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# Modeling spillovers from development and conservation: A story of competing land uses

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**Abstract**

While land protection is an increasingly popular means for communities to manage growth, its effectiveness is not well understood. Existing research has focused on the effect of land protection on development, overlooking its effect on future land protection. This paper fills an important gap in the literature on urban spatial structure by developing an empirical model of competing land uses to identify the feedback effects between land protection and development, using Boulder County, Colorado as a case study. I find that both protection and development are more likely to occur near protected parcels, but the increase in protection propensity is much greater than the increase in development propensity. The paper concludes with a simulation that incorporates endogenous land use to identify the parcels that were most likely to have been developed in the absence of land protection in Boulder County.

## 1 Introduction

A city's landscape matters a great deal to its residents, who are increasingly using public and private land conservation to maintain open space for recreation, environmental, and aesthetic amenities and to manage growth. In this paper I address the question: how does competition between conservation and development for the same land affect subsequent land use patterns? Previous research on land conversion has not considered the feedback between conservation and development in determining a community's landscape. In this paper I use land conversion data from Boulder County, Colorado to estimate an empirical model of land conversion that accounts for the interaction between development and conservation.

From 1999 though 2008, across United States voters passed 1,174 ballot initiatives to publicly fund open space and farmland preservation, totalling $37.8 billion (Trust for Public Land, 2009). Private conservation is also expanding rapidly, with the total number of private land trusts increasing by 32% between 2000 and 2005. Total acreage protected through private means increased by 54% over this period (Land Trust Alliance, 2005). In short, residents are voicing their preferences for open space preservation through their widespread support for publicly- and privately-funded preservation activities, and local governments and private organizations are responding. These initiatives are well-intentioned, but positive externalities from protected land may be associated with unintended consequences if protected land attracts more development further from the city center. Policy makers need to be aware of these possible effects so they do not diminish their own efforts at managing sprawl.

Despite the rapid increase in the popularity of land preservation as both a conservation and growth management tool, the effectiveness of land conservation in managing sprawl and protecting natural amenities is not well understood. Because land conservation and development both create positive and negative externalities that affect the probability of future conservation and development, either type of land use conversion today will affect future land conversion decisions on neighboring parcels. In aggregate, these land use conversion decisions determine a city's landscape and spatial structure. In this paper, I demonstrate how conservation and development compete for the same land, and how the interactions between conservation and development drive rural and suburban development patterns.

A city's spatial structure results from the interactions between numerous development and land protection entities, including municipal, county, state, and federal governments, private landowners, and conservation organizations. For example, in Boulder County, Colorado, the case study used for this paper's analysis, 36 public agencies have been involved in land preservation over the past 30 years. Specific information on particular private entities involved in land conservation in the county is unavailable. As a rough indicator of the involvement of private individuals and non-profit organizations in land conservation in the region, according to the Colorado Conservation Trust, in 2005 there were 46 land trusts operating in Colorado, protecting 2.4% of all land in the state. State and federal agencies protect another 42% of the land (Colorado Conservation Trust, 2005). A well-developed body of research has demonstrated that land protection significantly alters the rates at which a myriad of private developers convert raw, unprotected parcels to a developed state. However, the effects of both development and land protection on the rates of future conservation and the competition between development and protection have been overlooked. Given that large numbers of independent agents compete amongst themselves and with developers to protect individual parcels of land, a concurrent analysis of protection behavior is warranted. The current analysis fills this gap by modeling the competition between conservation and development for the same land, while considering the effect of current land use on future conversion for development and protection.

This is important, not just because of concerns about patterns of land protection, but also from the perspective of understanding the development process itself. This is because the land most desirable for development is often the land that residents most want to preserve. Thus, omitting the interactions between these land uses leaves one with an incomplete and inaccurate view of the process of suburban and rural land conversion.

Interactions between development and land protection arise from spatial externalities that each land use imposes on its neighbor - and, said neighbors' responses to these externalities. Previous research shows that individuals both value living near protected land (see McConnell and Walls (2005) for a comprehensive overview) and choose to locate near it. For example, Irwin and Bockstael (2004) and Smith, Poulos, and Kim (2002) demonstrate that protected land generates positive externalities for adjacent land. By creating an amenity, protecting land can increase adjacent development rates, diminishing ecological services, creating patchwork development patterns, and making it difficult for conservation entities to protect adjacent land in the future. In this analysis, I find that individuals prefer to build on raw parcels near protected land. However, due to competition with land protection interests, this effect differs depending on how recently the land was protected. As I describe in more detail in the Results section, this occurs largely because protection outcompetes development for undeveloped land near land that has been protected for a long period of time, while zoning regulations encourage both development and protection near recently protected land.

From a policy perspective, increasing our understanding of this process will enable private and public conservation interests to more effectively spend their limited resources. When development occurs near protected land, negative externalities from development can diminish the ecological services provided by the protected land. Ecological research demonstrates that land is best preserved in larger, contiguous tracts to protect migration corridors, minimize edge effects, and provide suitable habitat for species that require larger ranges (Armsworth, Daily, Kareiva, & Sanchirico, 2006). These conservation goals would be best met by establishing dense areas of development and large, contiguous protected parcels, not the patchwork development I described above. Along these lines, I find that the strategies used by land conservation groups in Boulder County have led to the clustering of protected land and developed land, with minimal patchwork of either protection or development.

Finally, because the process of land development and protection in Boulder County has nearly reached its end state (less than 10% of Boulder County's land is still raw), using Boulder as a laboratory for this analysis provides an opportunity to explore the entire process of land development and protection from start to finish.

The remainder of the paper is as follows: in the next section, I describe previous research on the relationship between land protection and urban spatial structure; in Section 3 I discuss the conceptual model I use to motivate my empirical work; in Section 4 I translate the conceptual model into an empirical approach; in Section 5 I describe the Boulder County data I use to estimate the model; in Section 6 I present the results from my empirical models; in Section 7 I simulate land use allocation in Boulder County in the absence of land protection to demonstrate the effect of land conservation on limiting development.

## 2 Literature Review

This paper builds on the presumption that people both value and are willing to locate near open space. In support of this premise I consider two lines of research that reinforce this supposition: one, research that estimates household value for open space and two, theoretical and empirical research addressing the effect of amenities on urban spatial structure. This research demonstrates that adjacent land use is an important determinant of land prices and significantly increases the probability of land conversion. Unfortunately, on the land protection side I am aware of no research analyzing the impact of proximate land uses on the probability of protection.

Extensive research in revealed and stated preference has demonstrated that individuals generally place a positive value on proximity to open space, as summarized by McConnell and Walls (2005). They find that individuals often have a positive value for open space, although the values vary widely depending on the size of the area, the proximity of the open space to residences, and the type of open space (Breffle, Morey, & Lodder, 1998; Peiser & Schwann, 1993; Bergstrom, Dillman, & Stoll, 1985; Rosenberger & Walsh, 1997).

What does this mean for a city's spatial structure? This paper builds on a broad foundation of theoretical and empirical research on the factors affecting a community's spatial structure, with particular attention to drivers of growth and development patterns. This section addresses the effect of the spatial allocation of amenities on urban spatial structure.

On the theory front, early monocentric city models (Mills, 1981; Titman, 1985; Wheaton, 1982) focused on a central business district (CBD), around which the urban area expanded as population increased. While insightful, these models were unable to explain why development does not necessarily occur contiguously with existing development. A patchwork pattern of development will arise when parcels repel or attract development on neighboring parcels due to negative or positive externalities, also known as "leapfrog" development. To explain this leapfrog pattern, researchers turned to models that account for the externalities associated with positive amenities such as open space or negative amenities such as pollution (Irwin & Bockstael, 2002; Strange, 1992; Turner, 2005; Wu, 2001; Wu & Plantinga, 2003; Wu, 2006). These authors found that open space designation can actually contribute to sprawl.[1] Using a model that specifically address the effect of different policies on urban sprawl, including an urban growth boundary (UGB), Bento et. al. (2006) find that despite its relatively high cost, a UGB is one of the most effective anti-sprawl policies.

Empirical work on the effect of open space on development patterns has largely focused on how proximity to environmental amenities affects the probability of development for individual parcels. Irwin and Bockstael (2004) apply the optimal development timing model developed in Irwin and Bockstael (2002) to large, subdividable parcels in Calvert County, Maryland. They find that the within-subdivision open space mandated by clustering policies leads to higher subdivision probabilities on adjacent land. These land use conversion models have been extended to evaluate incentives to target areas for higher density development (Irwin, Bell, & Geoghegan, 2003), to help target areas where preservation is most needed (Newburn, Berck, & Merenlender, 2006; Lewis & Plantinga, 2007) and to identify regional patterns (Carrion-Flores & Irwin, 2004). Walsh (2007) expands this work by allowing for

[1] Along these lines, Riddel (2001) provided empirical evidence from Boulder, Colorado that preserving land for open space can lead to more development when the area of land protected from development is smaller than the area of additional land developed in response to the designation of open space.

endogenous amenities, created as a result of the development process that creates more or less densely-settled communities. His work demonstrates that increasing the amount of publicly-preserved land can decrease the total quantity of open space in a region when households adjust the amount of privately-held open space.

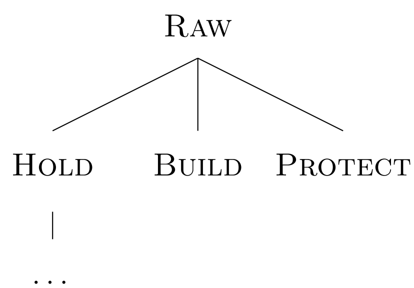
All of the literature discussed so far, with the exception of two papers (Walsh, 2007; Lewis & Provencher, 2007), has not addressed the fact that the amount and location of open space today will affect the amount and location of both development and protected land in the future. Theoretical models predict that if households place a sufficiently high value on land protection, development will be drawn to parcels closer to protected land. Empirical research has supported the theoretical models' predictions, finding that development rates increase near protected land, and these aggregated development decisions play an important role in determining where residential development occurs.

Interactions between development and land protection work to determine urban spatial structure. In the following sections I estimate this overlooked component of suburban and rural land conversion. Missing from the literature is an analysis of what influences the locations where land protection occurs and an evaluation of how this, in turn, affects a community's overall spatial structure.

# 3 Conceptual Model

Conceptually, I build on the theoretical model developed by Irwin and Bockstael (2002). I extend the single end use approach to incorporate multiple possible end uses. I use this framework to help identify which variables affect land use conversion decisions, understand how the different land uses interact, and sketch the intertemporal component of conversion decisions.

I assume owners of raw land have three alternatives: holding the land without changing its land use status, building on the land, or permanently protecting the parcel. As the decision tree in Figure 3 shows, I assume building and protection are "terminal": once a parcel is in either of these uses, the decision cannot be reversed. Landowners who hold their land in the current time period retain the option to hold, build, or protect in the future. The ellipsis indicate that all three land uses are still possible in later time periods, and this tree continues until all parcels are allocated to building or protection.




