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Grassland Easement Evaluation and Acquisition: an Integrated Framework

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Abstract: Efficient grassland easement management requires correct evaluation and cost-effective acquisition of easements. We develop an integrated theoretical framework to study grassland easement evaluation and acquisition. Grassland tracts can be either kept under grass gaining grazing returns or converted to cropland generating cropping returns. Under a two-period framework, grassland owners choose an optimal action from 'convert now,' 'ease now,' and 'wait and see' in period one to maximize total expected returns over the two periods, while taking easement payment from an easement agency as given. The easement agency, however, aims to maximize the increase in expected environmental benefits arising from a budget-constrained easement acquisition program.

We find that a mean preserving spread of the difference between cropping returns and grazing returns increases the value from action 'wait and see' and the minimum easement payment that landowners are willing to accept (i.e., the easement value). This change will decrease conversion probability in period one. If distribution of cropping returns and grazing returns undergo a shift such that they become larger in the supermodular order sense, then the easement value decreases and the period-one conversion probability increases. Therefore, the easement value and period-one conversion probability may go opposite directions, which indicates that an assumption commonly used in conservation literature (i.e., the larger the conversion probability the higher the easement value) may not hold. Solutions to the easement agency's problem show that a grassland tract whose owner chooses 'wait and see' in period one should not be acquired in that period. An easement acquisition index is developed to rank acquisition priority for different grassland tracts.

Keywords: Acquisition, Easement, Evaluation, Grasslands, Real Option

JEL Classification: Q24, Q21, Q28, G12

Grassland Easement Evaluation and Acquisition: an Integrated Framework

1. Introduction

Grassland ecosystems naturally exist on all continents except Antarctica. Human impacts, mainly through agricultural expansion and climate change, have put many grassland ecosystems under risks (White, Murray, and Rohweder 2000). The Prairie Pothole Region (PPR) in North America covers an area about 276,000 square miles (about the size of Texas) and provides habitat for a wide variety of wildlife and ecosystem services such as carbon sequestration, sedimentation reduction, and water purification (Gleason et al. 2008). Due to agricultural expansion, some areas in the PPR have annual grassland-to-cropland conversion rates estimated to be between 0.4% and 5.4% of grassland acreage (Wright and Wimberly 2013; Johnston 2012; Rashford, Walker, and Bastian 2011; Stephens et al. 2008; Lark, Salmon, and Gibbs 2015). Grassland protection has attracted much attention as significant investment has been made by the U.S. Fish and Wildlife Service (USFWS) and its conservation partners to protect grasslands and maintain the region's habitat.

Conservation easements are widely used to protect grasslands (Watson, Fitzgerald, and Gitahi 2010; Disselhoff 2015) because they are viewed as "the most cost-effective and socially acceptable means to ensure protection of important habitats" (USFWS 2011, p. 10). After signing an easement, landowners receive a lump-sum payment and perpetually forgo certain rights such as plowing and converting the land to crop production or draining the land if it contains wetland. Currently over 2 million acres of grassland is under USFWS easement protection in the PPR and the service's goal is to protect 12 million wetland and grassland acres in the region (USFWS 2011; Ringelman 2005). Among these 12 million acres, 10 million acres will be grassland protected under perpetual easements (Ringelman 2005, p.17). However, high

crop returns over the past decade have imposed substantial financial pressures on easement acquisition. Walker et al. (2013) show that the average easement payment rate almost quadrupled, from $195/acre to $778/acre, between 1998 and 2012. Consequently, easement evaluation and acquisition have attracted increasing attention (USGAO 2007; Armsworth and Sanchirico 2008; Walker et al. 2013).

We too aim to investigate the efficiency of grassland easement in providing conservation benefits, but from a new perspective. Evaluating conservation efficiency requires appropriate specification of the benefits and costs of an easement's acquisition. Since easements prevent potential grassland conversions in uncertain future states of nature, reliably accounting for future possible conversion incentives is key to understanding the benefits and costs of easement acquisition. It has been shown in the conservation literature that land costs, conversion probability, and environmental benefits should be taken into account when improving conservation efficiency (Ando et al. 1998; Newburn et al. 2006; Wilson et al. 2006; Walker et al. 2013). Previous studies on the effectiveness of grassland easements largely evaluate the easement costs and benefits from a static perspective that overlooks the dynamic and stochastic nature of landowners' conversion decisions and consequently mis-specifies the benefits and costs of easement acquisition. However, studies have shown that owners' land-use decisions under a dynamic and stochastic framework can significantly differ from those under a static framework (e.g., Song, Zhao, and Swinton 2011).

In addition, the hedonic approach is widely used to estimate easement value, which is often viewed as a portion of land value (e.g., Newburn et al. 2006; Walker et al. 2013). The hedonic approach provides a reduced form analysis on how some land characteristics, such as slope, elevation, and micro-climate variables, determine easement value. What it omits are the direct

economic forces that drive landowners' conversion decision. Although convenient, the hedonic approach disregards landowners' decision processes and therefore cannot be used to analyze how landowners respond to changes in market and policy environments.

Moreover, previous studies separate the estimation of conversion probability from the estimation of easement value. This separation can be problematic because conversion probability and easement value are closely related. Omitted-variable bias may occur when estimating easement value and conversion risk separately. It is intuitive that conversion probability and easement value should be positively correlated. For instance, if a tract of grassland will not be cropped for sure even without a grassland easement, then FWS should not acquire an easement on this tract (i.e., the easement value is zero). On the other hand, we also show that conversion probability can be negatively correlated with easement value. What the static approach omits is that in addition to 'convert now' and 'ease now' actions, the third action, 'wait and see', is of critical importance. Because of the perpetuity nature of grassland easement, a landowner may very much hesitate to place her land under a grassland easement. According to Magedanz (2004, p. 7),

> "Conservation easements can reduce the economic value of land and prevent future generations from making full economic use of the property. The idea that conservation easements restrict what succeeding generations can do with their property in perpetuity is a serious concern for those who oppose conservation easements."

When value of 'wait and see' is larger than that of 'convert now', then the conversion probability is low and the easement value should be able to offset the value of 'wait and see'. If the value of 'wait and see' decreases then the easement value will decrease whereas the conversion probability will increase. That is, the easement payment competes the higher of two choices: 'convert now' and 'wait and see.'

Our analysis intends to fill in the gaps described above by modeling grassland easement

evaluation and land conversion risk in an integrated framework. Owners of grasslands have the option to either convert their grasslands today or wait for further information. The landowner's decision will be influenced by the stochastic nature of cropping and grazing returns, as well as the relationship between these two kinds of returns. When owners commit to permanent grass under grassland easement, they forgo real options to switch at later dates. Approaches to calculating land conversion incentives and cropping profits foregone due to easement are mis-specified unless they account for these real options. On the other hand, total environmental benefits from protected grassland should not be viewed as the benefits secured by an easement's acquisition. This is because even without easement acquisition the grassland may remain unconverted and generate the same environmental benefits. Therefore, conversion probability is critical when evaluating easement acquisition benefits (Newburn et al. 2005, 2006; Merenlender et al. 2009). Our model simultaneously determines easement value and land conversion probability. To our best knowledge, this is the first study to do so in the conservation literature.

