hazard function, we get a fully parametric hazard model, which can me estimated via full information maximum likelihood.

The need to specify a specific distribution for the baseline hazard inherent in the parametric hazard models implies that we also must make some assumption about the proportionality and evolution of the baseline hazard itself. A more robust and flexible version of the proportional hazard, the Cox semi-parametric or partial likelihood model, does not require us to specify a specific form for the baseline hazard. The Cox regression model

(7) $$\frac{h_i(t)}{h_j(t)} = \exp\{\beta_1 (x_{i1} - x_{j1}) + \ldots + \beta_k (x_{ik} - x_{jk})\},$$

is the ratio of two individual specific models from (5). As can be seen, the baseline hazards cancel out in the numerator and the denominator and make it unnecessary to specify a distribution. The coefficients can then estimated without relying on any functional form assumption making the estimate much more robust (Allison 1995). Other additional features of this model are that it also allows for time-dependent covariates, which is critical in our empirical model and that is easy to incorporate multiple failure options into the model via competing risks. The general partial likelihood function for the Cox model with fixed covariates and one event occurring in each time period is given by:

(8) $$PL(\beta) = \prod_{i=1}^{n} \left[\frac{\exp(\beta x_i)}{\sum_{j=1}^{n} \exp(\beta x_j)} \right]$$

where the numerator includes all the events that occur during the study period and the denominator is the summation of the of all other censored and at risk observations during the same period. All tied events in a given year will be handled using the Efron Method[11] (Allison 1995).

Because we are interested in investigating whether there are statistically significant differences between specific types of subdivision development, we extend the Cox model to include the possibility of two types of subdivision events. The competing risk model recognizes that once one type of subdivision event occurs, it precludes the other type of event from occurring. As before, we let T_i be the random variable for each individual and further specify K_i as the type of event that happened to that individual. Thus, the type and individual-specific hazard is:

(9) $$h_{ik}(t) = \sum_{k=1}^{K} \frac{Pr\{t \leq T_i < t+\Delta t, K_i = k | T_i \geq t\}}{\Delta t}, \quad k = 1 \; or \; 2.$$

When we compare this with the standard hazard function, equation (4), we see that the only difference is the addition of the $K_i = k$ term. The corresponding natural log form is:

(10) $$log h_{ik}(t) = \log h_{0k}(t) + \boldsymbol{\beta_k x_i}(t), \quad k = 1 \; or \; 2.$$

Thus, the conditional probability is the probability that a subdivision event will happen between t and $t + \Delta t$ and that if will be of type k, given that neither type of subdivision development has not happened before time t. Censoring in the competing risks model happens as a result of either a parcel converting to some other land use such as residential or preservation or for those that were undeveloped at the end of the study period. In addition, in the competing risks model, when a parcel converts to subdivision type other than the one of interest for the current model, that event becomes part of the censored parcels as well.

As is the case with all duration models with censored observations, it relevant to ask what affect the censoring mechanism has on the outcome of the model. Thus, we must make the assumption that the censored observations are "non-informative." That is, conditional on all covariates, the potential risk for one type of event is no more likely than that of another type of event or the fact that one event occurred reveals no information (beyond what we know from the covariates) about another type of event occurring. This is implied by the fact that the random variables $T_{ik}s$ are assumed to be independent[12]. Unfortunately, there is no way to actually test the non-informative hypothesis. However, given the inclusion of certain covariates and the correct specification of the data this will not present a problem. Our future methods for testing for and validating this assumption will be discussed later in the paper.

(5) Data and Variables

5.1 Study Area

[11] Because the time interval for our study is one year, there are multiple conversion events that happen in each period. The Efron method accounts for this simultaneity by running the model in each time period for all combinations for orderings (i.e. two conversions would have two separate runs) and then taking the average of those runs to the get the coefficient estimates.

[12] The consequence of this independence assumption not being satisfied is that the parameter coefficients, while unbiased, will be inefficient. In short, the it means that the censoring distribution may depend on unknown parameters of the model and since we condition on censored observations in the Cox model, the parameter estimates will be inefficient.

To test our hypotheses regarding the subdivision timing and conversion decision and how the two types of development – major and minor – compete we used data from Carroll County, Maryland. Carroll is an urbanizing county located approximately 30 miles west of Baltimore, 55 miles northwest of Washington, D.C. and until recent decades was a largely rural county (Figure 1). From 1900-1950 the county's population grew slowly from around 34,000 in 1900 to just under 45,000 in 1950. However, over the next five decades the increase was much more rapid with the growth in population between 1980 and 2000 totaling 55% (Figure 2). This growth has resulted in the county shifting away from a predominantly agriculture-based landscape to one with a large portion of landscape developed land uses. The largest portion of the developed land is comprised of single-family residential dwellings. In 2007 residential developed comprised 22.5% of the county (Carroll County GIS Department). As was reported above, a large portion of this, at least in the last several decades, has been the result of subdivision development. Since 1960, close to 1,850 individual subdivision developments have been started in the county. While the number of major versus minor developments is currently about equal, the growth in the number of small developments has been greater than that of the major developments (Figure 3).