The landowner chooses the land use that maximizes net expected returns from the land, whether that is holding ($R_t^h$), building ($R_t^b$), or protecting ($R_t^p$). Returns from holding are a function of the maximum expected future value from either holding, building, or protecting in the next time period, as well as utility from not building in the current time period:

$$E[R_{it}^h] = \delta^{t+1} max(E[R_{i,t+1}^h], E[R_{i,t+1}^b], E[R_{i,t+1}^p]) + v_t^h, \tag{1}$$

where $R_{i,t+1}^h$, $R_{i,t+1}^b$, and $R_{i,t+1}^p$ are the total values of the option to hold, develop, or protect in $t+1$. The discount factor, $\delta$, is equal to $\frac{1}{1+r}$ where $r$ is the discount rate. If $R_h^{t+1}$ is replaced with $\delta^{t+2} max[E(R_{i,t+2}^h, R_{i,t+2}^b, R_{i,t+2}^p)] + v_{t+1}^h$, it is clear that the value of holding the land in $t$ includes the discounted expected value from each land use type in all future time periods. $v_{i,t}^h$ is the value from utility the landowner receives from not developing in $t$ and is defined as follows:

$$v_{i,t}^h = v^h(O^P, O^T, O^D, g, x_i) \tag{2}$$

To capture the effects of externalities from adjacent land uses on a parcel's conversion probability, I include a set of adjacent land use measurements. $O^P$ is the percentage of adjacent land comprised of permanently protected open space, $O^T$ is the percentage of surrounding land comprised of temporarily undeveloped land, and $O^D$ is the density of surrounding lots. Higher density means less "private" open space in the form of large yards. Trends in land use near a parcel are likely to affect conversion probabilities when landowners adjust their expected returns from each land use to reflect their expectation of future land use composition in the area. The matrix $g$, which includes the rate at which land has been converted to built ($g^b$) and protected status ($g^p$) near the parcel, allows landowners' value function to be updated when trends change. $x_i$ is a vector of time invariant parcel characteristics that account for a parcel's building cost as well as desirability for each land use.

Returns from building are a function of the net present value of the parcel in a developed state and the one-time conversion cost:

$$R_{it}^b = \left(\sum \delta^t v_{it}^b\right) - c_{it}, \tag{3}$$

where $c_{it}$ is the cost of land conversion and $v_{it}^b$, the building value function, is a function of open space levels and parcel attributes:

$$v_{it}^b = v^b(O^P, O^T, O^D, g, x_i, m_t) \tag{4}$$

Like the value function for holding the land, $v_{it}^h$, I include measures of adjacent land use ($O^P$, $O^T$, and $O^D$) to account for externalities generated by adjacent land uses and trends in nearby land use, $g$, to account for updated landowner expectations about values from building. I expect development pressure to change in response to changes in macroeconomic variables, including unemployment levels, real estate market vigor, and the availability of credit for construction loans. These macroeconomic conditions are incorporated in $m_t$.

Returns from protection are a function of the net present value of the parcel and the one-time conversion cost:

$$R_{it}^{p} = \left(\sum \delta^{t} v_{it}^{p}\right) - c_{it}, \tag{5}$$

Although previous research has only addressed the effect of adjacent land use on development propensity, it is likely that the factors affecting development propensity would also affect protection propensity. Therefore I assume the protection value function, like the building value function, is a function of the levels of three measures of adjacent land use, parcel size, parcel-specific attributes, and macroeconomic conditions:

$$v_{it}^{p} = v^{p}(O^{P}, O^{T}, O^{D}, g, x_i, m_t) \tag{6}$$

Although these three value functions have similar variables, I assume that the value functions for each land use differ. Therefore adjacent land use, growth rates, parcel attributes, and macroeconomic conditions affect each land use differently.

Land will transition from a raw state to one of the two other uses once returns from that use exceed the expected value of holding the land:

$$max(R_{it}^{b}, R_{it}^{p}) - E[R_{it}^{h}] \geq 0 \tag{7}$$

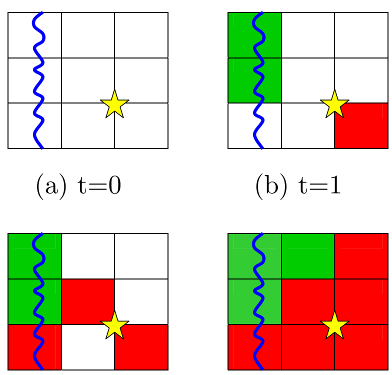
Assuming parcel attributes and macroeconomic characteristics are constant over time, returns from each land use will change when adjacent land uses change.

# 4 Empirical Strategy

## 4.1 Characterizing land use conversion for multiple land uses

To characterize land use conversion, I make two main modeling decisions. First, in a departure from existing literature, I jointly model the factors affecting both the probability of land conversion for development and protection. To my knowledge, this is the first analysis to handle the process of land protection in this manner. Second, to accomplish this task, I chose to model the conversion process using a hazard model of competing risks, rather than a simple hazard model of individual risks, to account for the possibility of competition between these two alternative land uses.

Using a simple illustration in a hypothetical county over four time periods, Figure 1 demonstrates the importance of including competing land uses in models of land use conversion. In this simple case there are nine parcels in the county, with a river running through the three western parcels and a city center located in the southeastern corner of the county, denoted by the star. Red indicates development and green indicates protection. In t=0, all nine parcels are raw. In t=1, two parcels are protected along the river and one parcel is built adjacent to the city center. In t=2, two more parcels are built adjacent to the protected parcels and in t=3 the remaining parcels fill in; one is protected adjacent to the original protected parcels and the remaining three are developed.



(a) t=0 (b) t=1

(c) t=2 (d) t=3

Figure 1: Simplified illustration of land conversion

Confronted with this pattern of development, what interences should be drawn? First, we see that protecting riparian corridors is a high conservation priority. Without considering the timing of protection, it also appears that access to riparian areas is not very important for development. However, when we account for the competition arising for this parcel from protection activities, it becomes clear that protection simply arrived first, out-competing development for riparian areas. Similarly, in t=3 protection occurred on a parcel contiguous to existing protection. We could conclude that contiguity has become a higher priority than riparian protection. Instead, we know that this is likely a second-best protection alternative because development has already won the competition for the remaining riparian parcel in t=2. This pattern of competition between land uses is only apparent when one models changes in both land uses over time. In the analysis of land use change in Boulder County, I find similar patterns of competition between protection and development.

I use a hazard model of competing risks to allow for the estimation of the effect of adjacent land use on protection and development probabilities simultaneously. Alternatively, I could have modeled these two types of land conversion separately in independent simple hazard models with one failure type in each. In this approach, built parcels can only become built and protected parcels can only become protected. Estimating two simple hazard models, however, has two main drawbacks in this application. First, the competing model matches my conceptual better far better, as any parcel is allowed to convert to either land use category, or remain raw, in each time period. Second, for policy simulations the competing hazard model provides the necessary flexibility to evaluate how land use policies change the probability that a parcel of land is built or protected, or remains raw. Separate simple hazard models for each land use do not allow simulations to predict, for example, that a built parcel would be protected under an alternative land use policy, or vice versa.

## 4.2 Empirical model

As presented in Equation 7, the landowner will convert their land to a new use when they are indifferent between holding their land for another time period and converting today, the timing of which is a function of the parcel's adjacent land use, attributes, and macroeconomic conditions. In practice, it is impossible to observe all factors that will affect the probability that a landowner holds, builds, or protects a parcel. By expanding the approach used by Irwin and Bockstael (2002) to allow for multiple conversion types, I include a stochastic error term $\varepsilon$ to the returns to holding, building, and protecting in Equations 1, 3, and 5. Doing this replaces the zero in Equation 7 with the difference in error terms for the most valuable and second-most valuable land uses. Using algebra to isolate the error terms on the left side of the inequality allows me to characterize the decision rules as the probability of conversion to each land use:

$$Prob(built) = Pr\{\varepsilon^b - (\varepsilon^p | R^p > E[R^h]) < R^b - max(R^p, E[R^h])\} \tag{8}$$

$$Prob(protected) = Pr\{\varepsilon^p - (\varepsilon^b | R^b > E[R^h]) < R^p - max(R^b, E[R^h])\} \tag{9}$$

In the above equations, I assume that holding the land is the least-valuable land use to ease exposition.

To describe the instantaneous probability that a parcel is converted at a given time $t$, I characterize $\varepsilon$ as a function of $t$, where $F(\varepsilon(t))$ is the cumulative distribution function of $\varepsilon$, describing the cumulative probability of failure at $t$. Let $\varepsilon_b^*$ and $\varepsilon_p^*$ be the value of the error term that equates Equations 8 and 9, respectively. Thus these values for $\varepsilon$ make the land owner indifferent between converting their land and holding until the next time period.

Given this characterization of heterogeneity of returns to each land use, the probabilities of conversion to built and protected at time $t$, given that it has remained raw until $t$, are as follows:

$$\lambda_i^b(t) = \frac{F[\varepsilon_b^*(t+1)] - F[\varepsilon_b^*(t)]}{1 - F[\varepsilon_b^*(t)]} \tag{10}$$

$$\lambda_i^p(t) = \frac{F[\varepsilon_p^*(t+1)] - F[\varepsilon_p^*(t)]}{1 - F[\varepsilon_p^*(t)]} \tag{11}$$

The term $1 - F[\varepsilon^*(t)]$ is equivalent to the survival function, $S(t)$, which estimates the probability an individual has survived until time $t$. These hazard rates represent the change in the probability of being built or protected between the current time period and the next, relative to the probability of remaining raw until the current time period (Kalbfleisch & Prentice, 2002).

$\lambda^b$ and $\lambda^p$ define the subhazards of conversion. The total probability of conversion in $t$ is:

$$\lambda_i(t) = \lambda_i^b(t) + \lambda_i^p(t) \tag{12}$$

I use the Cox proportional hazard model to estimate these probabilities, assuming the building subhazard takes the following general, multiplicative form:

$$\lambda_i^b(t) = \lambda_0^b(t) exp(X_i'\beta), \tag{13}$$

where $\lambda_0^b$ is the baseline hazard for building, $exp(X'\beta)$ is the relative hazard, and $X$ is a vector of parcel-specific attributes. Thus the relative hazard shifts the baseline hazard up or down, depending on a parcel's values of $X$ (Cox, 1972).

I assume the baseline hazard for protection is proportional to the baseline hazard for building, such that:

$$\lambda_0^p(t) = \lambda_0^b(t) exp(\delta) \tag{14}$$

To simplify notation, I shorten $\lambda_0^b$ to $\lambda_0$[2]. As I discussed in Section 3, I expect adjacent land use, parcel attributes, and macroeconomic conditions to have a different effect on the returns to building and protecting. To accommodate these differing effects I estimate a vector of coefficients, $\theta$, for interactions between the indicator for protected parcels, $I_p$, and the vector

[2] As a robustness check, I also specified the model allowing the baseline hazards to vary between built and protected parcels, with equivalent results. As the reported coefficients from these models are relative to the baseline hazard, forcing proportionality makes comparing marginal effects between built and protected parcels much simpler

of parcel attributes, $X$. Therefore the protection hazard rate is:

$$\lambda_i^p(t) = \lambda_0^b(t) exp(X_i'\beta + \delta I_p + I_p\theta' X_i), \tag{15}$$

The baseline probability of conversion, all other variables equal, is shifted down by a factor of $exp(\delta)$ and the relative hazard is shifted by $exp(\theta X_i)$ for protected parcels. The vector $\beta$ provides an estimate of the effect that $X$ has on the probability of building and $\beta + \theta$ provides an estimate of the effect of $X$ on the probability of protection.