Correctly specifying easement costs and benefits are necessary but not sufficient to improve easement efficiency. A large body of studies has shown that the acquisition mechanism plays a critical role in improving conservation efficiency and cost-benefit analysis is advocated to be a basic tool when prioritizing conservation activities (Arrow et al. 1996; Ando et al. 1998; Polasky, Camm, and Garber-Yonts 2001; Newburn et al. 2005; Wilson et al. 2006; Murdoch et al. 2010; Ando and Mallory 2012; Miao et al. 2016). Current easement acquisition decisions, however, are not yet based upon cost-benefit analysis. According to Walker et al. (2013), easements are basically prioritized based on conservation benefits whereas conservation costs have not been accounted for during easement acquisition. An optimal acquisition strategy design based on the correct benefit and cost evaluations of easements is in order. This has been

increasingly recognized but the challenge is to incorporate costs and benefits in an integrated framework. Therefore, this paper also aims to develop a framework that integrates environmental benefits, cost estimates, and conversion risks so as to solve an agency's optimal easement acquisition problem. Specifically, we obtain an index for ranking grassland acquisitions such that costs are minimized per unit of expected benefit obtained from easement acquisitions, which will provide easement managers with a more structured data-driven framework for thinking through acquisition decisions.

We first develop a simple two-period model to illustrate the basic trade-offs underlying grassland conversion decisions. To keep the model as simple as possible, we temporarily assume that grassland-to-cropland conversion is irreversible. This can be partially justified by the fact that once a tract of native grassland is converted to cropland, then it will be almost impossible to completely recover the original wildlife habitat and ecosystem services. By using this two-period model, we illustrate differences in easement benefits and costs between the stochastic dynamic approach and the static approach. We find that the static method tends to underestimate minimum easement payments that a landowner should be willing to accept. It also overestimates conversion probability and hence overestimates environmental benefits that an easement acquisition can secure. We also find that, all else equal, a mean preserving spread (MPS) of either crop returns or grassland returns increases this minimum payment. If distribution of cropping returns and grazing returns undergo a shift such that they become larger in the supermodular order sense, then this minimum payment decreases.

A line of research in the conservation literature considers dynamics of conservation acquisition (Costello and Polasky 2004; Wilson et al. 2006; Newburn et al. 2006; Underwood et al. 2009). This line of research assumes that conservation benefits and costs have already been

correctly estimated, mostly using hedonic approach, and then focuses on acquisition mechanism design. Our work is different in that we incorporate evaluation and acquisition of grassland easements into an integrated framework. Some previous studies acknowledge that environmental benefits may not be correctly measured. For example, Miao et al. (2016) discuss how environmental benefit measurement errors affect conservation results. Murdoch et al. (2010) acknowledge the presence of inaccurate information on conservation benefits and costs and seek alternative measurements of conservation benefits. However, none of these studies attempt to develop an integrated framework to evaluate conservation benefits and costs. The present study is an attempt to bridge this gap.

2. A two-period model

In this section we outline landowners' problem and easement agency's problem under a two-period framework. The analysis pertains to *K* grassland tracts, each with a single owner denoted as $k \in \{1,...,K\}$. Landowner *k* has three exclusive land-use choices in period one: (*i*) accept an easement offer, referred to as "ease now", (*ii*) reject the easement offer and convert the grassland to cropland, referred to as "convert now", and (*iii*) reject the easement offer but keep the land under grass, referred to as "wait and see". If the easement offer is accepted, then the landowner receives a lump-sum easement payment, $P_{k,1}$, from an agency and commits to leaving the land unconverted in both periods. Let $\pi^i_{k,t}$, $t \in \{1,2\}$ and $i \in \{c,g\}$ denote net returns from land tract *k* in period *t* under land-use type *i*, where *c* stands for cropping and *g* for grazing. At the beginning of period one, $\pi^i_{k,1}$ is realized whereas $\pi^i_{k,2}$ is unknown to the landowner. To make the analysis meaningful, we assume that $\pi^c_{k,1} > \pi^g_{k,1}$, i.e., realized returns from cropping are greater than those from grazing in period one. If $\pi^c_{k,1} \leq \pi^g_{k,1}$ then action 'convert now' is always dominated by 'wait

and see.' We further assume that the landowner knows the joint cumulative distribution function of $\pi_{k,2}^{c}$ and $\pi_{k,2}^{g}$, $G_k(\pi_{k,2}^{c}, \pi_{k,2}^{g})$.

At the beginning of period two, $\pi_{k,2}^{i}$ is realized and the landowner bases her decisions on the three actions in that period on realized returns. Let $P_{k,2} \geq 0$ denote the lump-sum easement payment the landowner receives if she decides to accept an easement offer in period two. Clearly in period two if the land were to be placed under grass (i.e., $\pi_{k,2}^{g} > \pi_{k,2}^{c} - \theta$) then the landowner would be better off with an easement because $\pi_{k,2}^{g} + P_{k,2} \geq \pi_{k,2}^{g}$. Let V_k^e, V_k^c, and V_k^w be the land values of tract *k* in period one when its owner takes actions (*i*), (*ii*), and (*iii*) in that period, respectively. Then we have

$$\begin{cases} \text{Ease now:} & V_k^e = \pi_{k,1}^{g} + \beta \mathbb{E}(\pi_{k,2}^{g}) + P_{k,1}, \\ \text{Convert now:} & V_k^c = \pi_{k,1}^{c} + \beta \mathbb{E}(\pi_{k,2}^{c}) - \theta_k, \\ \text{Wait and see:} & V_k^w = \pi_{k,1}^{g} + \beta \mathbb{E}\{\max[\pi_{k,2}^{c} - \theta_k, \pi_{k,2}^{g} + P_{k,2}]\}, \end{cases} \tag{1}$$

where β is discount factor. Let $V_k^g \equiv \pi_{k,1}^{g} + \beta \mathbb{E}(\pi_{k,2}^{g})$ denote value of tract *k* were the land to be placed under grazing in both periods without any easement. We can readily check that V_k^w is always greater than V_k^g because $\mathbb{E}\{\max[\pi_{k,2}^{c} - \theta_k, \pi_{k,2}^{g} + P_{k,2}]\} \geq \mathbb{E}(\pi_{k,2}^{g})$. The intuition is that keeping the option of conversion open is better than committing to place the land under grass in both periods if no compensation is provided for such commitment. Figure 1 depicts one possible relationship between V_k^e, V_k^c, V_k^w, and V_k^g as $\mathbb{E}(\pi_{k,2}^{c})$ increases.[1] When the mean of $\pi_{k,2}^{c}$ is very

[1] Note that an increase in $\mathrm{E}(\pi_{k,2}^{c})$ may not always strictly increase the value of $\mathbb{E}\{\max[\pi_{k,2}^{c} - \theta_k, \pi_{k,2}^{g}]\}$.

small then we may have $V_k^w > V_k^c$. When the mean becomes large enough then V^w will become the highest value that the owner can obtain.