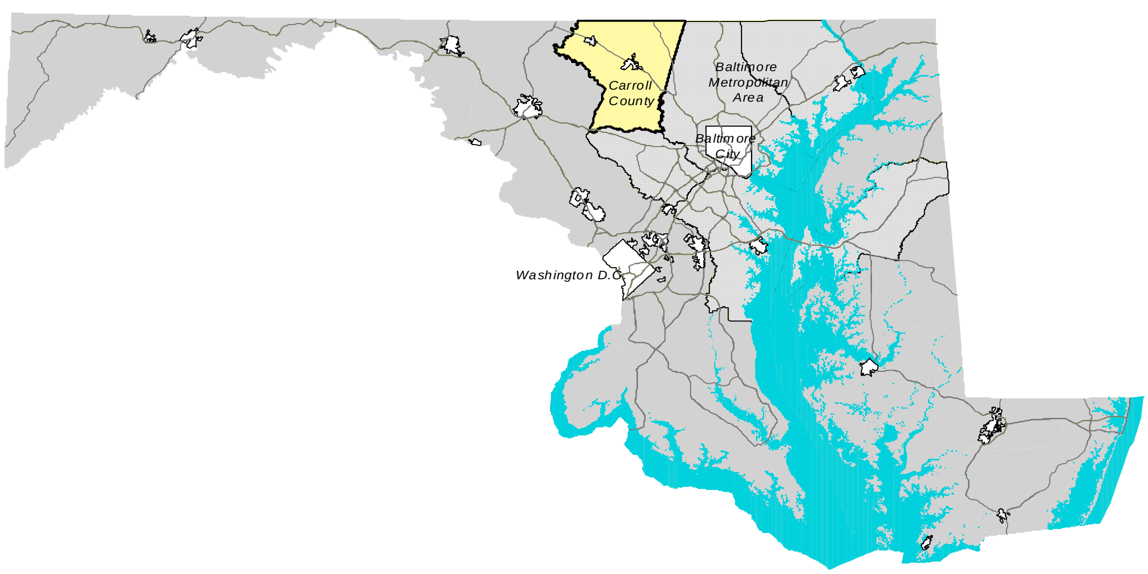

Figure 1: Carroll County and the Baltimore Metro Region

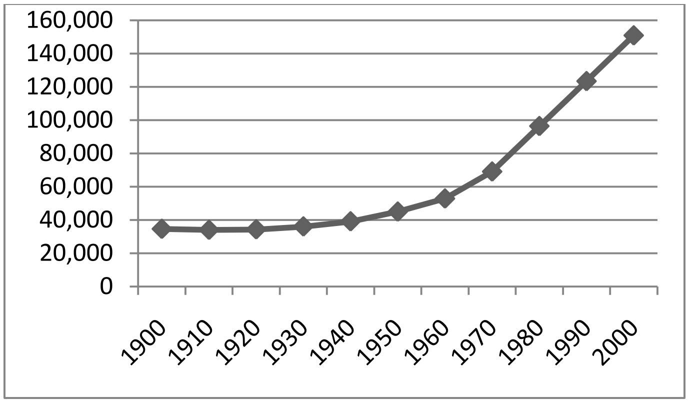

Figure 2: Carroll County Population Growth

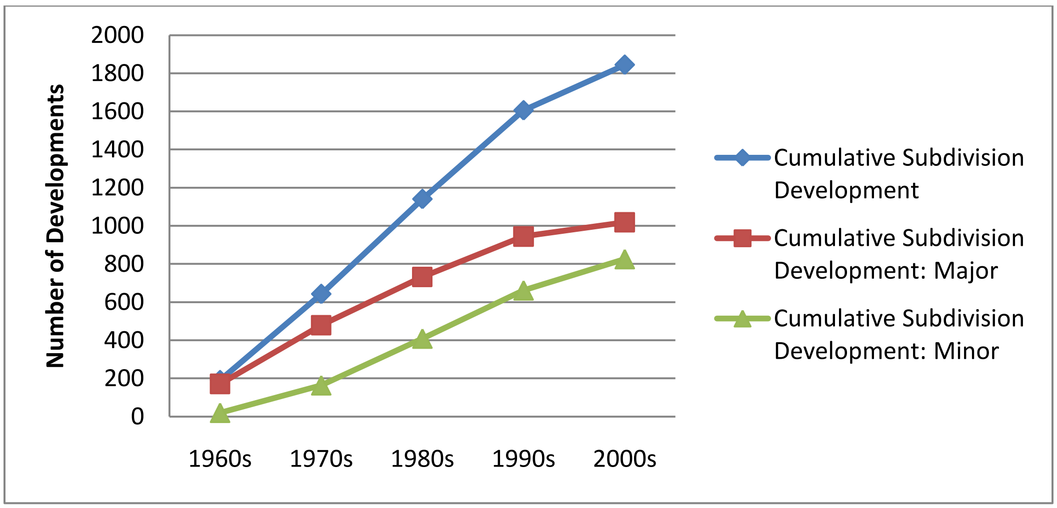

Figure 3: Cumulative Subdivision Development

5.2 Data Description, Datasets and Variables

The data used for this study was collected and constructed from a number of different sources[13]. We began with the parcel boundary GIS data obtained from the Carroll County GIS Department, which includes the actual parcel boundaries for the county. Then, using property tax assessment data from the state, we joined the two datasets using a common tax assessment ID. The property tax data contained information on the parcel and its characteristics, location and ownership. Also included in the dataset were two fields related to the subdivision plat for that parcel if it happened to be located in a specific subdivision. These fields contained information on the plat book and page number for the subdivision, which were in microfiche format and stored on-line at the Maryland Historical Archives[14]. Using these book and page numbers as a starting point and the information about the parent-child relationship for each subdivision contained on the plats, we were able to place the individual parcels from the parcel boundary dataset into their

[13] All data construction was done using ESRI ArcGIS 9.3 and SAS 9.2 software.
[14] The website from the Maryland Historical Archives is www.plats.net.

respective subdivisions. A unique name and ID number was created for each subdivision and the first year of platting was recorded.

We also constructed a dataset for historical land preservation to control for permanently preserved open space in addition to land that was simply undeveloped. Since the early 1970s Carroll County has used a number of growth management tools in order to control expansion and development. Two of the most significant measures applied were minimum lot zoning restrictions and purchase of development rights (PDR) programs. The county, along with the state, has a number of different programs into which a land owner, who wishes to forgo his or her development rights, can sell or donate their parcel in exchange for a per acre payment. In most cases, in order to be eligible for these programs, the parcel must be 50 acres or greater or join a previously preserved parcel and have a certain percentage of premium soils. Previous studies have shown that the presence of such a program will actually delay the development timing of a parcel (Towe et al. 2008). The data for land use preservation was created by matching the parcels in parcel-boundary subdivision dataset with the Carroll County Land Preservation Program data we collected from the county. Using these two datasets we were able to put easement dates on the parcels. The dataset consisted of 870 preserved parcels consisting of close to 54,000 acres preserved between 1980 and 2007. Figure 4 shows the historical evolution of all types of land use for the county for 1980-2000. Note that preservation started in 1980.

Because one of our primary interests in conducting this research is to investigate the actual factors influencing residential land conversion in the most exurban settings, we restrict our analysis to conversions and undeveloped parcels located in either a Conservation or Agriculture District for the county. The final dataset consisted of all undeveloped and unpreserved parcels as of 1992 that were eligible for both major and minor subdivision conversion[15]. For Conservation districts this is parcels of 12 acres or large and for Agriculture districts this is parcels of 46 acres or larger. Our observation period for the empirical survival model is from 1993 to 2007. During this period there were a total of 330 subdivision conversions that occurred on a total of 7,500 acres. Of these, 103 were major subdivisions and 230 were minor subdivisions. To account for those parcels that were or became eligible for preservation during period we included a time-dependent indicators variable. Our final dataset consisted of 1,321 parcels on a total of 86,500 acres of land.