The most attractive feature of the Cox model is that it obviates the need to make any assumptions about the functional form of the baseline hazard. By setting the problem up as a comparison between the hazard of the parcel that transitions relative to the hazards of all the other parcels that are raw in $t$, the baseline hazards cancels out in the following partial likelihood function[3]. The first term represents the building subhazard, the second represents the protection subhazard:

$$L_i = \left( \frac{\lambda_0(t) exp(X_i'\beta)}{\sum_j \lambda_0(t) exp(X_j'\beta)} \right) \left( \frac{\lambda_0(t) exp(X_i'\beta + \delta I_p + I_p\theta' X_i)}{\sum_j \lambda_0(t) exp(X_i'\beta + \delta I_p + I_p\theta' X_i)} \right), \tag{16}$$

$j$ indexes all parcels that were raw at the beginning of $t$ (Putter, Fiocco, & Geskus, 2007).

Equation 16 summarized the structure of the likelihood function for the competing hazard model. Further detail on the components of the model I use to estimate land transition probabilities follows:

$$L = \frac{exp((X_i + O_{it})'\beta + \delta_i I_p + I_p\theta'(X_i + O_{it}) + \upsilon_z + \tau_t + \gamma_{zt}^b + \gamma_{zt}^p)}{\sum_j exp((X_i + O_{it})'\beta + \delta_i I_p + I_p\theta'(X_i + O_{it}) + \upsilon_z + \tau_t + \gamma_{zt}^b + \gamma_{zt}^p)}, \tag{17}$$

I have separated the vector of parcel-specific attributes, $X$, into one vector of time-invariant

[3] If I did not assume proportional hazards between failure type and allowed different functions for $\lambda_0^b$ and $\lambda_0^p$, the baseline hazards would still drop out of each term

parcel attributes ($X$) and one vector of time-variant adjacent land attributes ($O$). The estimated model includes two sets of fixed effects. $\upsilon$ is a zipcode-level fixed effect, to control for time-invariant, unobservable differences between zipcodes. $\tau$ is a year fixed effect to control for unobservable differences between years across the study area, such as changes in the real estate market or unemployment. I include recent growth rates on nearby parcels: $\gamma^b$ is the number of parcels built of all remaining raw parcels within the zipcode, averaged over the previous three years, and $\gamma^p$ is the number of parcels protected of all remaining raw parcels in the zipcode. This will control for trends in building and land protection on nearby land, addressing the concern that land protection is endogenous to building rates and vice versa. For example, if protection only happens when an area is threatened by rapid development, $\gamma^b$ will control for this potential endogeneity problem.

The next section presents the components of vectors $X$ and $O$ in detail, along with descriptions of the study area and land transition patterns.

# 5 Data

I conduct this analysis using data for Boulder County, Colorado. Figure 2 shows the county, the geographic center of its incorporated towns, and distinguishes between the mountains (in green) and plains (in yellow), where mountains are defined as any parcel with an elevation exceeding 5,750 feet.[4]

Boulder County is a particularly useful case to study for two reasons. First, because less than 10% of the land in the county remained available for either development or protection as of 2005, I can observe the evolution of a community's spatial structure from start to near finish. Thus, the analysis presented here is useful from the perspective of communities that

[4] In 1959 the city amended its charter to prohibit providing city water and sewer above 5,750', or what is known as the "Blue Line." Although this move did not prohibit development in the foothills above the city, it did slow its pace. Due to changes in topography and city services available above this point, the mountains and plains are analyzed separately.

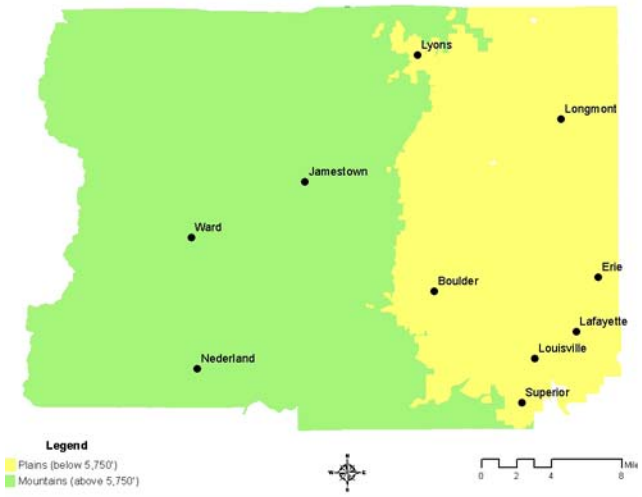



Figure 2: Boulder County cities and regions

are currently experiencing the rapid development and protection that occurred in Boulder County over the past 30 years. Second, in Boulder County, numerous conservation interests, often trying to accomplish multiple goals with their open space purchases, have participated in land conservation over the 33 years of this study period. These various agencies and organizations serve to highlight the different factors that drive protection decisions. For example, land that may be ideal for recreation, such as parcels that are easily accessible from major roads or are near population centers, may be less valuable for providing habitat for threatened species. While heterogeneous land conservation motivations all do result in land being protected, when motivations differ, the types of land protected may differ as well. By analyzing the conservation of many parcels by numerous agents over an extended time period, this study aims to identify which attributes are, overall, the most important factors in determining a parcel's protection status.

## 5.1 Land Protection in Boulder County

Boulder County is well-known for its long-standing and aggressive open space policies, with the first land in town being protected in 1898 at the base of the Flatirons, Boulder's signature rock formations. In 1967, the city became the first in the country to approve a sales tax specifically levied to preserve open space. This initial effort has been followed by a handful of sales tax increases and bond issues by the city and county for open space purchases. Because public funds to purchase open space are tied to sales tax revenue, population growth translated into increased development pressure but also increased resources for land protection. The county has also promoted voluntary open space preservation for developers seeking to subdivide land. There are several programs - the most popular of which is the Non-urban Planned Unit Development (NUPUD) - but all require the developer to set aside a certain amount of land as protected open space in exchange for being allowed to build more densely on the remaining parcel.

These open space protection policies, along with large tracts of federally-owned land in the foothills and numerous smaller conservation easements, have led to over 65% of the land in the county being permanently protected. Figure 3 shows land use allocation in the county as of 2005. Red areas are built, blue are protected, and white areas are parcels that remained raw in 2005. Purple areas show parcels that were dropped because they were commercial properties, multi-family dwellings, or parcels that were protected at an unknown date.

Of the parcels protected in the Boulder County prior to 1972, 89% were protected by the federal government, primarily through the U.S. Forest Service. Most of these parcels were very large (8,463 acres, on average) and located in the mountains, and had high value for timber or mineral resources. After 1972, local and private conservation interests dominated land conservation in the county, with city and county governments protecting 70% of all parcels and private interests and non-profit land trusts protecting 29%. State and local governments protected these parcels for wide-ranging reasons, including protecting watersheds and wildlife habitat, creating urban open space, establishing recreation areas, and preserving agricultural areas. Privately held protected land had similarly heterogeneous motivations for its establishment, but these parcels tended to be much smaller, averaging only 49 acres as opposed to the 171 and 115 acres for state and local governments, respectively.

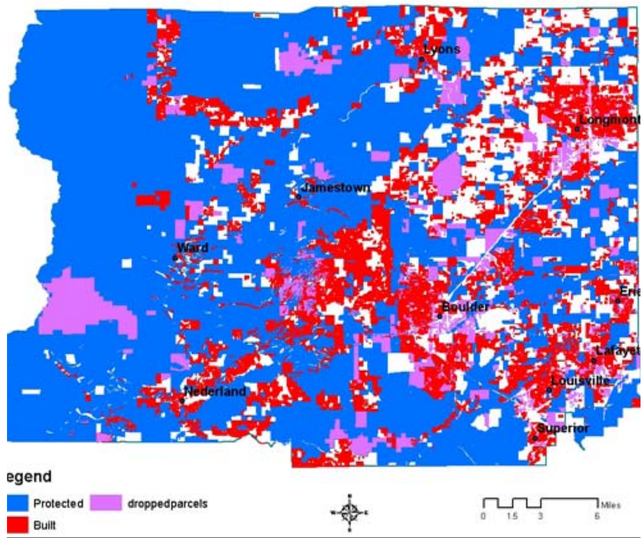



Figure 3: Boulder County land use, 2005

## 5.2 Data sources

I use the Colorado Ownership, Management and Protection (COMaP) Database, version 7 for the location and type of protected land through 2005. This dataset is relatively unique in that it contains data on all protected land in Colorado - both public *and* private. In addition to location, the COMaP dataset reports the year the parcel was protected.

To determine the date when a parcel was built, the year when a building permit was first issued for each parcel is identified, using data from the Boulder County Assessor's Office. I consider a parcel undeveloped until the year when the permit was issued and developed afterwards. This office also provided me with spatial data regarding each parcel's location and size, and whether it is in commercial use. I omit all commercial land from the dataset. From the Boulder County Land Use Department (BCLUD) I obtained data on the location and filing year for subdivisions, beginning in 1972. Subdivision is associated with higher rates of development and lower rates of protection, so to control for these differences I include an indicator for subdivision.[5] Land cover data came from the Colorado Gap Analysis Project, which uses Landsat imagery to interpolate habitat and vegetation cover throughout Colorado (http://ndis1.nrel.colostate.edu/cogap/). All other parcel data came from downloadable GIS files from the BCLUD.

I include five categories of explanatory variables in the model: adjacent open space characteristics, land cover types, current zoning, proximity to other amenities, and physical characteristics. As I present in Table 1, built parcels differ significantly from protected parcels across many of these variables.

I include six measures of adjacent land use to estimate different possible motivations for building and protecting land and identify substitutes for protected open space:

1. Undeveloped but developable vacant land, or "raw" land. Previous research such as Irwin and Bockstael (2001) has demonstrated that individuals place a premium on land that is undeveloped even if it is not protected.

2. Open space protected within the previous three years. I treat this type of protected land separately to account for transitions bundled with either development or other land protection (e.g., protecting open space within a new development or bundling protected parcels to create contiguous protected areas).

3. Open space protected more than three years prior to the current period.

4. The average building rate in the zipcode three years prior to observation date. This measures the rate of change of the supply of undeveloped, unprotected land in the area around a parcel.

5. The average protection rate in the zipcode three years prior to the observation date.

[5]Subdivision can be considered an intermediate land use, after which parcels are either built or protected. Although this intermediate conversion status can be modeled, for tractability I only consider the two "terminal" land uses.