Let $P_{k,t}^e$ be the minimum easement payment that a landowner is willing to accept in period $t \in \{1,2\}$. Certainly, the value of $P_{k,2}^e$ depends on the comparison between $\pi_{k,2}^c - \theta_k$ and $\pi_{k,2}^g$. If $\pi_{k,2}^c - \theta_k > \pi_{k,2}^g$ then $P_{k,2}^e = \pi_{k,2}^c - \pi_{k,2}^g$. If $\pi_{k,2}^c - \theta_k \le \pi_{k,2}^g$, however, then $P_{k,2}^e = 0$. So we have $P_{k,2}^e = \max[\pi_{k,2}^c - \theta_k - \pi_{k,2}^g, 0]$. The value of $P_{k,1}^e$ depends on the comparison between the expected returns from grazing the land in both periods without an easement (i.e., V^g), from "convert now", and from "wait and see". Replacing $P_{k,2}$ with $P_{k,2}^e$ in equation (1), we have:

$$P_{k,1}^e = \max[V_k^c, V_k^w] - V^g = \max[\omega_{k,1} + \beta\mathbb{E}(\omega_{k,2}) - \theta_k, \beta\mathbb{E}(\max[\omega_{k,2} - \theta_k, 0])], \tag{2}$$

where $\omega_{k,t} \equiv \pi_{k,t}^c - \pi_{k,t}^g$, $t \in \{1,2\}$, is the difference between crop returns and grazing returns. Note that only the difference between the two returns will affect the minimum easement payment in period one. The minimum easement payment in period two does not affect value from 'wait and see' and hence does not affect the magnitude of the minimum easement payment in period one. This is because in period two the landowner has the option to obtain the higher of cropping returns and grazing returns. The minimum easement payment is only large enough to bridge the gap between cropping returns and grazing returns. However, it does not increase the land value from exercising this option. In the next subsection we will discuss how $\omega_{k,2}$ affects $P_{k,1}^e$. Figure 1 also depicts how the value of $P_{k,1}^e$ changes with expected return of cropping in period two, from which we can see that the value of P_k^e depends on the comparison between V_k^g and the higher of return from "convert now" and that from "wait and see." In equation (2), $\omega_{k,1} + \beta\mathbb{E}(\omega_{k,2}) - \theta_k$ is the difference in land values when comparing actions "convert now" and "wait and see." Item

$\beta\mathbb{E}(\max[\omega_{k,2}-\theta_k,0])$ in equation (2) is the difference in land values between a) grazing the land across the two periods and b) 'wait and see.'

Define $\hat{P}_k \equiv \max[0,\omega_{k,1}+\beta\mathbb{E}(\omega_{k,2})-\theta_k]$, which can be interpreted as the minimum easement payment that a landowner is willing to accept as derived under a typical static net present value (NPV) approach. It is readily checked that $P_k^e \geq \hat{P}_k$. This reflects the forgone option values that must be compensated by easement acquisition agency. The static approach that only considers the expected returns from 'cropping always' and 'grazing always' is a special case of our analysis. It applies only if the value from 'cropping always' is greater than that from 'wait and see' (i.e., $V_k^c > V_k^w$ and hence $\omega_{k,1}+\beta\mathbb{E}(\omega_{k,2})-\theta_k > \beta\mathbb{E}(\max[\omega_{k,2}-\theta_k,0])$).

2.1. Effects of increasing risk and correlation

Since values of V_k^c and V_k^w can be determined based on realized period one returns and on expected returns in period two, in the absence of easement payment the conversion probability in period one, i.e., Prob($V_k^c > V_k^w$), degenerates to either 0 or 1. That is, if $V_k^c > V_k^w$ then the grassland will be converted in period one whereas if $V_k^c \leq V_k^w$ then no conversion occurs in period one. Suppose $\omega'_{k,2}$ first-order stochastically dominates $\omega_{k,2}$, i.e., for any increasing function $h(\cdot)$ inequality $h(\omega'_{k,2}) \geq h(\omega_{k,2})$ holds. Since $\max[\omega_{k,2}-\theta_k,0]$ increases in $\omega_{k,2}$, we have $\mathbb{E}(\max[\omega'_{k,2}-\theta_k,0]) \geq \mathbb{E}(\max[\omega_{k,2}-\theta_k,0])$. Therefore, P_k^e under $\omega'_{k,2}$ is larger than that under $\omega_{k,2}$. Intuitively, when the difference between cropping returns and grazing returns increases, then the opportunity costs of putting land under grazing will be larger and hence the minimum easement payment that the landowner is willing to accept will increase. An MPS of $\omega_{k,2}$ will increase P_k^e due to the convexity of $\max[\omega_{k,2}-\theta_k,0]$. In other words, an increase in

riskiness increases the value of "wait and see" and hence the easement payment. Therefore, the landowner is less likely to convert in period one. In sum, we can conclude that:

Remark 1. *Suppose* $\omega'_{k,2}$ *first-order stochastically dominates* $\omega_{k,2}$. *The minimum easement payment under* $\omega'_{k,2}$ *is larger than that under* $\omega_{k,2}$. *Everything else equal, an MPS of* $\omega_{k,2}$ *will increase the value of "wait and see" and hence increase the minimum easement payment.*[2] *Such a change will weakly decrease the probability of conversion in period one.*

We turn now to a consideration of how covariability between cropping returns and grass agriculture returns is likely to affect the value of waiting, land conversion probability and the size of minimum easement payments. The function $\max[\omega_{k,2} - \theta_k, 0]$ is convex in $\omega_{k,2}$, implying that $\max[\pi^c_{k,2} - \pi^g_{k,2} - \theta_k, 0]$ has a non-positive second difference in the pair $(\pi^c_{k,2}, \pi^g_{k,2})$, i.e., if $\hat{\pi}^c_{k,t} \geq \tilde{\pi}^c_{k,t}$ and $\hat{\pi}^g_{k,t} \geq \tilde{\pi}^g_{k,t}$ then $\max[\hat{\pi}^c_{k,2} - \hat{\pi}^g_{k,2} - \theta_k, 0] + \max[\tilde{\pi}^c_{k,2} - \tilde{\pi}^g_{k,2} - \theta_k, 0] \leq$ $\max[\hat{\pi}^c_{k,2} - \tilde{\pi}^g_{k,2} - \theta_k, 0] + \max[\tilde{\pi}^c_{k,2} - \hat{\pi}^g_{k,2} - \theta_k, 0]$. This observation is useful in light of the following definition:

Definition 1: (Ch. 9 in Shaked and Shanthikumar, 2007) *Define as supermodular the set of functions* $f(x_1, x_2)$ *satisfying* $f(x''_1, x''_2) + f(x'_1, x'_2) \geq f(x''_1, x'_2) + f(x'_1, x''_2)$ *whenever* $x''_1 \geq x'_1$ *and* $x''_2 \geq x'_2$. *The pair of random variables* $(\varsigma''_1, \varsigma''_2)$ *is larger than the pair* $(\varsigma'_1, \varsigma'_2)$ *in the supermodular order sense whenever, for any supermodular function* $f(\varsigma_1, \varsigma_2)$, *the function's expected value is larger under* $(\varsigma''_1, \varsigma''_2)$ *than under* $(\varsigma'_1, \varsigma'_2)$.

[2] If we restrict the distribution of $\omega_{k,2}$ to normal distributions, then based on Theorem 4 in Müller (2011) we can replace "*an MPS*" in Remark 1 with "*an increase in variance*."

An example is a pair of bivariate normal distributions that only differ in their correlation coefficient, see Example 9.A.20 in Shaked and Shanthiukumar (2007). The distribution with the larger correlation coefficient is larger in the supermodular order. Given that $-\mathbb{E}(\max[\omega_{k,2}-\theta_k,0])$ will increase (weakly) in value whenever the distribution of $(\pi^c_{k,t},\pi^g_{k,t})$ shifts to one that is larger in the supermodular order sense, it follows that

Remark 2. *Assuming that the distribution of cropping returns and grazing returns undergo a shift such that they become larger in the supermodular order sense. Everything else equal, this shift will decrease the value of "wait and see" and hence increase, at least weakly, the probability of conversion in period one. Such a change will weakly decrease the minimum easement payment*.