One issue with our current dataset is that we do not know if the subdivision events are mutually exclusive in all cases because if a minor development has not exhausted all of the development rights for a particular piece of property, then it would be possible to add additional lots in the future at which time the subdivision may become a major development. We are in the process of collecting this information about whether the current parcel has exhausted all of its development potential or if it still has more available developable land and will include this in future versions of this paper.

[15] As was stated above, minor subdivisions consisted of developments of two or three lots and no infrastructure and major subdivisions consisted of four or more buildable lots and additional infrastructure.

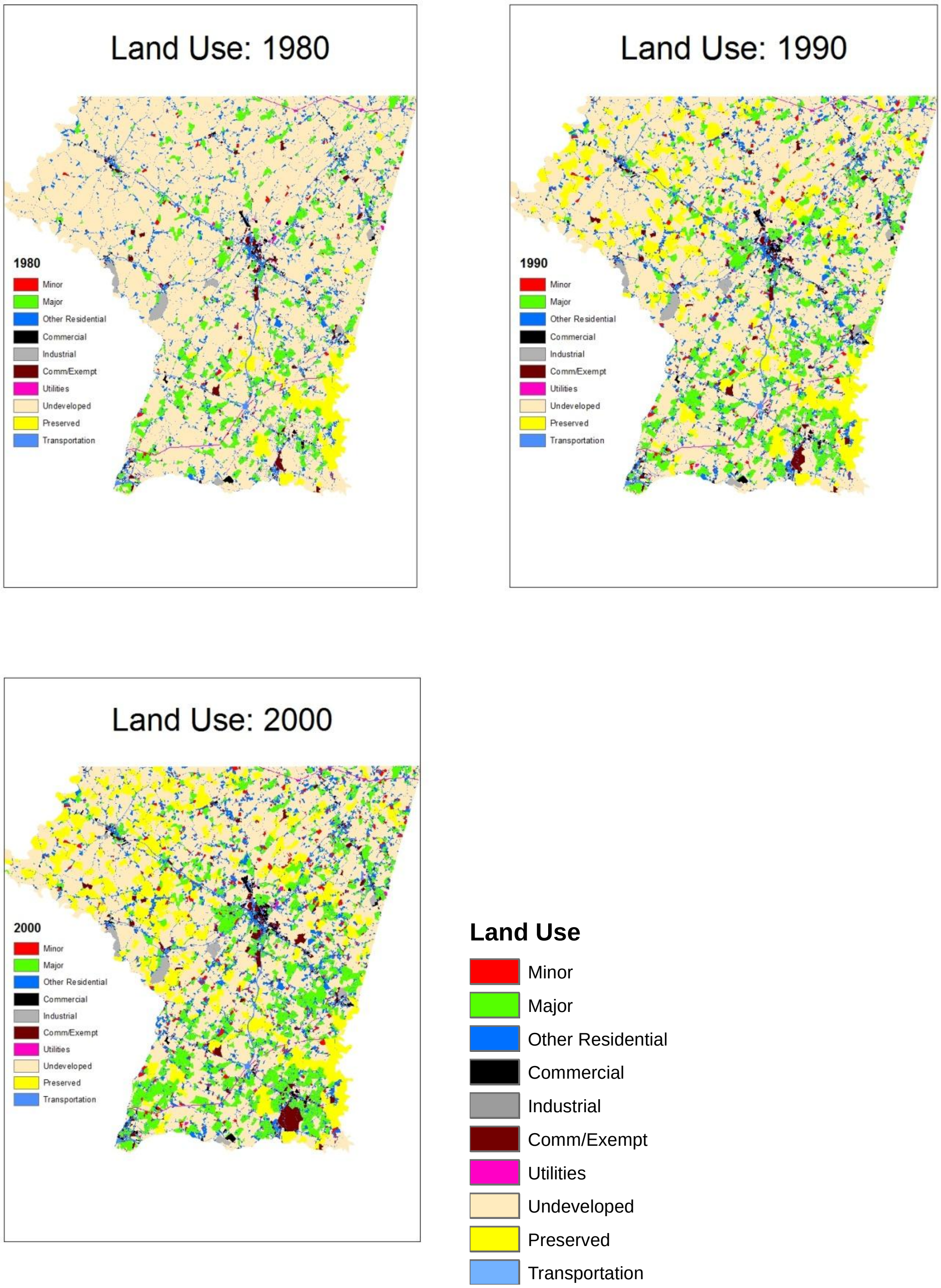

Figure 4: Carroll County Land Use

From the literature review and theoretical framework in the sections above (sections (2) and (3)), it is apparent that the decision to develop depends on a number of factors ranging from local interactions with other types of land uses to the monocentric models predictions about travel time and distance to a CBD. To represent the predictions of the monocentric model, we include three variables: (Wash_DC), (Balt_City) and (Trans). The first two variables are travel time, in minutes, from each parcel to the two closet CBDs, Washington, D.C. and Baltimore City. The monocentric model predicts a declining rent gradient outward from the CBD. So, we would expect if the commuter shed for either of these two CBDs extends into Carroll County it would have a negative impact on the timing of development as one moves further away from the city. At some point the urban would be reached and the gradient would be fall to zero or have a random effect at the point where the agriculture rent equals the value of developed land rent. The last variable is a land use proximity variable indicating the percentage of the land use surrounding each parcel that is a road. This is an additional proxy to account for access to business centers via existing road networks[16].

In addition to the monocentric model, we account for the effects of local interactions by accounting for several measures of surrounding land use. The variables are: (sluPre), (sluMin), (sluMaj) and (sluOthRes). The first variable accounts for the percentage of surrounding land in preservation or some other undevelopable form. There is empirical evidence that surrounding open space and preserved land creates a repelling effect and has been shown to speed up development (Irwin and Bockstael 2002, 2004). The second two variables are the percentage of surrounding land use in minor and major subdivisions, respectively. The final variable accounts for other residential. We include this final variable because in the early stages of growth for the county the regulatory environment for land conversion was less strict and many small lots were created without a corresponding plat map. Unfortunately, we do not have information on all this previous activity at the present time so we include this variable to try and determine if the influence of surrounding residential has the same effect as the influence of small, minor subdivision development. All of the surrounding land use development variables are relatve to the excluded land use type “undeveloped”. Finally, we include the variable (Westmin), which is the travel time in minutes from each parcel to the county seat for Carroll, Westminster.