This measures the rate of change of the supply of protected land.

6. The number of lots per acre surrounding the parcel; higher density means less private open space. This provides an estimate of the amount of "private" open space surrounding a parcel in the form of yards. Previous research has shown that private open space can be a substitute for public open space, even when access is prohibited (Kopits, McConnell, & Walls, 2007).

I calculated the amount of adjacent open space by creating a tenth mile buffer around the boundary of each parcel, calculating the percentage of parcels within that buffer that were raw and protected land. I consider this buffer a parcel's "neighborhood".[6] The adjacent land characteristics reported in Table 1 reflect land use at the time a parcel converted. For estimation, I include observations for all years leading up to a parcel's conversion.

Boulder County straddles the transition from the plains to the Rocky Mountains. The plains are characterized by agricultural land that is generally closer to population centers, and is relatively flat and therefore easier to develop. Parcels in the mountains are generally further from population and employment, with steeper slopes, rocky soils, and long winters that make building more difficult. Additionally, the mountains had extensive existing protected land in 1972, whereas the plains had relatively little. These differences between the mountains in the plains may translate into different underlying land conversion processes. To allow for different land conversion processes, I analyze the mountains and plains separately.

The summary statistics presented in Table 1 reflect the fact that the mountain landscape is characterized by very large protected areas clustered together and building occurring in interspersed corridors. On the plains, land use is much less clustered so both types have similar levels of raw land. Whether in the mountains or plains, protected parcels have

[6] I also estimated all models using the percentage of acres within the buffer rather than a count of parcels, with similar coefficients but larger standard errors. I also estimated all models using a quarter mile buffer around each parcel and found that open space this far away had little to no effect on development or protection propensity.

Table 1: Parcel summary statistics for mountains and plains

| | | Built parcels | | | | Protected parcels | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Mountains | | Plains | | Mountains | | Plains | |
| variable | Description | mean | median | mean | median | mean | median | mean | median |
| Adjacent open space characteristics when parcel transitions | | | | | | | | | |
| pctcountraw | % of adjacent parcels that are vacant and unprotected | 49% | 48% | 38% | 33% | 32% | 33% | 40% | 36% |
| pctcountLess3 | % of adjacent parcels protected within previous 3 years | 0.17% | 0.0% | 0.18% | 0.0% | 0.64% | 0.0% | 0.02% | 0.0% |
| pctcountMore3 | % of adjacent parcels protected over 3 years ago | 4.36% | 0.0% | 0.34% | 0.0% | 54.45% | 50.0% | 32.8% | 25.0% |
| avebuildrate | Average building rate in zipcode | 2.6% | 2.5% | 6.7% | 5.2% | 2.6% | 2.2% | 6.3% | 6.1% |
| aveprotrate | Average protection rate in zipcode | 0.3% | 0.1% | 0.2% | 0.0% | 1.5% | 1.3% | 0.9% | 0.4% |
| density | Lots per acre in tenth-mile buffer | 1.0 | 0.8 | 6.0 | 6.2 | 0.4 | 0.1 | 0.9 | 0.2 |
| Parcel land cover types | | | | | | | | | |
| stream | =1 if perennial stream on property | 17% | 0.0% | 0.5% | 0.0% | 46% | 0.0% | 16% | 0.0% |
| streammajor | =1 if major stream on property | 1.6% | 0.0% | 0.2% | 0.0% | 11% | 0.0% | 14% | 0.0% |
| ditch | =1 if irrigation ditch on property | 0.5% | 0.0% | 2.5% | 0.0% | 5% | 0.0% | 51% | 100% |
| forest | =1 if parcel contains forested land | 91% | 100% | 0.5% | 0.0% | 83% | 100% | 0.6% | 0.0% |
| shrub | =1 if parcel contains shrubland | 10% | 0.0% | 6.4% | 0.0% | 16% | 0.0% | 17% | 0.0% |
| ag | =1 if parcel is in agriculture | 0.0% | 0.0% | 50% | 0.0% | 0.0% | 0.0% | 78% | 100% |
| urban | =1 if parcel is urban | 0.5% | 0.00% | 46% | 0.0% | 0.0% | 0.0% | 19% | 0.0% |
| Parcel zoning | | | | | | | | | |
| subdivision | =1 if parcel is in a subdivision | 6% | 0.0% | 7% | 0.0% | 2% | 0.0% | 0.0% | 0.0% |
| forestry | =1 if parcel is in forestry zoning | 84% | 100% | 0.0% | 0.0% | 80% | 100% | 2% | 0.0% |
| agzoning | =1 if parcel is in agriculture zoning | 3% | 0.0% | 4% | 0.0% | 13% | 0.0% | 63% | 100% |
| incity | =1 if parcel is inside city limits | 11% | 0.0% | 86% | 100% | 7% | 0.0% | 29% | 0.0% |
| Proximity to other amenities | | | | | | | | | |
| distschool | Distance to school, miles | 3.55 | 3.20 | 0.77 | 0.57 | 3.13 | 2.56 | 1.68 | 1.55 |
| distmainroad | Distance to main road, miles | 0.92 | 0.75 | 0.24 | 0.18 | 0.88 | 0.66 | 0.35 | 0.26 |
| distnearestcity | Distance to nearest city's center, miles | 4.21 | 4.04 | 1.96 | 1.81 | 3.96 | 3.62 | 3.01 | 2.98 |
| Parcel physical characteristics | | | | | | | | | |
| acres | Parcel size, acres | 5.17 | 1.88 | 0.39 | 0.19 | 105.60 | 19.69 | 36.30 | 18.29 |
| sloperange | Range of slope steepness | 9% | 8% | 0.5% | 0.1% | 19.8% | 17.8% | 4% | 2% |
| slopemean | Average slope steepness | 8% | 7% | 1% | 0.6% | 9.5% | 9.2% | 1.3% | 0.8% |
| meanelevft | Mean elevation, feet | 7,596 | 7,904 | 5,232 | 5,211 | 7,740 | 7,926 | 5,259 | 5,242 |
| Number of parcels | | 3,501 | | 43,684 | | 778 | | 1,379 | |

a higher percentage of protected land around them than do built parcels. Land protection tends to occur in zipcodes where more land has been recently protected, suggesting clustering of protection in particular areas. Building rates within a parcel's zipcode, however, are essentially identical between built and protected land, suggesting that parcels in rapidly developing areas are not being targeted for protection. Building tends to happen in more densely platted neighborhoods; higher density means smaller yards and therefore less private open space.

I include land cover types to control for the cost of building and, most importantly, to control for land cover types that tend to be correlated with land protection. In the mountains, protected land is characterized by water features, shrublands, and agriculture, while built land is generally urban and/or forested. On the plains building tends to occur on lands identified as agricultural or urban; likewise for protected land. Land protection on the plains also tends to occur on parcels that contain an irrigation ditch, common on agricultural parcels.

Zoning, similar to land cover, also addresses building and protection feasibility. I use a parcel's location relative to the city boundary as a proxy for city water and sewer services. These zoning boundaries change over time as urban areas grow; unfortunately I could only obtain current zoning boundaries and must assume that they have not changed significantly.

In the mountains, development most commonly occurs in areas zoned for forestry, largely because almost all of the land is zoned for forestry. On the plains, almost all building occurs within city limits, with relatively little occurring in areas zoned for forestry or agriculture. Protected land in the mountains tends to occur on parcels zoned for forestry, whereas on the plains land is generally protected on parcels zoned for agriculture, with a large portion occurring within city limits. Very little land is protected within subdivisions.

I include controls for proximity to schools, the nearest city center, and major roads to control for the desirability of different parcels for development as a function of their access.

In the mountains, both built and protected parcels tend to be relatively far from schools, main roads, and the nearest city. On the plains, however, protected parcels are located much further from all amenities than built parcels.

To control for the effect a parcel's physical characteristics have on its attractiveness for development and protection, I include elevation, mean slope, the range of slope, and size. In both the mountains and plains, protected parcels are larger and steeper than built parcels. This reflects the fact that steeper land is more expensive to build upon, while larger parcels will protect more contiguous habitat. Protected parcels are also much larger than built parcels, and both built and protected parcels in the mountains are larger, on average, than parcels on the plains.

### 5.3 Transition Rates

Prior to moving on to the Results section, it is useful to observe building and protection conversion rates. Figure 4 presents the average hazard rates for building and protection across the county from 1972-2005, calculated as the number of parcels that were built (or protected) divided by the number of remaining raw parcels. In general, protection rates and building rates have followed similar paths over time, likely reflecting the fact that increased population leads to increases in conservation funding through greater tax revenue and increased donations to private conservation organizations.

Figure 5 shows average annual building (Panel a) or protection (Panel b) rates on the parcels surrounding a protected parcel before and after it is protected. These rates were subtracted from mean building and protection rates, respectively, in the county to control for trends in land conversion rates. This graph shows that land protection temporarily disrupts the development process, but is later associated with more development than occurred previously. On the plains, land protection also decreases adjacent protection, but causes a large increase in the mountains, suggesting that multiple adjacent parcels tend to be protected

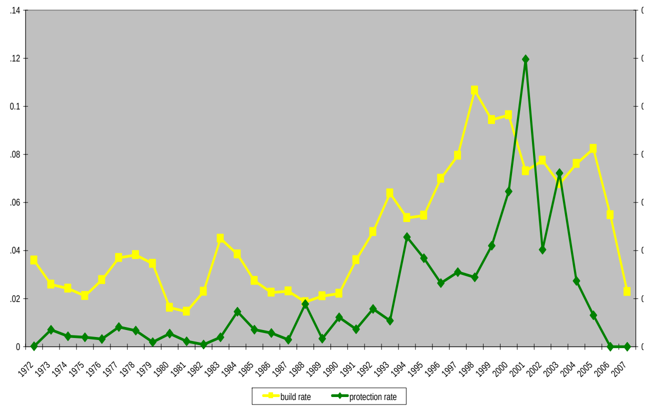
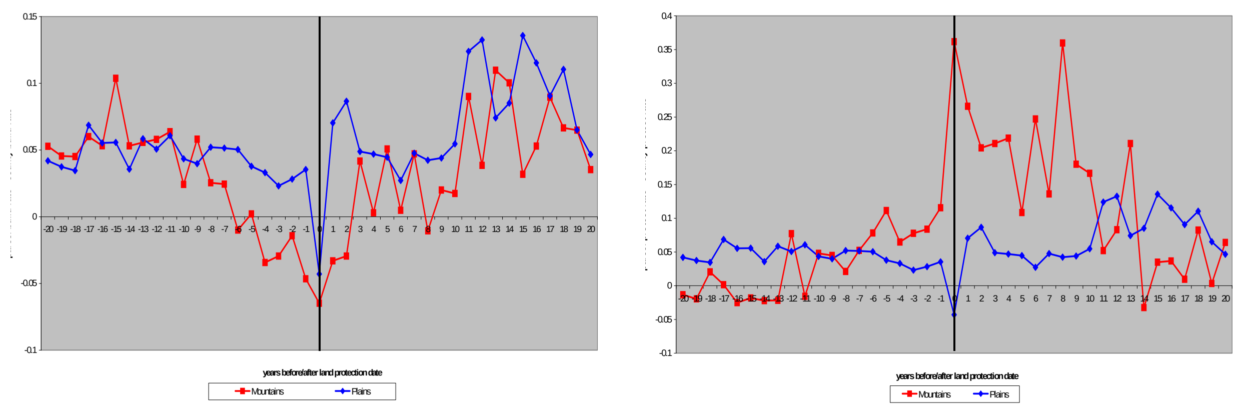



Figure 4: Average hazard rates for built and protected land in Boulder County, 1972-2005

concurrently in the mountains, but not on the plains.