Let us continue with the bivariate normal distribution example. Recall that in this example distribution that is larger in supermodular order has larger correlation coefficient. An increase in return correlation indicates that cropping returns and grazing returns are more likely to change in the same direction. Therefore, the chance that the landowner would regret on converting land use from grazing to cropping in the second period will be smaller. This indicates that the value of "wait and see" will decrease as the correlation between grazing returns and cropping returns increases. Consequently, the conversion probability will increase whereas easement payment will decrease.

Remarks 1 and 2 reveal that conversion probability and easement payment (or value) may vary in opposite directions. Easement value depends on comparisons between land values from "convert now," "graze always," and "wait and see." Previous studies usually focus on the comparison between "convert now" and "graze always". However, what is omitted is that the landowner may "wait and see" regarding the easement enrollment decision. For a landowner

whose land value from "wait and see" is higher than that from "convert now," she will keep the land under grass in period one. A decrease in risk in ω_2 will decrease land value from "wait and see" and hence increase the probability of converting land in period one. Previous studies usually take conversion probability and easement value to be positively correlated, which might be correct if the real options of the landowner were not to be accounted for. However, when the real options are accounted for and when the value of 'wait and see' is larger than that of 'convert now,' then everything else equal land with larger variation in returns may have a lower conversion probability but a larger easement value. In this case, conversion probability and easement value go the opposite directions. This may explain why there are many landowners do not place their lands under grassland easements while they leave their land under grass (Magedanz 2004; Gattuso 2008).

An actuarially fair crop insurance will reduce the variability of cropping returns and also have an ambiguous effect on how cropping returns and grazing returns co-vary. Therefore, the effects of crop insurance are unclear and remain to be investigated. These ambiguities leave the effect of crop insurance on easement payment and on conversion probability and empirical questions.

2.2. Environmental benefits from conservation easements

Before we formalize the easement agency's problem, let us first evaluate the environmental benefits secured by easement acquisition. Let b_k be environmental benefits of the kth tract of grassland per period and per unit of land, where $k \in \Omega \equiv \{1, 2, \ldots, K\}$. Recall that K is total number of grassland parcels. A static approach that does not account for conversion probability views the entire environmental benefits from the grassland across both periods as benefits obtained by the easement acquisition. Specifically, we have

$$B_{k,1}^{\mathrm{s}} = (1+\beta)b_k, \tag{3}$$

where the superscript 's' stands for static approach. Here B_k^{s} is the per-unit environmental benefit provided by parcel *k* were the land to be eased. It may be an over-estimate for the environmental benefits increased by an easement acquisition. This is because even if there is no easement purchase, the landowner may choose the action 'wait and see' in period one and the land would still generate environmental benefit b_k in that period. In period two, the landowner may or may not convert her grassland to cropping. Therefore, there is a positive probability that the grassland can provide its full environmental benefit, B_k^{s}, even without an easement. Specifically, this probability is $\Pr(\omega_{k,2} \le \theta)$. In other words, the value of real option (or 'flexibility') incentivizes the landowner to keep the land under grass but not enroll the land under easement. Consequently, the environmental benefits of grassland are maintained due to this real option value. While the real option value should be included in the opportunity costs of enrolling land under easement, the environmental benefits maintained through the real option value should be excluded from the environmental benefits secured by easement acquisition.

Without easement acquisition, the landowner's choice set in period one becomes {"convert now", "wait and see"} and the expected environmental benefits of the grassland across the two periods is

$$B_{k,1}^{\mathrm{ne}} = \begin{cases} 0, & \text{if } V_k^c > V_k^w, \\ b_k + \beta b_k \Pr(\omega_{k,2} \le \theta), & \text{if } V_k^c \le V_k^w; \end{cases} \tag{4}$$

where the superscript "ne" stands for "no easement" and the subscript "1" stands for period one. Therefore, the expected increase in environmental benefits on grassland parcel *k* due to easement purchase, denoted as $B_{k,1}^{\mathrm{e}}$, is

$$B_{k,1}^{\mathrm{e}} = B_k^{\mathrm{s}} - B_{k,1}^{\mathrm{ne}} = \begin{cases} B_{k,1}^{\mathrm{s}}, & \text{if } V^c > V^{\mathrm{w}}; \\ \beta b_k \Pr(\omega_{k,2} > \theta), & \text{if } V^c \le V^{\mathrm{w}}. \end{cases} \tag{5}$$

In period two, if the difference between returns from cropping and those from grazing is larger than the one-time conversion cost (i.e., $\omega_{k,2} > \theta$) then the landowner will convert the grassland to cropland. Therefore, when $\omega_{k,2} > \theta$ the environmental benefits secured by easement acquisition in period two is b_k. When $\omega_2 \le \theta$, however, the environmental benefits secured by easement acquisition in period two is 0 because the landowner will not convert the grassland even if there is no grassland easement. Specifically, we have

$$B_{k,2}^{\mathrm{e}} = \begin{cases} 0, & \text{if } \omega_{k,2} \le \theta_k; \\ b_k, & \text{if } \omega_{k,2} > \theta_k. \end{cases} \tag{6}$$

2.3. Easement agency's problem and easement acquisition index

We assume that there is only one easement agency, whose purpose is to maximize the increase in expected environmental benefits arising from a budget constrained easement acquisition program.

Let a_k denote the size of tract k. The set of all subsets of Ω is written as $\mathscr{P}(\Omega)$. Let $h_t \in \mathscr{P}(\Omega)$ be the sets of parcels being acquired under grassland easement in period *t*. Certainly, $h_1 \cap h_2 = \varnothing$, that is, if a parcel of grassland is acquired in period one then it will not be available for acquisition in period two and vice versa. The agency's problem is to maximize the expected environmental benefits secured by easement acquisition by selecting $h_1 \in \mathscr{P}(\Omega)$ in period one and $h_2 \in \mathscr{P}(\Omega) - \{h_1\}$ in period two, i.e.,

$$\begin{aligned} &\max_{h_1 \in \mathscr{P}(\Omega),\, h_2 \in \mathscr{P}(\Omega) - \{h_1\}} \sum_{k \in h_1} a_k B_{k,1}^{\mathrm{e}} + \beta \mathbb{E}(\max \sum_{k \in h_2} a_k B_{k,2}^{\mathrm{e}}) \\ &\text{s.t.} \quad \sum_{k \in h_1} a_k P_{k,1}^{\mathrm{e}} + \beta \sum_{k \in h_2} a_k P_{k,2}^{\mathrm{e}} \le M, \end{aligned} \tag{7}$$

where M is the present value of the agency's budget over two periods.

The agency's problem in equation (7) can be solved by backward induction. In period two, the agency's decision problem is straightforward: maximizing environmental benefits by selecting grasslands that have not been placed under a grassland easement or converted to cropland while taking set h_1 as given. As shown in Miao et al. (2016), the agency's decision rule in period two is to simply enroll the grassland with the highest ratio of secured environmental benefits over easement payment until the period two budget is exhausted. That is, selected available tracts with highest $I^e_{k,2} = B^e_{k,2} / P^e_{k,2} = b_k / (\omega_{k,t} - \theta_k)$ for $B^e_{k,2} > 0$ until easement budget is used up. Whenever $B^e_{k,2} = 0$ then tract k should not be considered for easement acquisition. In this case we define $I^e_{k,2} = 0$.