The final set of variables account for the opportunity costs for farmers as well as the cost of development for developers. The variables include: (Soil_Ind), (Steep_SLP), (Easement) and (AreaAcre). The first variable is an indicator variable taking a value of 1 if the soil for the parcel is one of the first classes of soil. The state of Maryland has four main categories of soil. Class I is considered prime soil but Carroll does not have any of this type. So, for this paper we considered the Class II as our top class and gave all other classes a zero indicator. The second variable is an indicator as to whether the parcel has a slope greater than 15 percent. We would expect very steep terrain to be a deterrent to future development. The Easement variable is a time-dependent variable indicating whether a parcel was eligible for preservation. The time dependency is the result of the fact that some parcels that were not eligible at the beginning of the period became eligible as their neighboring parcels were preserved. The fourth variable is the area of the parcel in acres. To construct this variable we combined the buildable area for the subdivision with any remaining portion. When subdivisions are platted, especially in agriculture districts, the plat

[16] All land use proximity or percentage of land use calculations were performed using the buffering tool in ArcGIS 9.3. The buffer distance for all calculations was set at 400 meters. Future version of this paper will test different distances.

maps designate the buildable lots as well as the "remaining portion" of the subdivision, which is the excess acreage set aside to comply with the zoning regulations. In Carroll County, for agriculture districts, this is one house for the first six acres and 20 for each house thereafter; for conservation districts it is one house per three acres. To try and account for the true size of the original parcel area that was used by the land owner in making the decision to convert we combined the remaining portion and the buildable area for those parcel that we had information on.

Table 2: Descriptive Statistics

A. All Parcels

Variable		Description	Mean	S.D.	Min.	Max.
Monocentric Model						
	Wash_DC	Distance to D.C. (Minutes)	62.83	9.99	39.06	83.41
	Balt_City	Distance to Baltimore (Minutes)	43.83	9.36	25.14	68.07
	Trans	SLU Transportation (%)	3.70	2.51	0	32.0
Local Interactions						
	SluPre	SLU Preservation (%)	11.30	15.91	0	87.10
	SluMin	SLU Minor Subdivisions (%)	2.40	3.40	0	21.40
	SluMaj	SLU Major Subdivisions (%)	12.72	14.83	0	85.23
	SluOthRes	SLU Other Residential (%)	8.60	6.40	0	47.27
	Westmin	Distance to Westminster (Minutes)	16.37	6.41	2.31	36.77
Costs						
	Soil_Ind	Indicator for Prime Soil	0.39	0.48	0	1.00
	Steep_Slp	Indicator for 15%> Slope	0.16	0.36	0	1.00
	Easement	Easement Qualification	0.57	0.48	0	1.00
	AreaAcre	Parcel Size (Acres)	67.90	56.46	1.93	591.16
	Zoning_Ind	Agriculture District	0.61	0.49	0	1.00

B. Major Subdivisions

Variable		Description	Mean	S.D.	Min.	Max.
Monocentric Model						
	Wash_DC	Distance to D.C. (Minutes)	59.64	10.07	41.11	81.64
	Balt_City	Distance to Baltimore (Minutes)	38.76	7.18	26.49	63.73
	Trans	SLU Transportation (%)	4.92	2.52	1.37	18.52
Local Interactions						
	SluPre	SLU Preservation (%)	5.67	10.68	0	44.50
	SluMin	SLU Minor Subdivisions (%)	2.87	3.77	0	21.37
	SluMaj	SLU Major Subdivisions (%)	19.24	17.32	0	78.85
	SluOthRes	SLU Other Residential (%)	10.61	6.66	0.05	78.85
	Westmin	Distance to Westminster (Minutes)	16.24	5.75	3.43	30.26
Costs						
	Soil_Ind	Indicator for Prime Soil	0.57	0.49	0	1.00
	Steep_Slp	Indicator for 15%> Slope	0.17	0.38	0	1.00
	Easement	Easement Qualification	0.32	0.46	0	1.00
	*AreaAcre**	Parcel Size (Acres)	80.24	89.71	2.82	591.16
	Zoning_Ind	Agriculture District	0.63	0.48	0	1.00

C. Minor Subdivisions

Variable		Description	Mean	S.D.	Min.	Max.
Monocentric Model						
	Wash_DC	Distance to D.C. (Minutes)	64.57	10.28	39.06	81.24
	Balt_City	Distance to Baltimore (Minutes)	43.39	7.58	28.49	64.02
	Trans	SLU Transportation (%)	3.64	19.66	0.56	16.57
Local Interactions						
	SluPre	SLU Preservation (%)	7.43	14.80	0	85.07
	SluMin	SLU Minor Subdivisions (%)	3.19	4.34	0	19.60
	SluMaj	SLU Major Subdivisions (%)	12.18	13.45	0	66.01
	SluOthRes	SLU Other Residential (%)	10.51	7.62	0	42.86
	Westmin	Distance to Westminster (Minutes)	15.78	5.76	4.40	31.99
Costs						
	Soil_Ind	Indicator for Prime Soil	0.44	0.49	0	1.00
	Steep_Slp	Indicator for 15%> Slope	0.19	0.39	0	1.00
	Easement	Easement Qualification	0.07	0.26	0	1.00
	*AreaAcre**	Parcel Size (Acres)	28.28	30.16	2.11	154.59
	Zoning_Ind	Agriculture District	0.91	0.28	0	1.00

* These area variables include the buildable area and remaining space

For those for which we did not have the additional information we used the original size from the plat map, which was just the combined are of the building lots for the subdivision. Table 1 presents the descriptive statistics for the aggregate dataset as well as those for the major and minor subdivisions separately.

(6) Results

Before we proceed to examine the parameter estimates of the competing risks model, an important question we must ask about a hazard model with the possibility of multiple events is whether the individual risk hazards are the same. That is, does $h_k(t) = h(t)$ for all event types. Moreover, it may be that even if they are not equal, they may be proportional to one another. One way to test this is by a graphical examination of the log-log survival functions for the individual events. Figure 5 displays the plot of the baseline survival functions for each type without the covariates. It is clear that the minor developments' curve is higher than the one for the major developments and rises more quickly than that of the major developments during the observation period. This final observation, of divergence in the curves, shows that the minor subdivisions are not proportional to the major developments and that their survival rate is decreasing (or hazard rate is increasing) faster than the major developments.