(a) Development rates

(b) Protection rates

Figure 5: Average transition rates on land adjacent to open space, before and after land protection

# 6 Results

I present results estimated using the competing hazard model, with robust standard errors clustered at the zipcode level. To facilitate interpretation, I report all results as the change in the probability of development or protection, given a one standard deviation change in the covariate. For built parcels, these are calculated as $exp(\beta s)$, where $s$ is the standard deviation for the covariate. For protected parcels these are calculated as $exp((\beta + \theta)s)$, where $\beta$ is the coefficient for built parcels and $\theta$ is the shift parameter for protected parcels. All models are estimated using zipcode and year fixed effects. Tests of joint significance for year and zipcode fixed effects are both highly significant ($p<0.0001$). I estimate conversion propensities separately for the mountains and plains, to account for differences in geography and access. Although I jointly estimate a parcel's development and protection propensities, I report the results separately.

## 6.1 Protection Propensity

In both the mountains and plains, land use variables within a parcel's neighborhood (tenth mile buffer) generally have the largest impact on a parcel's probability of being protected. In Sections 6.1.1 and 6.1.2 I discuss results for the mountains and plains separately.

### 6.1.1 Mountains

As reported in Table 2, the presence of permanently protected open space has the biggest effect on protection propensity for mountain parcels. The values reported in this table are equal to the coefficient multiplied by the standard deviation for that variable. These values are reported instead of the coefficients themselves to facilitate interpretation, and are essentially scaled coefficients. The model predicts that adjacent older open space increases protection probability the most, with a one standard deviation increase in older open space increasing the probability of protection by 2.9 times. These results suggest that, across the many conservation agents in Boulder County, purchasing land near existing open space to make larger contiguous blocks of protected land or connect already-protected land consistently drives land conservation. Recently protected open space has a much smaller effect.

Land protection also tends to occur in neighborhoods with lower lot densities (more

Table 2: Hazard rates for changes in protection probability given a one standard deviation increase in covariate values

| | Mountains | | | Plains | | |
|---|---|---|---|---|---|---|
| Variable | Mean | Std Dev | △pr(prot) | Mean | Std Dev | △pr(prot) |
| pctraw | 0.278 | 0.28 | 181%*** | 0.317 | 0.25 | 43%*** |
| pctopenspaceLess3 | 0.001 | 0.02 | 10%* | 0.001 | 0.01 | 7%*** |
| pctopenspaceMore3 | 0.141 | 0.22 | 291%*** | 0.018 | 0.09 | 47%*** |
| avebuildrate | 0.021 | 0.02 | 21%* | 0.063 | 0.04 | 25%** |
| aveprotectrate | 0.003 | 0.01 | 23%** | 0.002 | 0.004 | 8%** |
| density | 1.091 | 1.53 | -32%* | 5.464 | 2.78 | -67%** |
| stream | 0.223 | 0.42 | 15%*** | 0.017 | 0.13 | 0% |
| stream_major | 0.039 | 0.19 | 1% | 0.011 | 0.1 | 4%** |
| ditch | 0.011 | 0.1 | 1% | 0.06 | 0.24 | 13%*** |
| forest | 0.905 | 0.29 | -9%* | 0.007 | 0.09 | -13%** |
| shrub | 0.087 | 0.28 | 54%** | 0.07 | 0.25 | 12% |
| ag | 0 | 0.02 | -61%*** | 0.532 | 0.5 | 52% |
| urban | 0.003 | 0.06 | 3%*** | 0.426 | 0.49 | 1%** |
| subdivision | 0.032 | 0.18 | -8% | 0.067 | 0.25 | -60%*** |
| milestofastroad | 0.926 | 0.7 | -9%** | 0.256 | 0.24 | -3%*** |
| milestoacity | 4.096 | 2.39 | -14% | 2.059 | 1.32 | 9% |
| milestoschool | 3.584 | 2.36 | -10% | 0.856 | 0.74 | 1% |
| forestry | 0.833 | 0.37 | 9% | 0.002 | 0.04 | 10%*** |
| ag_zoning | 0.051 | 0.22 | 3% | 0.086 | 0.28 | 7% |
| sloperange | 11.451 | 9.54 | 16%** | 0.703 | 1.92 | -3% |
| slopemean | 7.997 | 4.25 | 1% | 1.011 | 1.16 | 11%* |
| meanelevft | 7,754 | 1,039 | -11% | 5,226 | 196.49 | 36%** |
| incity | 0.111 | 0.31 | 16%** | 0.819 | 0.39 | -25%** |
| acres | 17.16 | 115.87 | 19%* | 2.412 | 14.26 | 12%*** |
| type | 0.107 | 0.31 | -86%*** | 0.027 | 0.16 | -81%** |
| Significance levels : | $*$ : 10% | $**$ : 5% | $***$ : 1% | | | |

"private" open space) and higher proportions of raw land. When the percentage of adjacent raw land near a mountain parcel increases by one standard deviation, a parcel's probability of being protected increases by 1.8 times. More private open space - lower density - is associated with a 32% decrease in protection probability in the mountains. These finding suggest that raw land and private open space are complements for permanently protected land.

Recent land use conversion rates within the parcel's zipcode significantly affect its protection propensity. The model predicts that an increase in the zipcode protection rate by 1 percentage point will increase the probability of protection by 23% and a 2 percentage point increase in building rate will increase protection probability by 21%. These findings suggest that protection and development tend to occur in the same areas, but recent protection has a stronger effect on future protection than recent development has on future protection.

The coefficient on the indicator for protected parcels indicates that parcels are 86% less likely to be protected than built in the mountains. This reflects that building is more prevalent than protection, all else equal. Protection tends to occur on parcels that are in shrubland, contain a perennial stream, have steeper slopes, are not located in a forest or agricultural land, or are closer to a main road. Protection is also more likely on larger parcels. Because raw land in the mountains is generally in or near a town, mountain parcels in cities and in areas with urban land use are more likely to be protected.

### 6.1.2 The Plains

On the plains, protection is much more likely to occur in neighborhoods with lower density. The effect of adjacent permanent protection is similar to the mountains, with the presence of older open space substantially increasing protection probability and recently protected land having a much smaller effect. Parcels with higher proportions of raw adjacent land are also more likely to be protected.

Higher recent protection rates within the parcel's zipcode increases its protection probability by 8%. The recent development rate in the zipcode increases protection probability by 25% for a 4 percentage point increase in building rate. These findings suggest that open space entities have been targeting areas with more rapid development and therefore at higher risk of being developed.

Parcels on the plains are more likely to be protected if they include a major stream or irrigation ditch. Parcels outside forested areas, currently in agricultural use, outside a subdivision, zoned for forestry, or with steeper slopes are more likely to be protected. The model predicts a small decrease in protection probability as distance to a major road increases, but finds no effect from other access attributes. Larger parcels are also much more likely to be protected. These results suggest that land protection groups have targeted "open" lands - large spaces, particularly in agricultural use, that preserve the plains landscape that characterizes eastern Boulder County.

## 6.2 Development Propensity

As with protected parcels, land use variables within a parcel's neighborhood and zipcode consistently have the largest impact on a parcel's development propensity, relative to other adjacent land use measures. Table 3 reports predicted changes in a parcel's development probability due to a one standard deviation increase in the covariate.

### 6.2.1 Mountains

In the mountains, the amount of adjacent raw land is the largest factor determining a parcel's development propensity, with an additional 28 percentage points of raw land increasing building probability by 72%. New open space significantly increases building probability, but only by 5%, suggesting that bundling open space and development plays a small but significant role in determining the county's land use allocation. On the contrary, older

Table 3: Hazard rates for changes in development probability given a one standard deviation increase in covariate values

| | Mountains | | | Plains | | |
|---|---|---|---|---|---|---|
| Variable | Mean | Std Dev | △pr(built) | Mean | Std Dev | △pr(built) |
| pctrawcount | 0.28 | 0.28 | 72%*** | 0.32 | 0.25 | -42%*** |
| pctopenspaceLess3 | 0.001 | 0.02 | 5%* | 0 | 0.01 | 3%*** |
| pctopenspaceMore3 | 0.14 | 0.22 | -21%*** | 0.02 | 0.09 | -64%*** |
| avebuildrate | 0.02 | 0.02 | 15% | 0.06 | 0.04 | 8%** |
| aveprotectrate | 0.003 | 0.01 | -24%*** | 0 | 0 | -1% |
| density | 1.09 | 1.53 | -25%*** | 5.46 | 2.78 | 17%*** |
| stream | 0.22 | 0.42 | -2% | 0.02 | 0.13 | -3%** |
| stream_major | 0.04 | 0.19 | -6% | 0.01 | 0.1 | -7%*** |
| ditch | 0.01 | 0.1 | 0% | 0.06 | 0.24 | -10%*** |
| forest | 0.9 | 0.29 | 6% | 0.01 | 0.09 | -5%* |
| shrub | 0.09 | 0.28 | -99% | 0.07 | 0.25 | -6% |
| ag | 0.0004 | 0.02 | 2%*** | 0.53 | 0.5 | -2% |
| urban | 0.003 | 0.06 | 2%* | 0.43 | 0.49 | -5% |
| subdivision | 0.03 | 0.18 | 3% | 0.07 | 0.25 | -4% |
| milestofastroad | 0.93 | 0.7 | 0% | 0.26 | 0.24 | 3%*** |
| milestoacity | 4.1 | 2.39 | -19% | 2.06 | 1.32 | 15% |
| milestoschool | 3.58 | 2.36 | 62%** | 0.86 | 0.74 | 4% |
| forestry | 0.83 | 0.37 | 4% | 0 | 0.04 | 1% |
| ag_zoning | 0.05 | 0.22 | -14%*** | 0.09 | 0.28 | 6%** |
| sloperange | 11.45 | 9.54 | -6%* | 0.7 | 1.92 | -3% |
| slopemean | 8 | 4.25 | -25%*** | 1.01 | 1.16 | -2% |
| meanelevft | 7754.54 | 1039.34 | 0%*** | 5226.26 | 196.49 | 22%** |
| incity | 0.11 | 0.31 | 6% | 0.82 | 0.39 | -11% |
| acres | 17.16 | 115.87 | -84%*** | 2.41 | 14.26 | -86%** |
| Significance levels : | $*$ : 10% | $**$ : 5% | $***$ : 1% | | | |

open space plays a major role, with the presence of older open space decreasing building probability by 21%. Together with the results presented in Section 6.1.1 on protection propensity and consistent anecdotal evidence provided by individuals in the County's open space department, this result suggests that parcels near older open space are being protected before they can be built.