When the analysis is moved backward to period one, we find that it is optimal to not enroll any grasslands with $V^w_k \geq V^c_k$. This is because if $V^w_k \geq V^c_k$ then the tract will be under grass anyway in period one. With the option to acquire the land and place it under an easement in period two, the agency sees no point to spend funds on such land in period one. Therefore, in period one only grassland with $V^w_k < V^c_k$ will be considered for easement acquisition. This conclusion by no means weakens the importance of incorporating the real option value of 'wait and see' in easement acquisition. Without identifying V^w_k or comparing between V^c_k and V^w_k, the agency may ease some tracts that should not be placed under easement in period one.

Since a) only tracts with $V^w_k < V^c_k$ will be eased in period one and b) once a tract is converted then it cannot be converted back to grassland, we can conclude that h_1 is a subset of $c_1 \equiv \{k \mid V^w_k < V^c_k\}$ and that h_2 is a subset of $w_1 \equiv \{k \mid V^w_k \geq V^c_k\}$. Therefore, set choices in the two periods do not influence each other. In other words, for the agency the choice in period one does

not affect the choice in period two, and vice versa. This property significantly simplifies the agency's optimization problem. If the agency has no credit constraint (i.e., is able to save or borrow funds) then its period-one optimal easement acquisition strategy is to enroll tracts with highest $I_{k,1}^{e} = B_{k,1}^{e} / P_{k,1}^{e}$ among tracts $k \in c_1$ until expected environmental benefits secured by one dollar of easement acquisitions in period one equals those in period two. Let λ denote the the budget's shadow value. The acquisition criterion for tract $k \in c_1$ is

$$\begin{cases} \text{acquire if} & I_{k,1}^{e} \geq \lambda; \\ \text{do not acquire if} & I_{k,1}^{e} < \lambda. \end{cases} \tag{8}$$

In reality the agency will have a fixed budget in each period and the budget will be used up in each period. In equation (7) we assume that the agency has no credit constraint so it is able to save and borrow funds. Although the duck stamp funds can be saved indefinitely, the FWS may have difficulties in borrowing funds and paying them back by using duck stamp funds (USGAO, 2007). On the other hands, the FSW has abundant landowners demanding easements (Walker et al. 2013). Therefore, FWS does not have much interest in saving the funds to 'wait and see' for a few years either to ride out a commodity-related land price boom or to collect further information about the land-use decision in the future. They are seeing loss of grassland and might think it irresponsible to wait. Therefore, for policy simulation work we believe that 'spend as you go' is reasonable. A similar approach is adopted in some other studies. For example, Wilson et al. (2006) assume a myopic conservation planner who just maximizes conservation gains or minimizes conservation loss in each period with a fixed per-period budget. They found that conservation allocation results under a myopic conservation planner are close to those under a rational planner.

When following a "spend as you go" approach, the agency's dynamic programming problem reduces to a static optimization problem under which the agency maximizes the expected environmental benefits increased by easement acquisition under the fixed budget in period one. Following Miao et al. (2016) and using equation (2), we construct a benefit over cost index, $I^{e}_{k,1}$, to rank easement acquisition in period one. Specifically,

$$I^{\mathrm{e}}_{k,1} = \frac{B^{\mathrm{e}}_{k,1}}{P^{\mathrm{e}}_{k,1}} = \begin{cases} \dfrac{(1+\beta)b_k}{\omega_{k,1} + \beta\mathbb{E}(\omega_{k,2}) - \theta} & \text{if } V^c > V^w; \\ \dfrac{b_k}{\mathbb{E}(\omega_{k,2} - \theta \mid \omega_{k,2} > \theta)} & \text{if } V^c \le V^w. \end{cases} \tag{9}$$

When $V^c > V^w$, the index numerator is the expected environmental benefits secured by easement acquisition whereas the denominator is the minimum easement payment that the landowner is willing to accept. Under this case the index is only affected by the first moment of random variable ω_2. But note that an MPS in ω_2 may switch $V^c > V^w$ to $V^c \le V^w$ and hence decrease I^e. This indicates that everything else equal, a tract of land that has higher risk in returns should receive lower priority in easement acquisition. In other words, land with higher risk in returns (in an MPS manner) will be more likely kept under grass in period one.

When $V^c \le V^w$, however, the index numerator is the environmental benefits secured in period two and the denominator is the expected easement payment conditional on conversion being profitable (i.e., $\omega_{k,2} > \theta$). Under this case, the effects of an MPS of $\omega_{k,2}$ on $\mathbb{E}(\omega_2 - \theta \mid \omega_2 > \theta)$ are ambiguous without further specification of $\omega_{k,2}$'s distribution.[3] Recall that $\omega_{k,2} \equiv \pi^c_{k,2} - \pi^g_{k,2}$. The effects of an increase in covariability between $\pi^c_{k,2}$ and $\pi^g_{k,2}$ on the

[3] The precise distribution shift in $\omega_{k,2}$ that increases the value of $\mathbb{E}(\omega_{k,2} - \theta \mid \omega_{k,2} > \theta)$ is the mean residual life order. For further details, see Chapter 2 in Shaked and Shanthikumar (2007).

easement index are ambiguous as well without further information about $G(\pi_2^c, \pi_2^g)$, leaving the impacts of riskiness and covariability between returns as empirical questions.

Figure 2 depicts how the acquisition index is affected by the mean of return difference in period 2. Define $\hat{\mu}$ as the value of $\mathbb{E}(\omega_{k,2})$ that equates V_k^c and V_k^w. When $\mathbb{E}(\omega_{k,2}) > \hat{\mu}$ then the acquisition index decreases in $\mathbb{E}(\omega_{k,2})$. When $\mathbb{E}(\omega_{k,2}) \leq \hat{\mu}$ the acquisition index decreases in $\mathbb{E}(\pi_{k,2}^c)$ as well assuming that V_k^w increases in $\mathbb{E}(\pi_{k,2}^c)$. We know that $\mathbb{E}(\omega_{k,2})$ does not arise, directly in the lower branch, with $V_k^c \leq V_k^w$. If $\omega_{k,2}$ increases in the hazard rate order then by Theorems 1.B.1 and 1.D.1 in Shaked and Shanthikumar (1994) we know that $\mathbb{E}(\omega_{k,2})$ increases and that $\mathbb{E}(\omega_{k,2} - \theta \mid \omega_{k,2} > \theta)$ increases in $\mathbb{E}(\omega_{k,2})$. Therefore, Figure 2 only depicts one possible relationship between the acquisition index and $\mathbb{E}(\omega_{k,2})$. Notice that once $\mathbb{E}(\omega_{k,2})$ becomes larger than $\hat{\mu}$ then the acquisition index jumps, due to *i*) a jump in environmental benefits from $\beta \text{Prob}(\omega_{k,2} > \theta) b_k$ to $(1+\beta) b_k$ secured by easement acquisition and *ii*) a continuous increase in easement payment. Tracts with $V_k^c > V_k^w$ typically have higher easement acquisition index values and are more likely to be enrolled under easements. This is consistent with the prediction in problem (7): tracts with $V_k^c \leq V_k^w$ should not be eased in period one. Therefore, the simplified approach should generate results close to the optimal acquisition results.