As noted above, Figure 5 gives some evidence that the two types of developments may not be equal or even proportional. Thus, we need to test the null hypothesis that $\beta = \beta_k$ for all k . To construct a likelihood ratio chi-square statistic we take -2*log-likelihood for the likelihood values in table 3. We then sum the values for both the major and minor models and subtract this value from the value for the combined model. Noting that we have 12 degrees of freedom for the test statistic (24 parameters for the summed individual models minus those for the combined model), we can reject the hypothesis that the coefficients are all equal across the models for our test value of 85.196. Furthermore, the likelihood ratio and Wald tests for the individual models also provide evidence that not all of individual coefficients are equal to zero.

Figure 5: Log-log Survival Plot

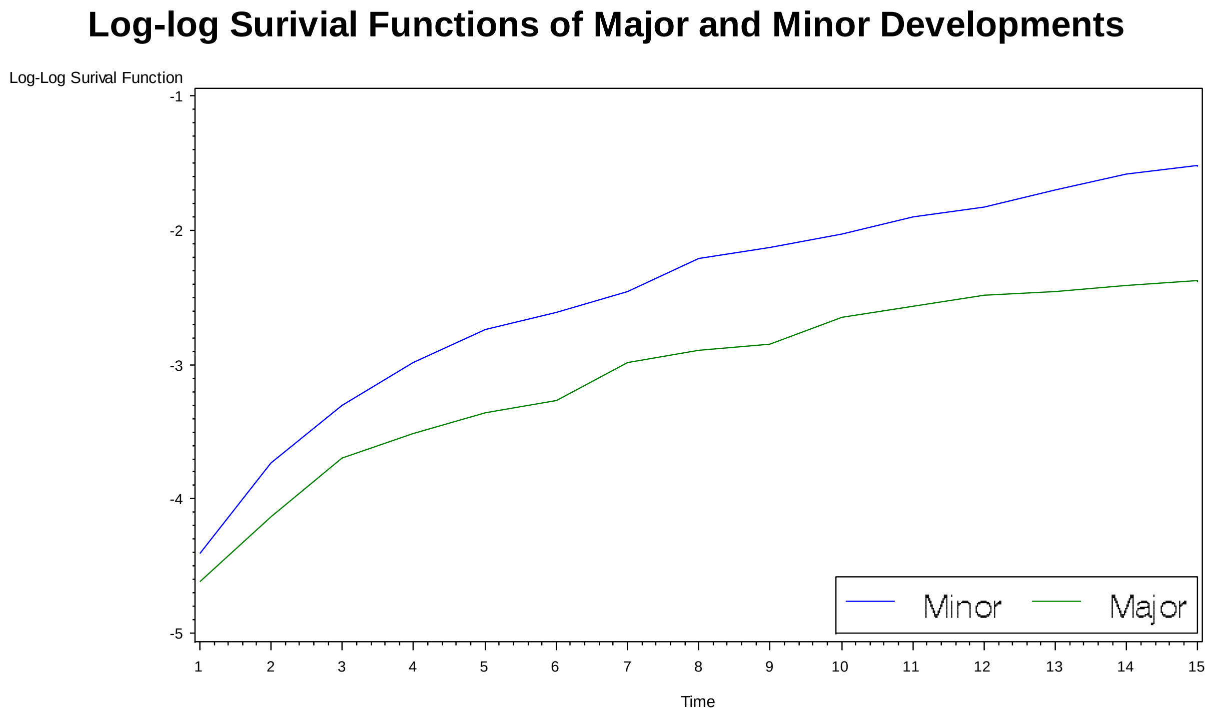

Table 3 presents the preliminary results of our competing risk survival model. The first section, All Subdivisions, reports the results from the combined model with both types of developments together and estimates the combined coefficients β . The next two sections report the results for the major and minor subdivision models β_k for k equals major or minor. We report both the coefficient values and the hazard ratios along with the Chi-square values for all three models. A hazard ratio above one indicates that the variable has the effect of proportionally increasing the baseline hazard rate of conversion. Values below one indicate a decreasing hazard rate. Above each section we also report the log-likelihood function for each model estimated with the covariates.

6.1 Monocentric Results

For the combined model, only the distance to Washington D.C. is significant with a one minute increase in travel time resulting in a 1.9% increase in the hazard rate. The values for this coefficient as well as the one for Baltimore City are both positive indicating that the hazard of development increases the further you move away from the CBD. However, when we examine the values for the individual models we see that the value for the Baltimore City coefficient is significant for both models but for the major developments it is negative as would be predicted by the monocentric model with hazard rates decreases with distance. For the major model, one minute increase in travel time from Baltimore leads to 4.6% decrease in the hazard. For the minor developments it is positive suggesting a 4.0% increase in the hazard rate for every minute increase in travel time from Baltimore; for the D.C. the increase in 2.0%. For both models, the coefficient is positive for Washington D.C. but only significant in the minor development model. Noting the weak relationship described in Table 1 for the descriptive landscape metrics for minor developments this result is not surprising. These suggest that the predictions of the monocentric model in terms of distance gradients do not hold for minor develops and that it the case of our model the effect is actually opposite of the monocentric predictions.

The final variable, surrounding roads, is significant for the major developments but insignificant for the minor developments. This suggests that roads may speed up the hazard rate or rate of conversion for major developments but not for minor developments. For major developments, a 1% increase in the surrounding roads increases the hazard rate by 7.9%. One question, however, is whether, even in light of the significance for majors and insignificance for minors, the transportation coefficients for the two subdivision models are equal. To check this we constructed a one-degree-of-freedom Wald statistic[17]. The test statistic is equal 0.02, which provides insufficient evidence to conclude that the two coefficients are different. The significant result for major developments may simply be the result of the fact that major developments are located closer to more dense development areas and thus more roads. This is also supported by the strong negative distance gradient for the major subdivision developments. As most of the road network for the county was already established by the time of our study it seems that road access would be exogenous throughout, but at the present time we lack sufficient data on the timing of road improvements and so we are not able to test the direction of causality for this variable.