Land conversion trends within a parcel's zipcode play a smaller role in development decisions than immediately adjacent land use. In the mountains, a 1 percentage point increase in recent protection rates decreases development probability by 24%. This decrease combined with the predicted increase for protection probabilities suggests that protection displaces development in certain areas. Recent building rates in the zipcode (avebuildrate) have no effect on a parcel's development propensity.

More private open space from larger lots is associated with a higher building propensity in the mountains: 1.5 fewer lots per acre increases building propensity by 25%. The marginal effect on density is larger than on new protected land, suggesting that private open space can substitute for public open space, and that living in a neighborhood with larger lots is more important to new residents than access to protected land.

The parcel characteristic with the largest effect on development probability is size, with an additional 116 acres (one standard deviation) decreasing development propensity by 84%. Surprisingly, parcels further from schools are more likely to be developed. This relationship is likely due to the prevalence of second home ownership in the mountains: the smaller communities that are popular locations for second homes do not have schools. Parcels outside areas zoned for agriculture are the most likely to develop, along with parcels with low average slope or relatively even slope, or parcels in urban or agricultural use.

### 6.2.2 The Plains

As with the mountains, on the plains the presence of older open space is the most important determinant of development propensity: an increase in older open space by 9 percentage points decreases the probability of development by 64%. This occurs because land protection outcompetes development on land adjacent to older open space. I find that new open space has a small but positive and significant effect on development probability, indicating that bundling land protection and development into single projects has had a modest impact on development rates. The amount of adjacent raw land is nearly as important as older open space: a parcel will be 42% less likely to develop when there is 25 percent more adjacent raw land. This result likely speaks to the effectiveness of the county's land use department, which discourages development that is not adjacent to existing development.

Area land transition rates also play an important a role in determining development probabilities on the plains. I find no effect from protection rates in the parcel's zipcode, but more rapid recent development increases development probabilities from 8%. These findings suggest that new building does tend to be clustered in areas with more rapid recent development. What is unclear, however, is if this is due to cost minimization on the part of the developers or developer responses to zoning-related incentives to develop in certain parts of the county.

A parcel's physical characteristics have a smaller effect than adjacent land use on a parcel's development propensity. Parcels on the plains are less likely to be built if they are large, if there is some kind of stream or irrigation ditch on it, or if it is in a forested area. The model also predicts increased development probability when the parcel is in an area zoned for agriculture or further from a major road. Higher elevation is also associated with higher development probability.

## 6.3 Robustness Analysis

### 6.3.1 Spatial Autocorrelation

Because adjacent parcels often resemble one another, variables measuring parcel attributes may be spatially autocorrelated, introducing bias in parameter estimates when estimation procedures do not account for these patterns. To determine whether spatial autocorrelation is biasing my results, I adopted a method used by Newburn, Berck, and Merenlender (2006), taking 25% random bootstrapped samples of the full dataset, stratified by zipcode and whether the parcel is on the mountains or plains. By taking a sample distributed randomly over space I use parcels that are further apart than in the full sample, thereby diminishing the effect of spatial autocorrelation on estimation.

I estimated coefficients using 50 samples from the data, and find that the sampling approach has little effect on the parameter estimates. For the six open space variables the average deviation from the parameter estimates when I used the full sample is less than 5%. Because the smaller sample sizes increased the standard errors substantially, I opted to use the full sample in my analyses.

### 6.3.2 Evaluating the proportional hazards assumption

The key assumption I make in using a competing hazard approach is that the underlying transition hazards are proportional between the two land uses. To evaluate the reasonableness of the proportional hazards assumption I estimated a simple hazard model including all covariates, stratified by transition type, and calculated the survivor curves for built and protected land. Using relationship between the hazard function and survival function allows the following statement of the relationship between the baseline survival function and the conditional survival function:

$$S(t|x) = S_0(t)^{exp(x'\beta)} \tag{18}$$

Taking the log of the above function twice leads to the following equation, which demonstrates that the conditional survivor curve is parallel to the baseline survivor curve, and the distance between the two is $x'\beta$ (Cleves, Gould, Gutierrez, & Marchenko, 2008):

$$-ln[-ln\{S(t|x)\}] = -ln[-ln\{S_0(t)\}] - x'\beta \tag{19}$$

I plot the two survivor functions for built and protected parcels against $ln(time)$ in Figure 6, and find strong evidence for proportional hazards between the land uses.[7]

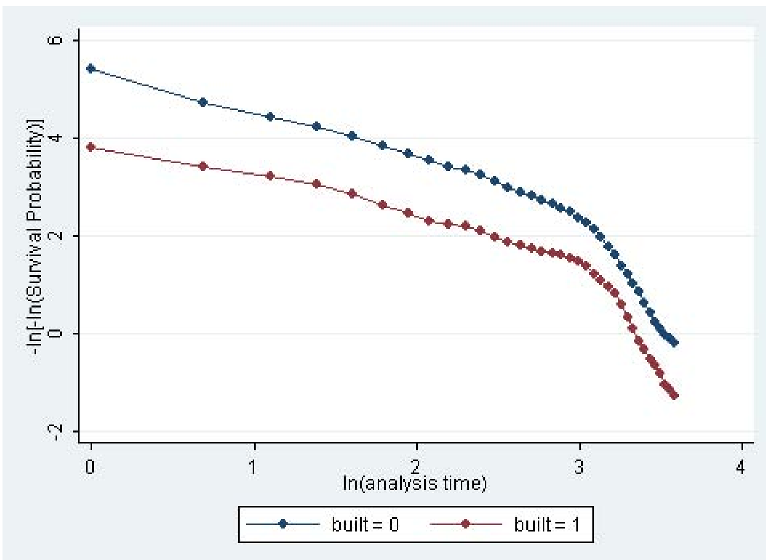



Figure 6: Graphical evaluation of the proportional hazard assumption for built and protected land

## 6.4 Summary of empirical results

The results reported in this section demonstrate that a parcel's adjacent land use characteristics are consistently the most important factors determining its propensity to convert

[7]As an additional robustness check, I also estimated the competing hazard models allowing the baseline hazards to vary by stratifying the estimation by built/protected parcels. The coefficients were not statistically different from the specification that assumes proportional hazards, providing additional evidence that my assumption of proportional hazards is reasonable.

from raw to developed or protected. While proximity to recently-protected land significantly increases a parcel's development propensity, the effect is small relative to the effect on the parcel's protection propensity. Thus it appears that policies intended to encourage bundled development and protection have relatively little effect on the rate of conversion for development.

The results from these models show that an interest in protecting contiguous areas has been the most important factor driving land conservation. The results suggest that the drive to create contiguous protection in turn may determine where development does and does not occur. This competition between development and protection is exemplified by parcels that are adjacent to land protected for at least three years: these parcels are generally protected before they can be built.

# 7 Policy simulation

The empirical results of Section 6 demonstrate that feedback between land protection and development plays a major role in determining a community's spatial structure. What remains an open question, however, is the effect that the land protection in Boulder County had on curbing and directing growth. To address this question, I use the competing hazard model to simulate what the spatial pattern of land use in Boulder County would have been if land protection had stopped in 1972. In these simulations land use is determined endogenously, based on the initial allocation of land use in 1972 and land conversion in each subsequent year. This scenario enables me to identify which parcels were protected that likely would have been developed, potentially providing supporting evidence that conservation and development do, indeed, compete for similar land.

This simulation is conducted in a partial equilibrium framework. Thus, implicit in the results is the assumption that this scenario does not affect underlying demand for developed and protected land. Instead, I assume it only affects the county's landscape through direct and indirect effects on parcel conversion probabilities. The direct effects occur through prohibiting protection. Indirect effects arise when the policy affects an *adjacent* parcel's conversion probability, and the externalities generated by its subsequent land use changes the original parcel's conversion probability.

In analyzing the simulation results, I focus on the spatial distribution of the effect these policies have on development and protection, as well as differences in parcel attributes for parcels most likely and least likely to change land use under this scenario.

## 7.1 Methods

Based on the results from the competing hazard models estimated in Section 6, I use a Monte Carlo analysis to predict the probability that each parcel will be built or remain raw at any given time. Because protection is omitted, the probability of protection for all parcels in all years is zero. This simulation requires estimating the development hazard rate for each parcel, which is the probability that the parcel will be developed in a particular year, given that it has remained raw until that year.

Beginning in 1972, the first year in the study, I estimate the baseline hazard, $\lambda_0(t)$, (constant for all parcels in that year) and the relative hazard for each parcel. The relative hazard is simply $exp(X_i'\beta + \delta I_p + I_p\theta' X_i)$, a function of the parcel's attributes as of 1972 and the competing hazard model coefficients. The baseline hazard is equal to the increment in the cumulative baseline hazard function each year, which is the cumulative hazard function when all coefficients are set to zero.

I predict each parcel's building probabilities ($p^b$ ) for time $t$ by multiplying the relative hazard by the baseline development hazard. I define the probability of a parcel remaining in a raw undeveloped state as $p^r = 1 - p^b$. In each period I draw a random number, $i$, from a uniform distribution, assigning a parcel to one of the three land uses according to the following rules:

1. landuse=built if $0 < i <= pr^b$
2. landuse=raw if $pr^b < i <= 1$

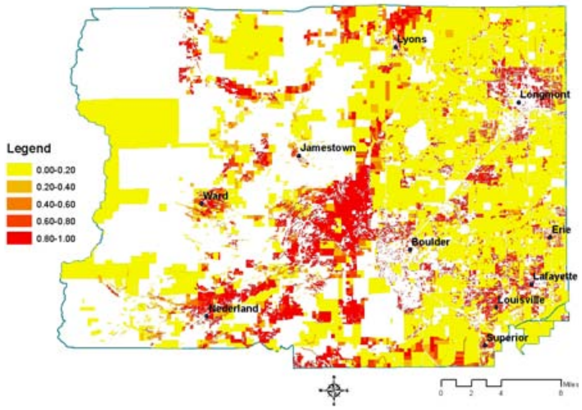
After predicting the parcel's land use the number of parcels built in the county changes. This in turn changes the land use for parcels adjacent to each parcel, affecting adjacent raw land and average building rates over the previous three years. Adjacent levels of protected land and zipcode protection rates remain zero throughout the simulation. As building probability is a function of adjacent land use in the current time period, this process allows for endogenous land use.

Because I assume development is irreversible, the number of parcels that transitioned in the current year are precluded from transitioning in any subsequent years. This process iterates over 33 years, 1972-2005, to simulate what Boulder County's landscape would have looked like in 2005. I then repeat this 33 year process to generate estimates of the probability that a parcel will be built and remain raw in 2005. A parcel's most likely land use is the land use that occurred most frequently across the iterations. The simulated land uses reported in the maps in this chapter reflect a parcel's most likely land use after 50 iterations. Summary statistics reported in this section reflect the distribution of predicted land uses for all parcels over 50 iterations.