3. Four-State Case

In this section we examine a four-state case to show how easement payment and the acquisition index are affected by various parameters described in the previous section. To ease exposition we drop parcel subscript *k* in this section's notation but bear in mind that the analysis is still

parcel-specific. Following Dasgupta and Maskin (1987), we assume that the joint distribution of (π_2^c, π_2^g) in period two has the following four states:

$$(\pi_2^c, \pi_2^g) = \begin{cases} (\pi_1^c - \epsilon, \pi_1^g - \eta) & \text{with probability } 0.25(1+\rho), \\ (\pi_1^c - \epsilon, \pi_1^g + \eta) & \text{with probability } 0.25(1-\rho), \\ (\pi_1^c + \epsilon, \pi_1^g - \eta) & \text{with probability } 0.25(1-\rho), \\ (\pi_1^c + \epsilon, \pi_1^g + \eta) & \text{with probability } 0.25(1+\rho), \end{cases} \tag{10}$$

where $\epsilon > 0$, $\eta > 0$, and $\rho \in [-1,1]$ are non-stochastic parameters. It is readily checked that $\mathbb{E}(\pi_2^c) = \pi_1^c$, $\mathbb{E}(\pi_2^g) = \pi_1^g$, $\text{Var}(\pi_2^c) = \epsilon^2$, $\text{Var}(\pi_2^g) = \eta^2$, and $\text{Cov}(\pi_2^c, \pi_2^g) = \rho\epsilon\eta$. Therefore, ρ is the correlation coefficient between π_2^c and π_2^g. To exclude some trivial cases, in addition to $\pi_1^c > \pi_1^g$ we specify the following assumption:

Assumption 1. *i*) $\pi_1^c + \epsilon - \theta > \pi_1^g - \eta$, and *ii*) $\pi_1^c - \epsilon - \theta < \pi_1^g + \eta$.

The two inequalities in Assumption 1 exclude cases in which the land will be converted in period two with probability zero, for inequality *i*), or probability one, for inequality *ii*). One can readily check that Assumption 1 restricts the range of the one-time conversion cost, θ, to $\theta \in (\omega_1 - \epsilon - \eta, \omega_1 + \epsilon + \eta)$.

3.1. Land Values under Various Actions

By equation (1) we know that $V^e = (1+\beta)\pi_1^g + P$ and $V^c = (1+\beta)\pi_1^c - \theta$. Notice that the values of V^e and V^c are affected only by the first moments of returns. Returns from taking the "wait and see" action is slightly more complicated. Based on Assumption 1 and the relationship between returns from converting and from grazing in period two, we have four cases to consider:

$$\begin{cases} \text{Case 1: } \pi_1^c + \epsilon - \theta > \pi_1^g + \eta \text{ and } \pi_1^c - \epsilon - \theta > \pi_1^g - \eta, \\ \text{Case 2: } \pi_1^c + \epsilon - \theta > \pi_1^g + \eta \text{ and } \pi_1^c - \epsilon - \theta < \pi_1^g - \eta, \\ \text{Case 3: } \pi_1^c + \epsilon - \theta < \pi_1^g + \eta \text{ and } \pi_1^c - \epsilon - \theta > \pi_1^g - \eta, \\ \text{Case 4: } \pi_1^c + \epsilon - \theta < \pi_1^g + \eta \text{ and } \pi_1^c - \epsilon - \theta < \pi_1^g - \eta. \end{cases} \tag{11}$$

From equation (11) we can see that the correlation coefficient, ρ, is not directly involved in the case division. However, this does not mean that ρ is irrelevant to the landowner's choices. As we will show in what follows, ρ is critical for the value of 'wait and see.' Figure 3 provides a visual presentation of these four cases. Note that Case 2 requires $\epsilon > \eta$ whereas Case 3 requires $\epsilon < \eta$. The values of θ underlying each case are such that:

$$\begin{cases} \text{Case 1: } \theta \in \omega_1 + (-\epsilon - \eta, \min[\epsilon - \eta, \eta - \epsilon]), \\ \text{Case 2: } \theta \in \omega_1 + (-\epsilon + \eta, \epsilon - \eta), \\ \text{Case 3: } \theta \in \omega_1 + (\epsilon - \eta, -\epsilon + \eta), \\ \text{Case 4: } \theta \in \omega_1 + (\max[\epsilon - \eta, \eta - \epsilon], \epsilon + \eta). \end{cases} \tag{12}$$

Values of V^w in the four cases are

$$V^w = \begin{cases} \pi_1^g + 0.25\beta[(3+\rho)(\pi_1^c - \theta) + (1-\rho)(\pi_1^g + \epsilon + \eta)] & \text{under Case 1} \\ \pi_1^g + 0.5\beta(\pi_1^c + \epsilon - \theta + \pi_1^g - \rho\eta) & \text{under Case 2} \\ \pi_1^g + 0.5\beta(\pi_1^c - \rho\epsilon - \theta + \pi_1^g + \eta) & \text{under Case 3} \\ \pi_1^g + 0.25\beta[(3+\rho)\pi_1^g + (1-\rho)(\pi_1^c + \epsilon + \eta - \theta)] & \text{under Case 4.} \end{cases} \tag{13}$$

Item A in SI presents algebra to obtain equation (13). Based on Assumption 1 it is readily checked that $\partial V^w(\pi_1^c, \pi_1^g) / \partial\rho < 0$ across all the four cases. This indicates that an increase in the correlation coefficient between cropping returns and grazing returns decreases the value of "wait and see," which is consistent with Remark 2. Intuitively, an increase in the one-time conversion cost, θ, will decrease the value of "wait and see" by decreasing the expected returns in period two. That is, $\partial V^w / \partial\theta < 0$.

Under cases 1 and 4 $\partial V^w / \partial \epsilon > 0$ and $\partial V^w / \partial \eta > 0$. That is, an MPS of π_2^c and π_2^g will increase the value of "wait and see" under these two cases. However, under Case 2, we have $\partial V^w(\pi_1^c, \pi_1^g) / \partial \epsilon > 0$ and $\partial V^w(\pi_1^c, \pi_1^g) / \partial \eta = -0.5\beta\rho$. Under Case 3, we have $\partial V^w / \partial \epsilon = -0.5\beta\rho$ and $\partial V^w(\pi_1^c, \pi_1^g) / \partial \eta > 0$. Here we only discuss Case 2. For Case 3 a similar discussion applies. Under Case 2 we have $\partial V^w(\pi_1^c, \pi_1^g) / \partial \eta = -0.5\beta\rho$. Therefore, if $\rho > 0$ then $\partial V^w / \partial \eta < 0$. This indicates that if cropping returns and grazing returns are positively correlated then an increase in the variance of grazing returns will decrease the value of "wait and see." The intuition is as follows. Note that conditional on $\pi_2^c = \pi_1^c - \epsilon$, the probability that $\pi_2^g = \pi_1^g - \eta$ is $0.5(1+\rho)$ whereas the probability that $\pi_2^g = \pi_1^g + \eta$ is $0.5(1-\rho)$. If the two returns are positively correlated and if a lower cropping return occurs, then the lower grazing return ($\pi_2^g = \pi_1^g - \eta$) has a larger probability of occurrence. Because the landowner will not convert the land under the lower cropping returns (recall that $\pi_1^c - \epsilon - \theta < \pi_1^g - \eta$ under Case 2), the lower grazing return indicates a lower value of "wait and see." An increase in η will further reduce the already low grazing returns and increase the high grazing returns. However, since cropping returns and grazing returns are positively correlated, whenever the lower cropping returns occur then the lower grazing returns are more likely occur. On the other hand, if cropping returns are high, then the land owner will convert the grassland whether grazing returns are high or low. That is, if $\pi_2^c = \pi_1^c + \epsilon$ then marginal changes to grazing return variance does not affect the value of "wait and see." Therefore, the aggregate effect of η on V^w is decreasing.