6.2 Local Interactions Results

For the combined model, the minor subdivision and other residential surrounding land use variables are significant and positive. These two types of development increase the hazard rate and thus likelihood of development of both types of developments combined. The variable for surrounding preservation also increases the hazard of development, which is consistent with previous research and suggests that open space may be an important factor in development, but the coefficient is insignificant. For the major subdivision model, both the variables for surrounding major developments as well as other residential development are significant and positive. A 1% increase in the amount of land area dedicated to other major developments increases the hazard rate for major developments by 1.4%. For other residential, it increases the hazard by 2.3%. These results imply that other large developments have the effect of increasing the likelihood of similar developments around them. Inspection of the land use maps for the county and the values for the descriptive regressions in Table 1 provide some confirmation of this result. Larger developments, especially in the last couple decades, appear to be located mostly in the eastern and southern parts of the county and cluster much more than the smaller, minor developments. The coefficient on minor developments is significant at the 15% confidence level and the sign is positive suggesting that minor developments also increase hazard rate.

[17] $The\ Wald\ statistic\ for\ testing\ the\ hypothesis, \beta_1 = \beta_{2,}, is\ \frac{(b_1-b_2)^2}{(s.e.(b_1)^2+(s.e.(b_2))^2}. It\ is\ distibuted\ chi-square..$

For the minor development model, we have that other residential development increases the rate of development as does the presence of preserved land and other minor subdivision developments. For minor subdivisions, a 1% increase in surrounding preservation leads to a 1.3% increase in the hazard rate; for surrounding minor developments it is 3.6%. These results suggest that the underlying processes driving the decision to subdivide a major subdivision and that driving the decision to preserve or develop a minor subdivision may be different. The final variable for distance to Westminster is not significant for any of the models.

Table 3: Parameter Estimates of Cox Competing Risks Proportional Hazard Model

Variable	**All Subdivisions** $Coef.$	$\text{Exp}(\beta)$	$P > \|z\|.$	**Major Subdivisions** $Coef.$	$\text{Exp}(\beta)$	$P > \|z\|$	**Minor Subdivisions** $Coef.$	$\text{Exp}(\beta)$	$P > \|z\|$
	-2*Log(L) = 4,330.938			-2*Log(L) = 1337.741			-2*Log(L) = 2,868.312		
Monocentric Model									
Wash_DC	0.018	1.019	0.007**	0.023	1.024	0.103	0.022	1.023	0.021**
Balt_City	0.015	1.016	0.123	-0.047	0.954	0.016**	0.039	1.040	0.001**
Trans	0.034	1.035	0.096*	0.076	1.079	0.005**	-0.018	0.981	0.549
Local Interactions									
SluPre	0.006	1.006	0.199	-0.005	0.995	0.553	0.012	1.013	0.014**
SluMin	0.041	1.043	0.001**	0.042	1.043	0.106	0.035	1.036	0.010**
SluMaj	0.005	1.005	0.160	0.013	1.014	0.029**	0.002	1.002	0.614
SluOthRes	0.028	1.029	0.000**	0.023	1.023	0.090*	0.032	1.033	0.000**
Westmin	-0.006	0.994	0.487	-0.010	0.990	0.532	-0.011	0.989	0.299
Opportunity Costs									
Soil_Ind	0.300	1.350	0.021**	0.145	1.157	0.528	0.316	1.372	0.044**
Steep_Slp	0.182	1.200	0.199	0.119	1.127	0.645	0.148	1.161	0.383
Easement	-2.501	0.082	0.000**	-1.647	0.193	0.000**	-2.206	0.110	0.000**
AreaAcre	0.005	1.006	0.000**	0.010	1.011	0.000**	-0.011	0.988	0.000**

Note: A double asterisk (**) represents a 5% confidence interval and the single asterisk (*) represents a the 10% level.

6.3 Opportunity Cost Results

The soil indicator variable is significant for the combined and minor models but not for the major development model. This variable, however, is ambiguous as the gains from better soil for development are offset by the gains for better soil in agriculture – especially in more rural areas of the county. One possible explanation for the reason it is significant in the minor model and not in the major model is that the decision to develop a minor subdivision is likely much more closely related to the decision to farm or develop small than for that of the major subdivision development decision. We currently do not have complete information about the entire parent-child relationship for all minor developments or how the minor subdivision developments relate to one another (if they were developed by the same person off of the same original parcel). However, a preliminary analysis of the data suggests that it is possible that the decision to development a minor subdivision and to continue farming the remainder of the property may be strategically connected. For example, given a certain parcel size, it may be that the optimum choice for the owner is to develop a minor subdivision and then to continue farming or preserve the remaining part of the property. This would show up in our data as two separate events but to truly uncover the relationship we need to improve the data to include this prior relationship. The steep slope variable is insignificant in all models. This likely comes from the fact that only a small portion of the county is over 15% relief and it is in a more remote section of the county so it may not have an effect on the majority of the development decisions.

The final two variables are significant for all three models. Consistent with other findings (Towe et al. 2008), the option to ease a parcel reduces the likelihood of conversion. The values for our model are somewhat higher than in other studies; however this is like the result of the fact that we have focused on the rural sections of the county where the interaction between the preservation option and development is likely the greatest. Also, noting that the value for the minor developments suggests a lower hazard rate than major development model provides further evidence that the decision to preserve and/or continue farming is likely much more connected with the minor subdivision development process than it is for the major development process.

An increase in the parcel or subdivision area increases the hazard rate for all three models. The results are consistent with what we would expect for the major developments – and increase in parcel size increases the likelihood of development. For large developments, there is likely to be more economies of scale for developing a larger development than a small one. For major developments, a one acre increase in lot size lead to 1.1% increase in the hazard rate. For minor subdivision developments, the coefficient on the area variable is negative. A 1% increase in parcel area decreases the hazard rate by 1.2%. This is what we expect given that as the parcel size increases more lots can be build and the parcel owner is probably more likely to choose a major over a minor development.

One of the issues with our area variable for the minor model is that for some of the minor developments we did not have a complete history of what the original parcel looked like and so the current parcel is likely much smaller than what it would be if we had that additional information. To test whether this may be the case, we constructed an additional area variable (AREAACRE2). For those minor subdivisions for which we did not have information about the remaining portion or for which it appeared the area size was much smaller than it should have been according to zoning at the time the subdivision was platted, we filled in the acres with what the parcel size should have been in compliance with the zoning regulations in the agriculture district. We then reran our models using this new area variable. The results of these additional models are given in Table 4. All coefficient signs remained the same all but one (sluOthRes for major developments) retained their significance. For the new area variable, the coefficient was positive but not statistically different from zero. This result confirms that we may be missing something in terms of data about the original parcel size for some of the minor developments.