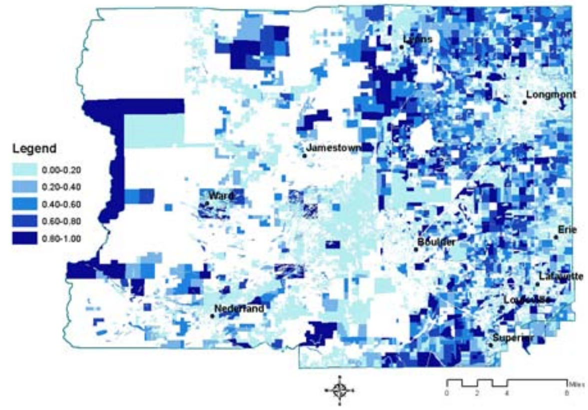
## 7.2 Results

### 7.2.1 Baseline

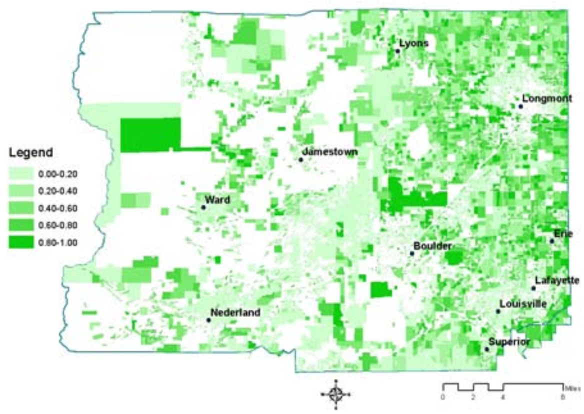
Prior to conducting policy simulations, I use baseline conditions to see how well the simulations using model parameters match land use in 2005. Figure 7 shows the probability each parcel will be built (Panel (a)), protected (Panel (b)), and remain raw in 2005 (Panel (c)).




(a) Probability of building




(b) Probability of protecting




(c) Probability of remaining raw

Figure 7: Predicted land use probabilities, baseline

These probabilities reflect the number of times a parcel was built, protected, or remained raw over 50 iterations. White areas in these maps are parcels that were already built or developed in 1972.

Parcels most likely to be built are concentrated in the foothills just west of Boulder and near the mountain towns of Nederland and Ward. Parcels with a high probability of being protected also generally have a high probability of remaining raw. Protection is most likely in rural areas on the plains, with relatively little protection expected in the mountains after 1972. While parcels most likely to be protected are interspersed with parcels likely to remain raw, parcels most likely to be built tend to be clustered together.

Table 4: Actual and predicted land use allocation in 2005

| | Mean | Std Err | Min | P25 | P50 | P75 | Max |
|---|---|---|---|---|---|---|---|
| Predicted baseline allocation | | | | | | | |
| % Built | 76.3 | 0.02 | 76.1 | 76.2 | 76.3 | 76.4 | 76.6 |
| % Protected | 3.6 | 0.01 | 3.5 | 3.5 | 3.6 | 3.6 | 3.7 |
| % Raw | 20.1 | 0.02 | 19.8 | 20.0 | 20.1 | 20.2 | 20.4 |
| Actual allocation | | | | | | | |
| % Built | 78.6 | | | | | | |
| % Protected | 3.5 | | | | | | |
| % Raw | 17.9 | | | | | | |

Table 4 presents the summary statistics for predicted baseline land use allocation over 50 iterations, as well as the actual land use allocation, and shows that the simulations do an excellent job predicting the overall land use allocation. These percentages are relative to the 61,501 parcels that remained undeveloped and unprotected as of 1972, when this study begins. The model under-predicts the amount of development and over-predict the probability a parcel will remain raw. The protection probability is nearly identical to the actual percentage of parcels that are protected. There is very little variation in the predicted allocation between model iterations as is evident in the narrow range of allocation probabilities across the iterations for all land uses. Overall, the simple and competing models predict a parcel's most likely land use correctly 69% and 68% of the time, respectively.

It is also worth noting that the standard error over the iterations is very small across all of the descriptive measures. This indicates that the overall predicted land use allocation in the county is relatively stable over iterations, and additional iterations would not likely change the mean allocation.

### 7.2.2 No new land protection

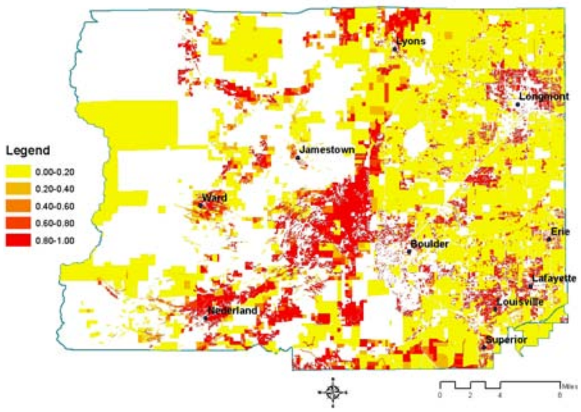
The simulations predict that stopping land protection in 1972 would have little effect on land use allocation. On average, 77.2% of parcels are likely to be built, relative to 76.3% for baseline, and 22.8% are likely to remain raw, relative to 20.1% for baseline. As with the predicted baseline land use allocations, the range of predicted land use allocations is quite narrow across model iterations.

The left column of Figure 8 presents the probability that the simulations predicted a parcel would be built (first row) and remain raw (second row) under this scenario, with darker colors indicating higher probability of that particular land use. White areas were already built or protected in 1972. Because no land was protected in this scenario, the predicted probability of protection for all parcels is zero. The right column shows the change in probability of that land use between baseline and this scenario. Parcels shaded in yellow or red in the right column are predicted to have an increased probability of being built (Panel (b)) or remaining raw (Panel (d)); parcels shaded in light or dark blue are *less* likely to be built or remain raw. Darker colors show parcels that are predicted to have a larger change in development or raw probabilities.

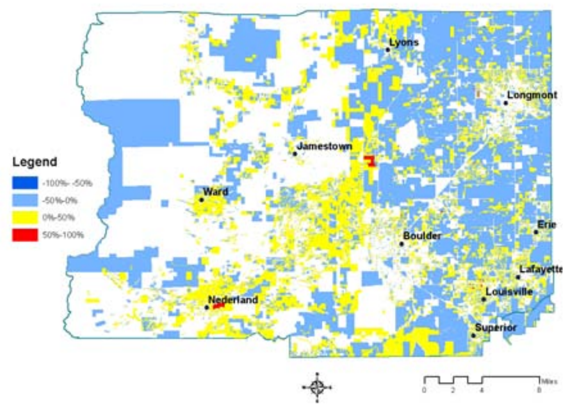
In general, the spatial arrangement of development pressure is predicted to change very little if no new land were protected. Development propensity does not increase substantially when the competing land use is eliminated because, relative to land protection propensity, development propensity is relatively insensitive to adjacent land use.

It is more likely that parcels that had been protected would remain raw instead of being built. This result is consistent with Figure 7, which showed parcels that were most likely to be protected also had a relatively high probability of remaining raw. When protection was eliminated, these parcels' next most probable land use was to remain raw.

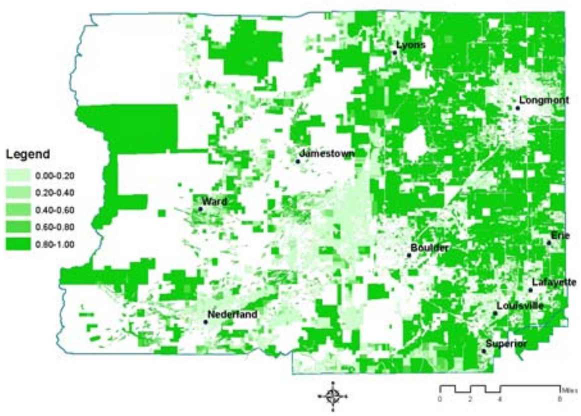
This policy actually decreases the development probability for many parcels in rural areas on the plains. This is likely due to the fact that the second most likely land use for many



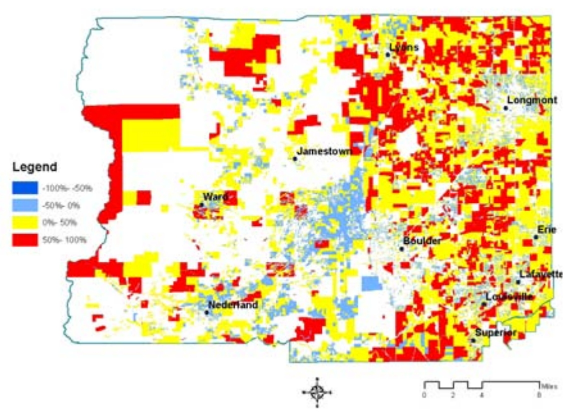

(a) Development probability




(b) Change in development probability from baseline




(c) Probability of remaining raw




(d) Change in probability of remaining raw

Figure 8: Predicted land use probabilities when no land is protected after 1971

protected parcels is raw. Therefore when protection is eliminated as an alternative, these parcels will remain raw rather than being developed. This is supported by the dramatic increase in the probability of remaining raw shown in Panel (d) of Figure 8.

Table 5 shows mean attribute levels for four categories of changes in development probability from baseline: 50-100% decrease (Q1), 0-50% decrease (Q2), 0-50% increase (Q3), and 50-100% increase (Q4) for probability of being developed and remaining raw. In other words, the values in column Q4 of the Raw column show the mean parcel characteristics for parcels that are much more likely to remain raw under this scenario. Likewise, column Q1 shows mean attribute levels for parcels are much *less* likely to remain raw under this

Table 5: Mean parcel attributes by range of predicted change in conversion probability if protection were prohibited

| | Probability of development | | | | Probability of remaining raw | | | |
|---|---|---|---|---|---|---|---|---|
| | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 |
| % built adjacent | | 61.1 | 60.2 | 75.2 | | 64.8 | 59.3 | 29.3 |
| % protect adjacent | | 0 | 0 | 0 | | 0 | 0 | 0 |
| % raw adjacent | | 21.5 | 16.9 | 11 | | 17.9 | 17.7 | 47.1 |
| subdivision | | 0.08 | 0.04 | 0 | | 0.08 | 0.04 | 0 |
| stream | | 0.04 | 0.05 | 0.11 | | 0.03 | 0.05 | 0.33 |
| stream_major | | 0.01 | 0.01 | 0 | | 0 | 0.02 | 0.21 |
| ditch | | 0.06 | 0.05 | 0.44 | | 0.03 | 0.08 | 0.67 |
| forest | | 0.08 | 0.15 | 0.11 | | 0.11 | 0.11 | 0.12 |
| shrub | | 0.08 | 0.08 | 0.22 | | 0.07 | 0.08 | 0.26 |
| ag | | 0.48 | 0.45 | 0.56 | | 0.41 | 0.54 | 0.72 |
| urban | | 0.4 | 0.36 | 0.78 | | 0.44 | 0.29 | 0.13 |
| milestofastroad | | 0.31 | 0.35 | 0.2 | | 0.31 | 0.35 | 0.56 |
| milestoacity | | 2.24 | 2.32 | 1.77 | | 2.24 | 2.29 | 3.64 |
| milestoschool | | 1.09 | 1.26 | 0.9 | | 1.08 | 1.26 | 2.39 |
| slopemean | | 1.55 | 2.19 | 2.7 | | 1.81 | 1.93 | 2.73 |
| meanelevft | | 5445 | 5630 | 5877 | | 5533 | 5539 | 5610 |
| incity | | 0.76 | 0.72 | 0.89 | | 0.76 | 0.73 | 0.15 |
| acres | | 6 | 3 | 36 | | 1 | 5 | 99 |
| density | | 5.07 | 4.49 | 0.43 | | 5.07 | 4.55 | 0.16 |
| % of obs | | 52 | 49 | 0.01 | | 59 | 39 | 1 |
| Mean % change in category | | -3 | 5 | 56 | | -2 | 7 | 71 |

Q1: probability decreases by 50-100%, Q2: probability decreases by 0-50%, Q3: probability increases by 0-50%, Q4: probability increases by 50-100%

scenario. Columns are blank where no parcels fell in that category. The adjacent land use calculations reflect the percentage of adjacent land built and protected after 1972. This table also reports the percentage of observations in each category of probability change, as well as the mean change in probability in the category.