3.2. Choices between Actions

In this subsection, for simplicity we only consider choices between actions under Case 1. Choices under Cases 2-4 follow a similar pattern. Based on equation (1) we obtain $\bar{\theta} = (1+\beta)\delta - P$ such that $V^e = V^c$. An increase in the one-time conversion cost will decrease the value from converting land in period one. For grassland with one-time conversion cost greater than $\bar{\theta}$, the landowner prefers to accept an easement rather than converting the land into cropping in period one.

Let $\tilde{\theta}$ be the one-time conversion cost such that $V^e = V^w$ and let $\hat{\theta}$ be the conversion cost such that $V^c = V^w$. We show that $\partial\tilde{\theta}/\partial\rho < 0$, $\partial^2\tilde{\theta}/\partial\rho^2 > 0$, $\partial\hat{\theta}/\partial\rho > 0$, and $\partial^2\hat{\theta}/\partial\rho^2 > 0$ (see Item B in SI for the proof). Figure 4a presents one possibility for the relationships between these indifference curves in the θ-ρ space because under some conditions of parameters these indifference curves may not cross each other. Conditions regarding *P* and other parameters (π_1^c, π_1^g, ϵ and η) that support this figure are presented in Item C in SI. In Figure 4a, the three indifference curves between V^c, V^e, and V^w divide the ρ-θ space into six areas: Areas A to F. It is readily checked that in Area A we have $V^w > V^e > V^c$ (denoted by vector (*w*,*e*,*c*)) in Figure 4a. Since what matters for the landowner's decision is the largest among V^c, V^e, and V^w, we can conclude that in Areas A and B the landowner will 'wait and see,' in Areas C and D 'convert now,' and in Areas E and F 'ease now.' Figure 4b present a clean version of Figure 4a by combining areas with the same actions and by using dotted lines to present irrelevant parts of those indifference curves.

When the variance of cropping returns increases, then the $V^e = V^w$ curve is twisted clockwise while the $V^c = V^w$ curve is twisted anticlockwise (Figure 5). These twists increase the 'wait and see' area and decrease both 'ease now' and 'convert now' areas. The reason is quite

intuitive: under Case 1 an increase in return variance increase the value of 'wait and see.' When easement payment P increases, then the curve $V^c = V^w$ is unaffected whereas curves $V^c = V^w$ and $V^e = V^w$ shift downward (Figure 6). Therefore, the 'ease now' area increases whereas both 'wait and see' and 'convert now' areas decrease.

3.3. Acquisition Indexes

When $V^c > V^w$ then the acquisition index is not affected by returns variance and correlation:

$$I^{\mathrm{e}} = \frac{B^{\mathrm{e}}}{P^{\mathrm{e}}} = \frac{(1+\beta)b}{(1+\beta)\omega_1 - \theta}. \tag{14}$$

When $V^c \le V^w$, the probability of converting in period two can be written as,

$$\Pr(\omega_2 > \theta) = \begin{cases} 0.25(3+\rho) & \text{under Case 1} \\ 0.5 & \text{under Case 2} \\ 0.5 & \text{under Case 3} \\ 0.25(1-\rho) & \text{under Case 4,} \end{cases} \tag{15}$$

from which we can see that a marginal change in return variances (ϵ^2 and η^2) does not affect the probability of non-converting in period two. However, an increase in the correlation between the two returns, ρ, will increase (respectively, decrease) the probability under Case 1 (respectively, Case 4). Therefore, based on equation (9), we have

$$I^e = \begin{cases} b/[\omega_1 - \theta + (\epsilon+\eta)(1-\rho)/(3+\rho)] & \text{under Case 1} \\ b/(\omega_1 + \epsilon - \theta - \rho\eta) & \text{under Case 2} \\ b/(\omega_1 - \rho\epsilon - \theta + \eta) & \text{under Case 3} \\ b/(\omega_1 + \epsilon - \theta + \eta) & \text{under Case 4.} \end{cases} \tag{16}$$

Item D in SI presents details in how to obtain equation (16). From equation (16) we can see that an increase in the one-time conversion cost will decrease the easement payment, and hence increase the acquisition index. That is, everything else equal, a parcel of grassland with a higher one-time conversion cost should have higher priority in easement acquisition because this parcel

of grassland needs a smaller easement payment. Under Case 1, if the correlation increases then the acquisition index increases. This is because that an increase in ρ will increase the probability of converting in period two and hence increase the benefit of putting grassland under easement. On the other hand, an increase in ρ will decrease the easement payment because it decrease the value of "wait and see." Therefore, an increase in ρ will increase the easement acquisition index. Under Cases 2 and 3, an increase in ρ will increase the index of easement acquisition simply because such increase will decrease easement payment. Under Case 4, however, the index is invariant in ρ because an increase in ρ decreases converting probability and the value of "wait and see" at the same relative amount so they cancel out each other. Since return variances do not affect conversion probability in the four cases arising in period two, their effects on the acquisition index are in the opposite direction when compared with those on easement payment. Note that since under Case 3 (respectively, Case 2) the effect of ϵ (respectively, η) on easement payment is undetermined, the effect of ϵ on the index is also undetermined.

3.4. Effects of Crop Insurance

Now suppose that there is a crop insurance program that pays an indemnity ι whenever lower cropping return occurs (i.e., $\pi_2^c = \pi_1^c - \epsilon$). Insurance premium is $\alpha\iota$, where $\alpha \in [0, 0.5]$. One can check that if $\alpha = 0.5$ then the crop insurance is actuarially fair and if $\alpha = 0$ then the crop insurance is free (e.g., fully subsidized by federal government). The joint distribution of (π_2^c, π_2^g) can be written as

$$(\pi_2^c, \pi_2^g) = \begin{cases} (\pi_1^c - \epsilon + (1-\alpha)\iota, \pi_1^g - \eta) & \text{with probability } 0.25(1+\rho), \\ (\pi_1^c - \epsilon + (1-\alpha)\iota, \pi_1^g + \eta) & \text{with probability } 0.25(1-\rho), \\ (\pi_1^c + \epsilon - \alpha\iota, \pi_1^g - \eta) & \text{with probability } 0.25(1-\rho), \\ (\pi_1^c + \epsilon - \alpha\iota, \pi_1^g + \eta) & \text{with probability } 0.25(1+\rho). \end{cases} \tag{17}$$

Let $\hat{V}$ denote land values in the presence of crop insurance. The value of $\hat{V}^w$ under the four cases then becomes

$$\hat{V}^w = \begin{cases} \pi_1^g + 0.25\beta[(3+\rho)(\pi_1^c - \theta) + (1-\rho)(\pi_1^g + \epsilon + \eta) + ((1+\rho) - (3+\rho)\alpha)\iota] & \text{under Case 1} \\ \pi_1^g + 0.5\beta(\pi_1^c + \epsilon - \theta + \pi_1^g - \rho\eta - \alpha\iota) & \text{under Case 2} \\ \pi_1^g + 0.5\beta[\pi_1^c - \rho\epsilon - \theta + \pi_1^g + \eta + (0.5(1+\rho) - \alpha)\iota] & \text{under Case 3} \\ \pi_1^g + 0.25\beta[(3+\rho)\pi_1^g + (1-\rho)(\pi_1^c + \epsilon + \eta - \theta - \alpha\iota)] & \text{under Case 4.} \end{cases} \tag{18}$$

For Case 1, if $\alpha < (1+\rho)/(3+\rho)$ then the presence of the crop insurance will increase the value of "wait and see." Under Case 3, if $\alpha < (1+\rho)/2$ then the presence of the crop insurance will increase the value of "wait and see." Notice that a smaller α indicates a larger insurance premium subsidy. When the subsidy is large enough then the value of 'wait and see' will increase due to the presence of crop insurance. If $\alpha = 0.5$ then the effect of crop insurance is actuarially fair and equivalent to reducing ϵ by 0.5ι. Therefore, under Cases 1, 2, and 4, the presence of an actuarially fair crop insurance will decrease the value of "wait and see." However, under Case 3, the effect of an actuarially fair crop insurance on the value of "wait and see" depends on the sign of ρ. When $\rho > 0$ then an actuarially fair crop insurance will increase the value from 'wait and see' and when $\rho < 0$ then the opposite is true. This is because when cropping returns and grazing returns are positively correlated, then the simultaneous occurrence of a low cropping return and a low grazing return is more likely. Under this scenarios crop

insurance has greater value because if a low cropping return occurs then the landowner cannot resort to high grazing return.