While there are economies of scale for larger developments, larger plots are also better than smaller ones in producing higher returns to agriculture. As we move to more rural and remote areas of the county, the ability of developers to outcompete farmers diminishes and at some point the value of land in agriculture should equal the value of land in development (Capozza and Helsley 1989). In addition, while population levels and growth in rural areas are significantly less than in areas closer to the CBD, there is still some migration outward into these exurban areas by individuals with stronger preferences for open space. However, the combination of the limited number of people and their corresponding preferences for open space may mean that larger developments would not be feasible even if the possibility to develop them existed.

Table 4: Parameter Estimates of Cox Competing Risks Proportional Hazard Model

Variable	**All Subdivisions** $Coef.$	$\text{Exp}(\beta)$	$P > \|z\|.$	**Major Subdivisions** $Coef.$	$\text{Exp}(\beta)$	$P > \|z\|$	**Minor Subdivisions** $Coef.$	$\text{Exp}(\beta)$	$P > \|z\|$
	-2*Log(L) = 4,306.938			-2*Log(L) = 1341.199			-2*Log(L) = 2,880.543		
Monocentric Model									
Wash_DC	0.021	1.021	0.007**	0.023	1.024	0.102	0.022	1.023	0.021**
Balt_City	0.012	1.013	0.231	-0.048	0.953	0.014**	0.036	1.037	0.002**
Trans	0.034	1.035	0.105	0.076	1.079	0.005**	-0.018	0.981	0.549
Local Interactions									
SluPre	0.006	1.006	0.173	-0.005	0.995	0.553	0.012	1.013	0.014**
SluMin	0.041	1.042	0.001**	0.042	1.043	0.106	0.013	1.014	0.009**
SluMaj	0.005	1.005	0.135	0.013	1.014	0.029**	0.002	1.003	0.589
SluOthRes	0.028	1.029	0.000**	0.023	1.023	0.108	0.034	1.035	0.000**
Westmin	-0.007	0.993	0.424	-0.009	0.991	0.558	-0.013	0.986	0.205
Opportunity Costs									
Soil_Ind	0.277	1.320	0.033**	0.138	1.148	0.549	0.312	1.367	0.048**
Steep_Slp	0.182	1.200	0.247	0.100	1.106	0.700	0.148	1.161	0.373
Easement	-2.785	0.062	0.000**	-1.588	0.204	0.000**	-3.216	0.110	0.000**
AreaAcre	0.009	1.009	0.000**	0.010	1.010	0.000**	0.003	1.003	0.215**

Note: A double asterisk (**) represents a 5% confidence interval and the single asterisk (*) represents a the 10% level.

(7) Discussion and Future Research

The main purpose of this study is to gain further insight into the underlying processes determining the land use conversion decisions and attendant land use patterns observed in exurban areas. The long-term goal is to be able to use the estimates of this and future studies as inputs into land use simulation models to reconstruct the land development process as a means of doing counterfactual analysis of the land development process, policy and to make some assessment of the welfare gains and losses thereof. One of the most important processes dictating land use change in rural areas is the decision of a land owner to convert their parcel to a residential development. In many areas land owners have a number of options open to them in terms of size of development or alternative options to development. The results in the previous section provide some evidence that the processes governing the decision of a land owner to develop a major subdivision differ from those for the minor subdivision development process for one rural county in Maryland.

The parameter estimates reveal that distance does not matter at all for minor developments and that it does for major developments, with major developments following much more closely to the monocentric model predictions. In addition, transportation seems to matter more for large developments. Both types of development seem to be attracted by other developments like themselves and both are attracted by other residential. Surrounding restricted open space has a positive influence on minor developments but not for majors but there is insufficient evidence that the parameters are statistically different from one another. Finally, the potential for easement seems to increase the likelihood for development for all types and parcel area does so for the combined and major models. For the minor models, the case is less certain but it appears that the main issue with this parameter is the fact that we lack a complete data story.

The next step in this research will be to go back and piece together the exact connect between the subdivisions, other subdivisions developments and the large parcels from which they were developed. There is reason to believe that given the current zoning laws and preservation opportunities in the county, the decisions to develop a minor subdivision may be part of a simultaneous maximization problem on the part of the land owner. If that is indeed the case, then the non-informative claim about censoring in the competing risk model may only hold if we can gather this additional information as the assumption is made based on the fact that the covariates contain all relevant information. By controlling for the connection between both subdivisions that were platted out of the same parcel or subdivisions that have been developed by the same person as well as gathering information when subdivisions and preserved parcels are connected via common ownership, it will be possible to reduce the effect of omitted variables and potential spillovers that may be biasing our results. Even in light of these issues, the results from our model provide some preliminary evidence of that fact that the two types of developments are indeed different that it is relevant for policy makers and local officials concerned with development patterns in the county to take closer look at these processes and mechanisms underlying these two development options.

