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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 e ectiveness is not well understood. Existing research has focused on the e ect of land protection on development, overlooking its e ect 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 e ects 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.

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,

2

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

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 e ect 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 e ect 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 (Bre e, 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 foun-dation of theoretical and empirical research on the factors a ecting a community's spatial structure, with particular attention to drivers of growth and developmef la9x   ximit

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

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

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

one-time conversion cost:

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

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

$$max(R_{it}^b, R_{it}^p) - E[R_{it}^h] \quad 0$$
(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.
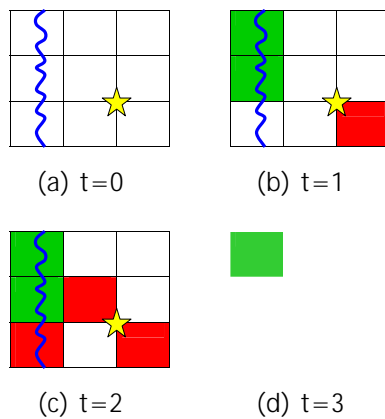

(a) t=0   (b) t=1

(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 ε 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 ε as a function of t, where $F(\varepsilon(t))$ is the cumulative distribution function of ε, describing the cumulative probability of failure at t. Let ε^*_b and ε^*_p be the value of the error term that equates Equations 8 and 9, respectively. Thus these values for ε 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:

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

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

The term $1 - F[\varepsilon^*(t)]$ is equivalent to the survival function, $S(t)$, which estimates the proba-

bility 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).

λ^b and λ^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 λ_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:

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

To simplify notation, I shorten λ_0^b to λ_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, δ, for interactions between the indicator for protected parcels, I_p, and the vector

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[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:

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

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

$$L_i = \left(\frac{\lambda_0(t) \exp(X_i' \beta)}{} \right.$$

parcel attributes (X) and one vector of time-variant adjacent land attributes (O). The estimated model includes two sets of fixed effects. is a zipcode-level fixed effect, to control for time-invariant, unobservable differences between zipcodes. 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: ^{b} is the number of parcels built of all remaining raw parcels within the zipcode, averaged over the previous three years, and ^{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, ^{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

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[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.

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 O ce. I consider a parcel undeveloped until the year when the permit was issued and developed afterwards. This o ce 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.

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 di er significantly from protected parcels across many of these variables.

I include six measures of adjacent land use to estimate di erent 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.

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[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

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[6] I also estimated all mod475(r)-32eTdᵩ3cm54er1(.)-51(t)1(BT/76.974T4irun)27(ta)1(n)144.327(h)(s-1(o)-2c10(so)-410(b)

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 di erent 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.
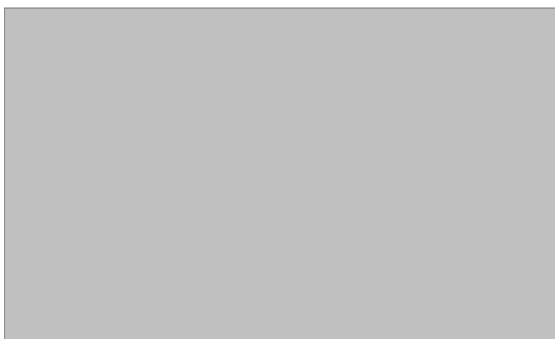
5.3   Transition Rates

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

24

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
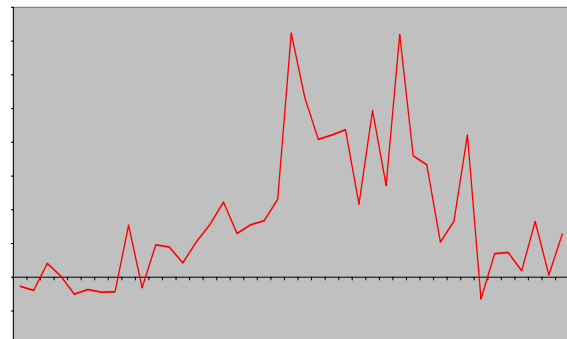
(b) Protection rates

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 $exp((\beta + \delta)s)$, where β is the coe cient for built parcels and δ is the shift parameter for protected parcels. All models are estimated using zipcode and year fixed e ects. Tests of joint significance for year and zipcode fixed e ects are both highly significant (p<0.0001). I estimate conversion propensities separately for the mountains and plains, to account for di erences 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 bu er) 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 e ect on protection propensity for mountain parcels. The values reported in this table are equal to the coe cient multiplied by the standard deviation for that variable. These values are reported instead of the coe cients themselves to facilitate interpretation, and are essentially scaled coe cients. 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 e ect.

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

Variable	Mountains			Plains		
	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%

"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

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

Variable	Mountains			Plains		
	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			

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

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 e ect of spatial autocorrelation on estimation.