Using output from these simulations, I identified 655 parcels that were most likely to be protected in baseline but were, on average, most likely to be built in the absence of open space. This represents 30% of all protected parcels in the county, totalling 11,084 acres. The parcels with the greatest expected increase in development probability (Column Q4 of the Development column in Table 5 have, on average, a much higher proportion of adjacent land that has already been built. The parcels are most vulnerable to development in the absence of land protection are large, located in low density areas, and relatively close to major roads, cities, and schools. They are also more likely to contain a perennial stream or irrigation ditch, increasing their conservation value. Conservation entities interested in protecting only the parcels with high conservation value and high vulnerability to development should target these "trophy" parcels, which lie relatively close to population centers.

In sum, these results indicate that land protection has played the biggest role in reducing development on smaller, more accessible parcels that may be important recreation resources for communities. Although protection successfully outcompetes development in many cases, because protection has relatively little effect on overall development rates, it is best used to target specific parcels of interest for their environmental, recreation, aesthetic, or cultural value to the community rather than as a strategy to limit overall development. Large parcels with high conservation values, however, appear to be too large and remote to have high development pressure, findings that are consistent with Walsh (2007). While these parcels may not have ever been developed, formal land protection did allow conservation entities to have more control over other land management questions than they would have had if the parcels had been in private ownership, including public access, wildlife, and fire management.

# 8 Conclusions

Anecdotal evidence suggests that conservation groups compete fiercely with developers for raw land adjacent to open space, particularly on the plains.[8] The results here suggest that land protection wins that competition near older open space, and competes closely with development near recently protected open space. Previous models of land use conversion did not account for this competition between land uses.

Together, the coefficients on new and old open space suggest that concerns over land protection attracting development, as articulated by Armsworth et al. (2006), may be unwarranted. That said, land protection is not attracting development precisely because conservation entities in the county, including the land use department, have been very active in discouraging development adjacent to protected land. These entities have the support of the residents and local government, as well as substantial financial resources, to discourage development in important areas and encourage the creation of large, contiguous parcels of protected land. In the absence of such strong community support for growth management and environmental protection, Boulder County's landscape may have been very different. The results presented here are relevant for communities that are beginning to grow rapidly but whose residents also prioritize protecting part of the rural landscape.

Results from these models help disentangle some of the diverging priorities of the numerous land protection entities in Boulder County, and allow me to identify the factors that, across entities, are driving land protection. First, I find that the most important criteria for new land protection is whether it is adjacent to existing protected land. Creating contiguous parcels is, in aggregate, the highest priority for conservation organizations. Second, I find that protection is more likely to happen in areas experiencing higher recent development rates, suggesting that land in areas being threatened by development are also being

[8] This conclusion is based on conversations with employees at the Boulder County Land Use and Parks and Open Space Departments.

targeted. Third, a parcel's accessibility has little or no impact on the decision to protect a parcel. This suggests that creating easily accessible amenities for the community has not been a priority, and may reflect a lower relative ranking of recreation. Fourth, preserving "open" landscapes, such as shrub, agricultural, and otherwise non-forested lands, has been a priority in the county to preserve the county's agricultural aesthetic and maintain the grassland ecosystem.

By allowing for the endogenous evolution of multiple land uses, the policy simulation presented here demonstrates how the interaction between land protection and development determines a community's landscape. While the partial equilibrium approach limits the conclusions I can draw from the scenario, it does illustrate the likely change in the allocation of land uses.

While most protected parcels likely would have remained raw in the absence of land protection, nearly one-third of protected parcels likely would have been developed. I find that, in general, the parcels most vulnerable to development are large trophy parcels relatively close to population centers, which also have high value for conservation due to their inclusion of riparian areas and contiguity with existing protected land.

Conservation organizations interested in protecting land most vulnerable to development should focus on parcels near new open space, with a particular focus on the trophy parcels that are most likely to be developed. Although land protection entities are already targeting these lands, new adjacent open space still significantly increases the probability that a parcel will be developed and land is, overall, less likely to be protected than built. Land trusts or other conservation agencies could leverage their budgets by coordinating purchase decisions with public agencies.

# References

Armsworth, P., Daily, G., Kareiva, P., & Sanchirico, J. (2006). Land market feedbacks can undermine biodiversity conservation. *Proceedings of the National Academy of Sciences*, *103*, 5403-5408.

Bento, A., Franco, S., & Kaffine, D. (2006). The efficiency and distributional impacts of alternative anti-sprawl policies. *Journal of Urban Economics*, *59*, 121-141.

Bergstrom, J., Dillman b., & Stoll, J. (1985). Public environmental amenity benefits of private land: The case of prime agricultural land. *Southern Journal of Agricultural Economics*, *17*, 70-78.

Breffle, W., Morey, E., & Lodder, T. (1998). Use of contingent valuation to estimate a neighbourhood's willingness to pay to preserve undeveloped urban land. *Urban Studies*, *35*, 715-727.

Carrion-Flores, C., & Irwin, E. (2004). Determinants of residental land use conversion and sprawl at the rural-urban fringe. *American Journal of Agricultural Economics*, *86*, 889-904.

Cleves, M., Gould, W., Gutierrez, R., & Marchenko, Y. (2008). *An Introduction to Survival Analysis Using Stata* (2 ed.). Stata Press.

Colorado Conservation Trust. (2005). *Colorado Conservation at a Crossroads.* http://www.coloradoconservationtrust.org/goingon/cccfullreportsmall.pdf.

Cox, D. (1972). Regression models and life-tables (with discussion). *Journal of the Royal Statistical Society, Series B*, *34*, 27-36.

Irwin, E., Bell, K., & Geoghegan, J. (2003). Modeling and managing urban growth at the rural-urban fringe: A parcel-level model of residential land use change. *Agricultural and Resource Economics Review*, *32*, 83-102.

Irwin, E., & Bockstael, N. (2001). The problem of identifying land use spillovers: Measuring the effects of open space on residential property values. *American Journal of Agricultural Economics*, *83*, 698-704.

Irwin, E., & Bockstael, N. (2002). Interacting agents, spatial externalities, and the evolution of residential land use patterns. *Journal of Economic Geography*, *2*, 31-54.

Irwin, E., & Bockstael, N. (2004). Land use externalities, open space preservation, and urban sprawl. *Regional Science and Urban Economics*, *34*, 705-725.

Kalbfleisch, J., & Prentice, R. (2002). *The Statistical Analysis of Failure Time Data*. Wiley-Interscience.

Kopits, E., McConnell, V., & Walls, M. (2007, July). The trade-off between private lots and public open space in subdivisions at the urban-rural fringe. *RFF Discussion Paper*, *DP 07-33*.

Land Trust Alliance. (2005). *2005 National Land Trust Census Report*. http://www.landtrustalliance.org/about-us/land-trust-census/2005-report.pdf.

Lewis, D., & Plantinga, A. (2007). Policies for habitat fragmentation: Combining econometrics with gis-based landscape simulations. *Land Economics*, *83*, 109-127.

Lewis, D., & Provencher, B. (2007). The implications of heterogeneous preferences in environmental zoning. *University of Wisconsin-Madison Dept. of Agricultural and Applied Economics Working Paper*.

McConnell, V., & Walls, M. (2005). The value of open space: Evidence from studies of nonmarket benefits. *Resources for the Future Working Paper*.

Mills, D. (1981). Growth, speculation, and sprawl in a monocentric city. *Journal of Urban Economics*, *10*, 201-226.

Newburn, D., Berck, P., & Merenlender, A. (2006). Habitat and open space at risk of land-use conversion: Targeting strategies for land conservation. *American Journal of Agricultural Economics*, *88*, 28-42.

Peiser, R., & Schwann, G. (1993). The private value of public open space within subdivisions.

*Journal of Architectural and Planning Research*, *10*, 91-104.

Putter, H., Fiocco, M., & Geskus, R. (2007). Tutorial in biostatistics: Competing risks and multi-state models. *Statistics in Medicine*, *26*, 2389-2430.

Riddel, M. (2001). A dynamic approach to estimating hedonic prices for environmental goods: An application to open space purchase. *Land Economics*, *77*, 494-512.

Rosenberger, R., & Walsh, R. (1997). Nonmarket valye of Western valley ranchland using contingent valuation. *Journal of Agricultural and Resource Economics*, *22*, 296-309.

Smith, V., Poulos, C., & Kim, H. (2002). Treating open space as an urban amenity. *Resource and Energy Economics*, *24*, 107-129.

Strange, W. (1992). Overlapping neighborhoods and housing externalities. *Journal of Urban Economics*, *32*, 17-39.

Titman, S. (1985). Urban land prices under uncertainty. *American Economic Review*, *75*, 505-514.

Trust for Public Land. (2009). *Landvote.* http://www.tpl.org/.

Turner, M. (2005). Landscape preferences and patterns of residential development. *Journal of Urban Economics*, *57*, 19-54.

Walsh, R. (2007). Endogenous open space amenities in a locational equilibrium. *Journal of Urban Economics*, *61*, 319-344.

Wheaton, W. (1982). Urban residential growth under perfect foresight. *Journal of Urban Economics*, *12*, 1-21.

Wu, J. (2001). Environmental amenities and the spatial pattern of urban sprawl. *American Journal of Agricultural Economics*, *83*, 691-697.

Wu, J. (2006). Environmental amenities, urban sprawl, and community characteristics. *Journal of Environmental Economics and Management*, *52*, 527-547.

Wu, J., & Plantinga, A. (2003). The influence of public open space on urban spatial structure. *Journal of Environmental Economics and Management*, *46*, 288-309.