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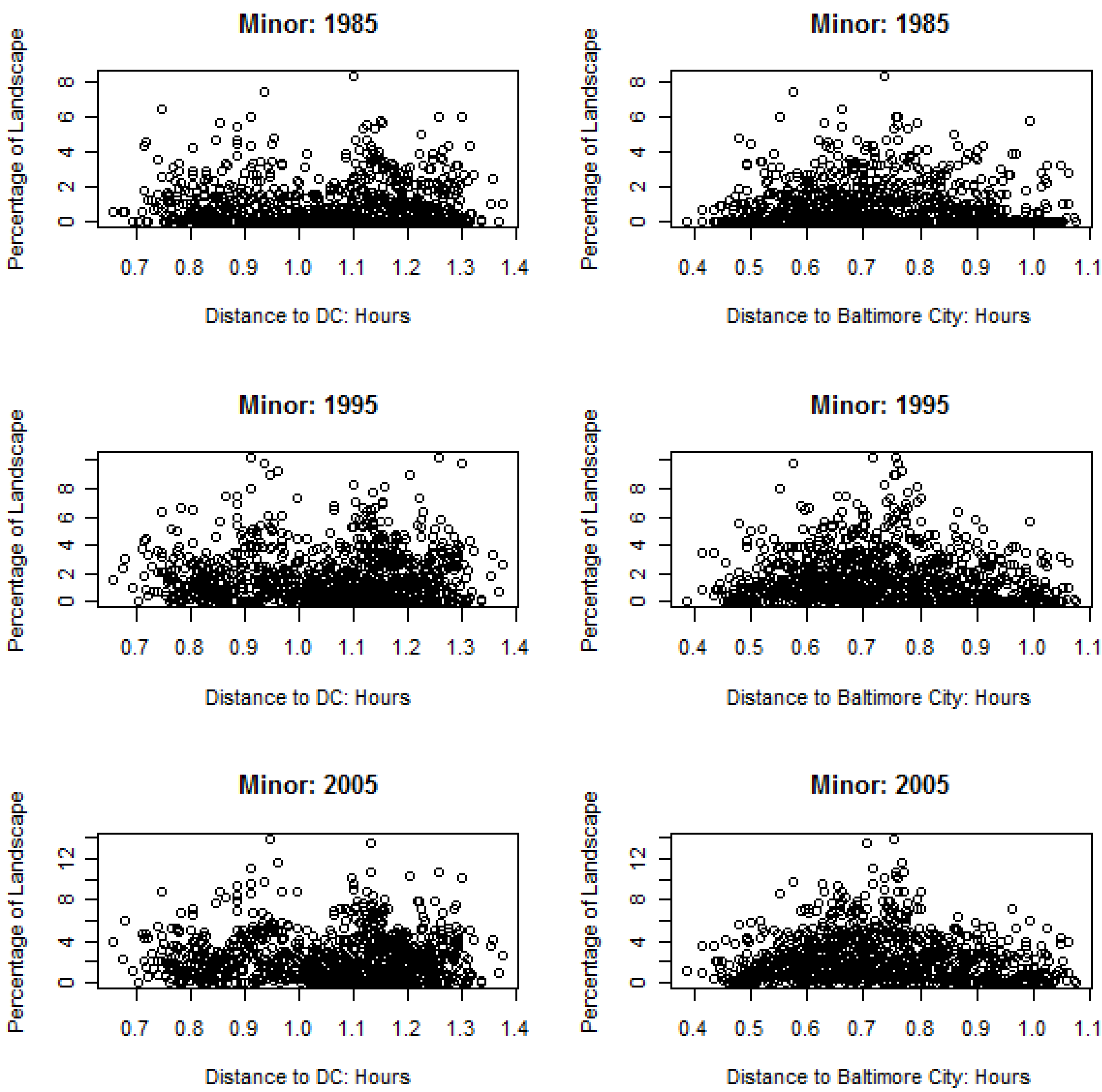
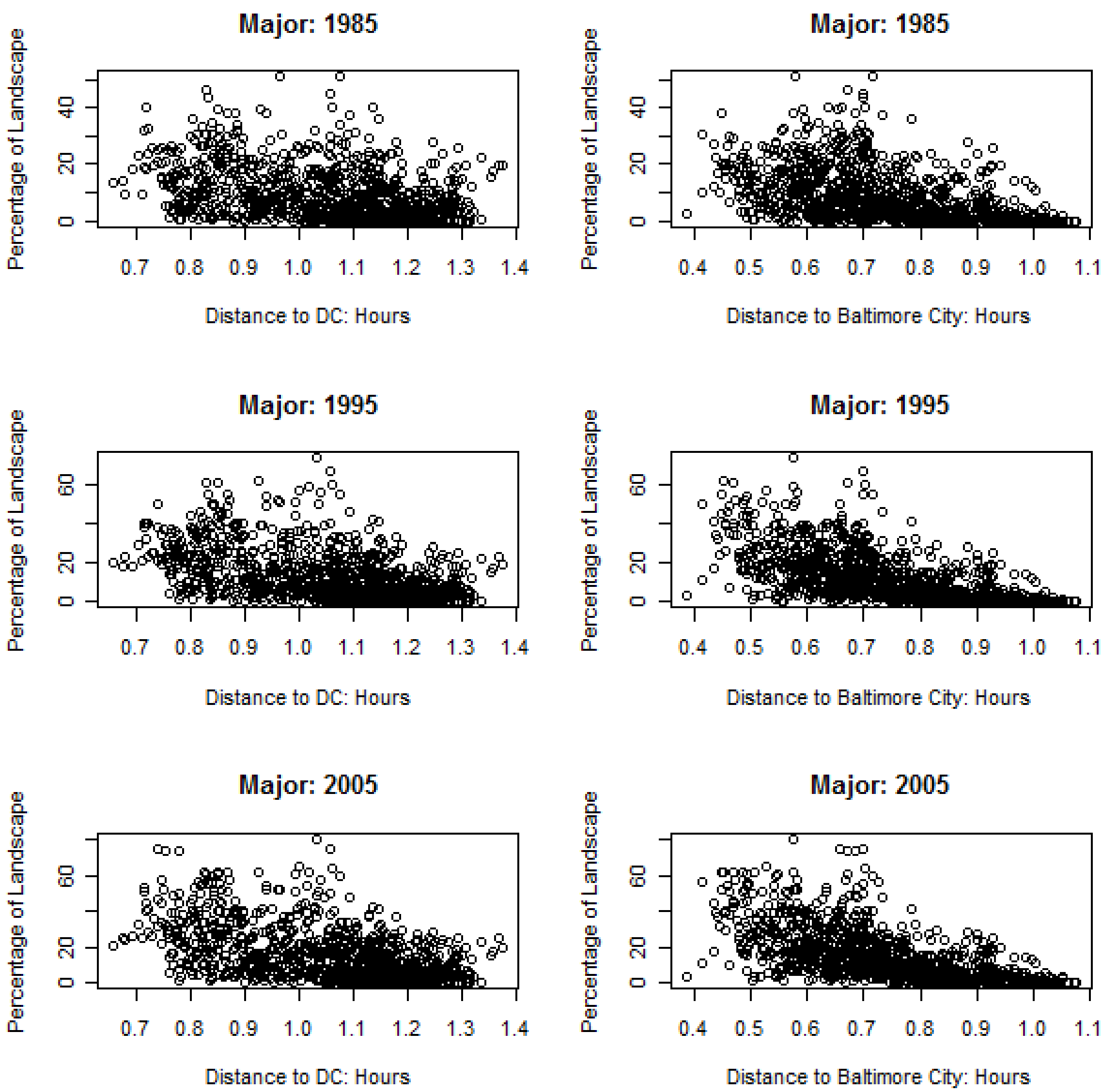
(9) Appendix

Figure A1: Scatter Plots of Landscape Metric

Minor Subdivisions



Major Subdivisions



Preserved Land