I estimated coe cients using 50 samples from the data, and find that the sampling approach has little e ect 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:

$$S(t/x) = S_0(t)^{exp(x)} \tag{18}$$

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' (Cleves, Gould, Gutierrez, & Marchenko, 2008):

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

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]
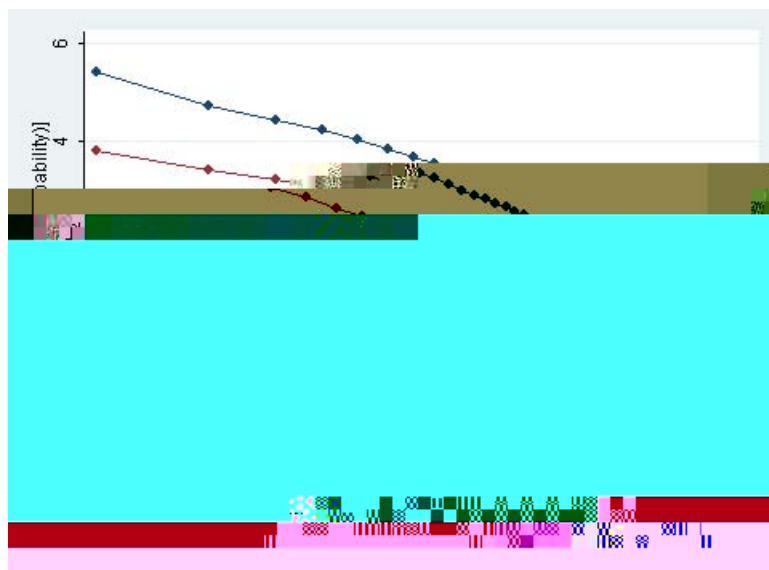

Figure 6: Graphical evaluation of the proportional hazard assumption for built and protected land

6.4 Summary of empirical results

The results reported in this section demonstrate that a parcel's adjacentcted

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

35

and protected land. Instead, I assume it only a ects the county's landscape through direct

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, a ecting 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
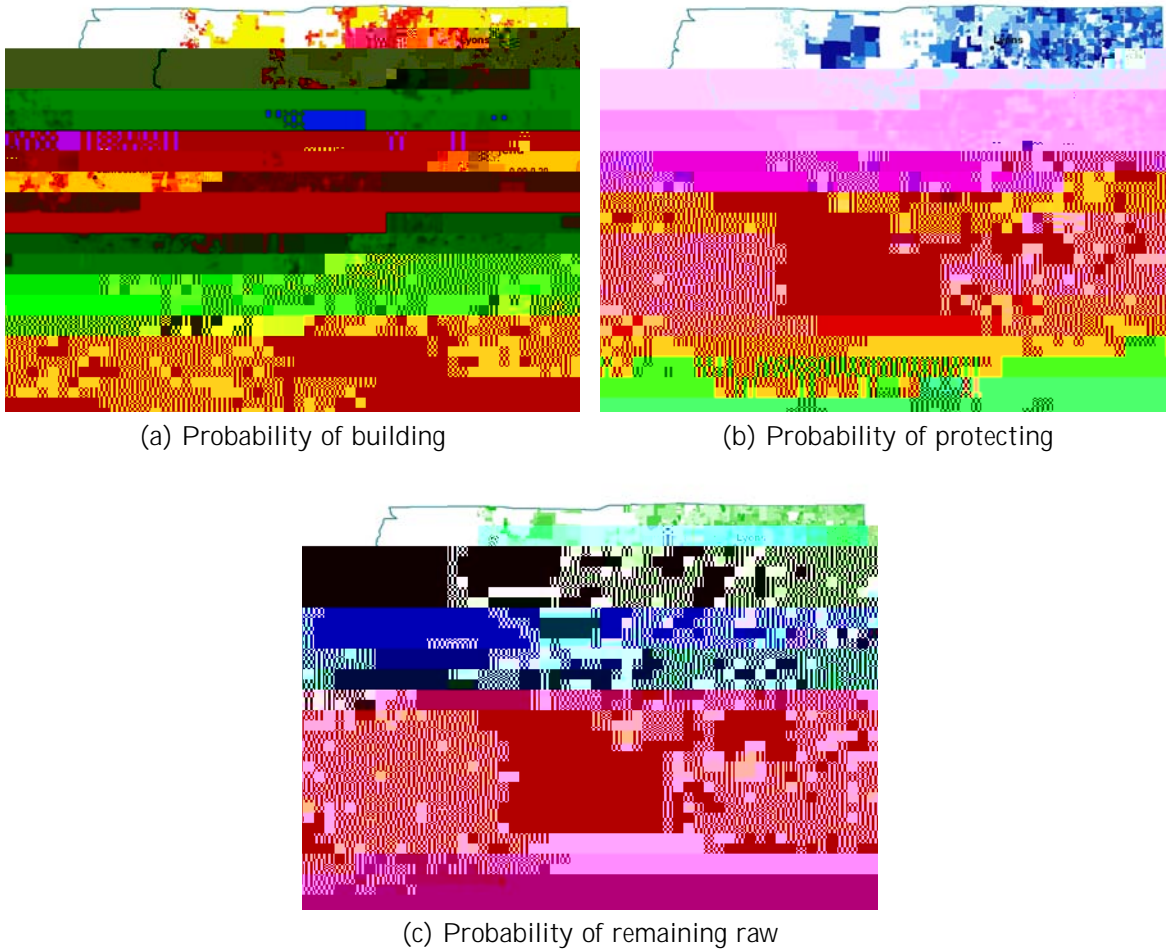

(c) Probability of remaining raw

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							

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

(a) Development probability

(b) Change in development probability from baseline

(c) Probability of remaining raw

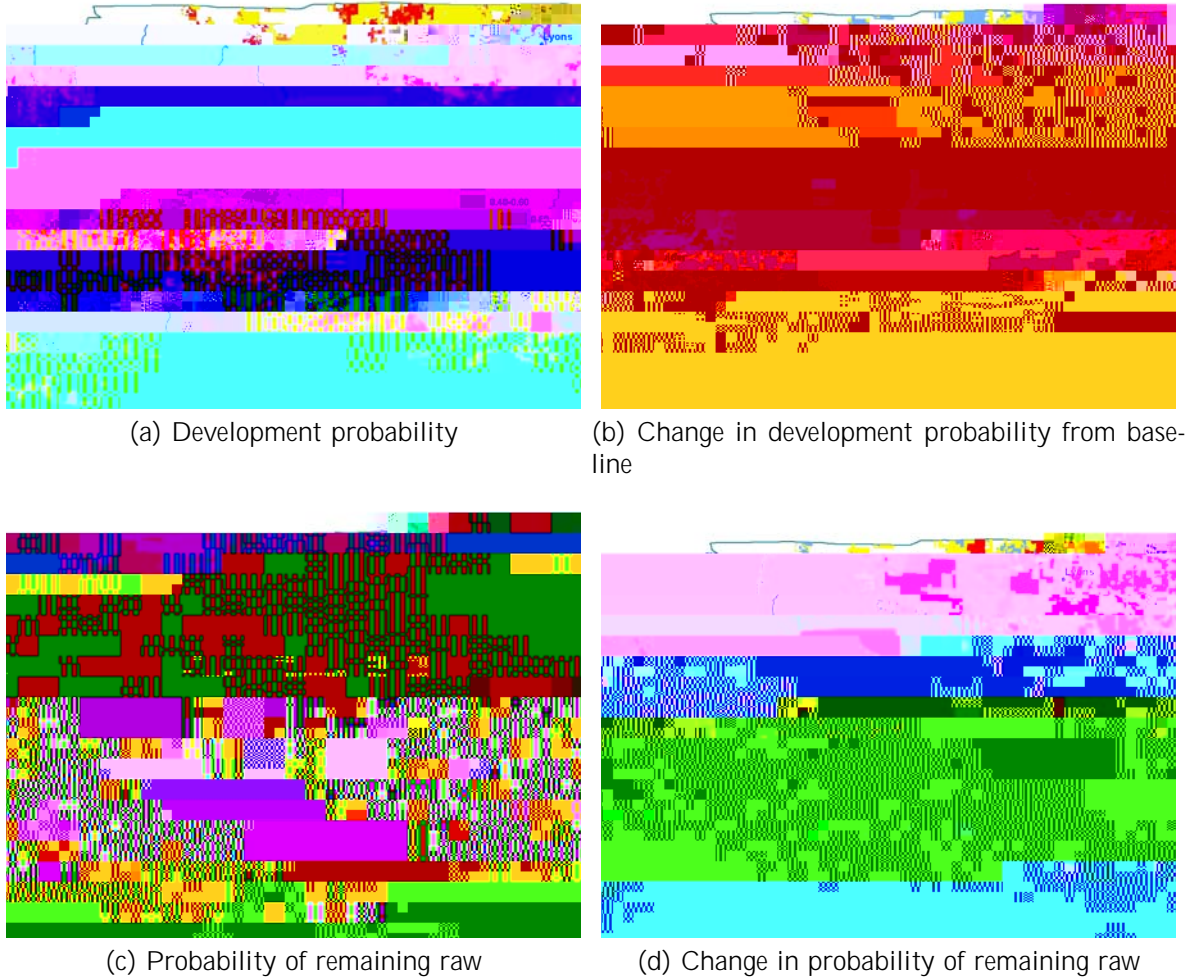(d) Change in probability of remaining raw

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

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

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

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[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.

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