Under cases 2 and 4 the presence of crop insurance contracts will always (at least weakly) decrease the value of "wait and see." The reason is that low cropping return is dominated by grazing returns under these two cases and hence the benefit of having crop insurance is zero whereas the cost of having crop insurance is to reduce high cropping returns. Moreover, if the crop insurance is free then it does not affect high cropping returns either so the value of "wait and see" is not influenced by the crop insurance.

With crop insurance, land value from 'convert now' is

$$\hat{V}^c = (1+\beta)\pi_1^c + \beta(0.5-\alpha)\iota - \theta. \tag{19}$$

Based upon equations (13) and (19) one can readily check that $\hat{V}^c - V^c \geq \hat{V}^w - V^w$ holds for any $\alpha \in [0, 0.5]$. This indicates that the presence of crop insurance will always incentivize 'convert now' to a greater extent than that of incentivizing 'wait and see', which is consistent with the findings in Miao, Hennessy, and Feng (2014). Therefore, the presence of crop insurance may change $V^w \geq V^c$ to $\hat{V}^w < \hat{V}^c$ for some tracts of grassland.

Figure 7 illustrates how the presence of an actuarially fair insurance will affect the land-use decision. With an actuarially fair insurance contract, the value of 'convert now' is unaffected. However, the value of 'wait and see' decreases. Therefore, the curve $V^c = V^w$ twists clockwise whereas the curve $V^e = V^w$ twists anti-clockwise. As a results, the 'wait and see' area shrinks whereas both 'ease now' area and 'convert now' area expand.

Figure 8 shows an example how subsidized crop insurance may affect land-use decisions. Under a subsidized insurance, the value of 'convert now' increases for sure. A heavily subsidized insurance may also increases the value of 'wait and see' due to net gains from

indemnity payments. Under this case, the curve of $V^e = V^w$ twists clockwise. Because subsidized crop insurance always causes a larger increase in V^c than in V^w, the curve of $V^c = V^w$ twists clockwise as well. Therefore, under heavily subsidized crop insurance, 'convert now' area and 'wait and see' area will increase whereas 'ease now' area will decrease. That is, such insurance program may hinder easement acquisition.

For a grassland tract, if $V^w < V^c$ then the presence of crop insurance will decrease the easement acquisition index. Perhaps a more interesting question is how crop insurance will affect ranking among grassland tracts with various return riskiness. Let ι be $\phi\pi_1 - (\pi_1 - \epsilon)$. That is, the crop insurance contract guarantees return $\phi\pi_1$ and will pay the landowner return shortfall $\phi\pi_1 - (\pi_1 - \epsilon)$ whenever the low cropping return occurs. From equation (19) we can check that whenever $\alpha < 0.5$ (i.e., insurance premium is subsidized) then $\partial\hat{V}^c / \partial\epsilon > 0$, indicating that an increase in risk will increase the land value from 'convert now' and hence decrease the acquisition index. This implies that everything else equal, in the presence of subsidized crop insurance tracts with higher risk in cropping returns will be ranked lower in easement acquisition than tracts with lower cropping risk.

If $V^w \geq V^c$ then the effect of the presence of crop insurance on the acquisition index is ambiguous, which leaves us with an empirical question. Plugging $\iota = \phi\pi_1 - (\pi_1 - \epsilon)$ into equation (18), we then obtain

$$\hat{V}^w = \pi_1^g + 0.25\beta \begin{cases} (3+\rho)(\pi_1^c - \theta) + (1-\rho)(\pi_1^g + \epsilon + \eta) + ((1+\rho) - (3+\rho)\alpha)(\epsilon - (1-\phi)\pi_1) & \text{under Case 1} \\ 2[\pi_1^c + \epsilon - \theta + \pi_1^g - \rho\eta - \alpha(\epsilon - (1-\phi)\pi_1)] & \text{under Case 2} \\ 2[\pi_1^c - \rho\epsilon - \theta + \pi_1^g + \eta + (0.5(1+\rho) - \alpha)(\epsilon - (1-\phi)\pi_1)] & \text{under Case 3} \\ (3+\rho)\pi_1^g + (1-\rho)(\pi_1^c + \epsilon + \eta - \theta - \alpha(\epsilon - (1-\phi)\pi_1)) & \text{under Case 4.} \end{cases} \quad (20)$$

We can check that under Cases 1, 2 and 4 $\partial \hat{V}^w / \partial \epsilon \geq 0$. Because $\partial V^w / \partial \epsilon \geq 0$, we can conclude that under Cases 1, 2 and 4 the presence of crop insurance does not affect the ranking of land tracts. Under Case 3, we know that $\partial V^w / \partial \epsilon = -0.5\beta\rho$ and $\partial \hat{V}^w / \partial \epsilon = 0.5\beta[0.5(1-\rho)-\alpha]$. Therefore, whenever $\rho < 0$ then $\partial V^w / \partial \epsilon > 0$ and $\partial \hat{V}^w / \partial \epsilon > 0$, indicating the presence of crop insurance does not affect the ranking. Whenever $\rho \geq 0$, then $\partial V^w / \partial \epsilon \leq 0$ but the sign of $\partial \hat{V}^w / \partial \epsilon$ is undetermined: if $\alpha \geq (1-\rho)/2$ then $\partial \hat{V}^w / \partial \epsilon \leq 0$ and if $\alpha < (1-\rho)/2$ then $\partial \hat{V}^w / \partial \epsilon > 0$. We can conclude that under Case 3, if premium subsidy is large enough (i.e., $\alpha < (1-\rho)/2$) then the presence of crop insurance can affect the ranking among tracts.

4. Conclusions

This study presents an integrated theoretical framework to investigate grassland easement evaluation and acquisition. Based on a two-period model, we find that an MPS of the difference between cropping returns and grazing returns increases the value from action 'wait and see' and the minimum easement payment that landowners are willing to accept. This change will decrease conversion probability in period one. If distribution of cropping returns and grazing returns undergo a shift such that they become larger in the supermodular order sense, then the minimum easement payment decreases and the period-one conversion probability increases. Therefore, the minimum easement payment and period-one conversion probability may go opposite directions. Solutions to the easement agency's problem indicate that a grassland tract whose owner chooses 'wait and see' in period one should not be acquired in that period. An easement acquisition index is developed to rank acquisition priority for different grassland tracts.

We developed a framework for land conversion trade-offs that easement managers can use to better understand economic determinants of conversion choices. It will allow land planners to

think through whether easement dollars are spent effectively. Discussions with easement managers in the PPR point to strategic issues when purchasing easements, such as program reputation, that warrant serious consideration by economists but are beyond the current scope of research.

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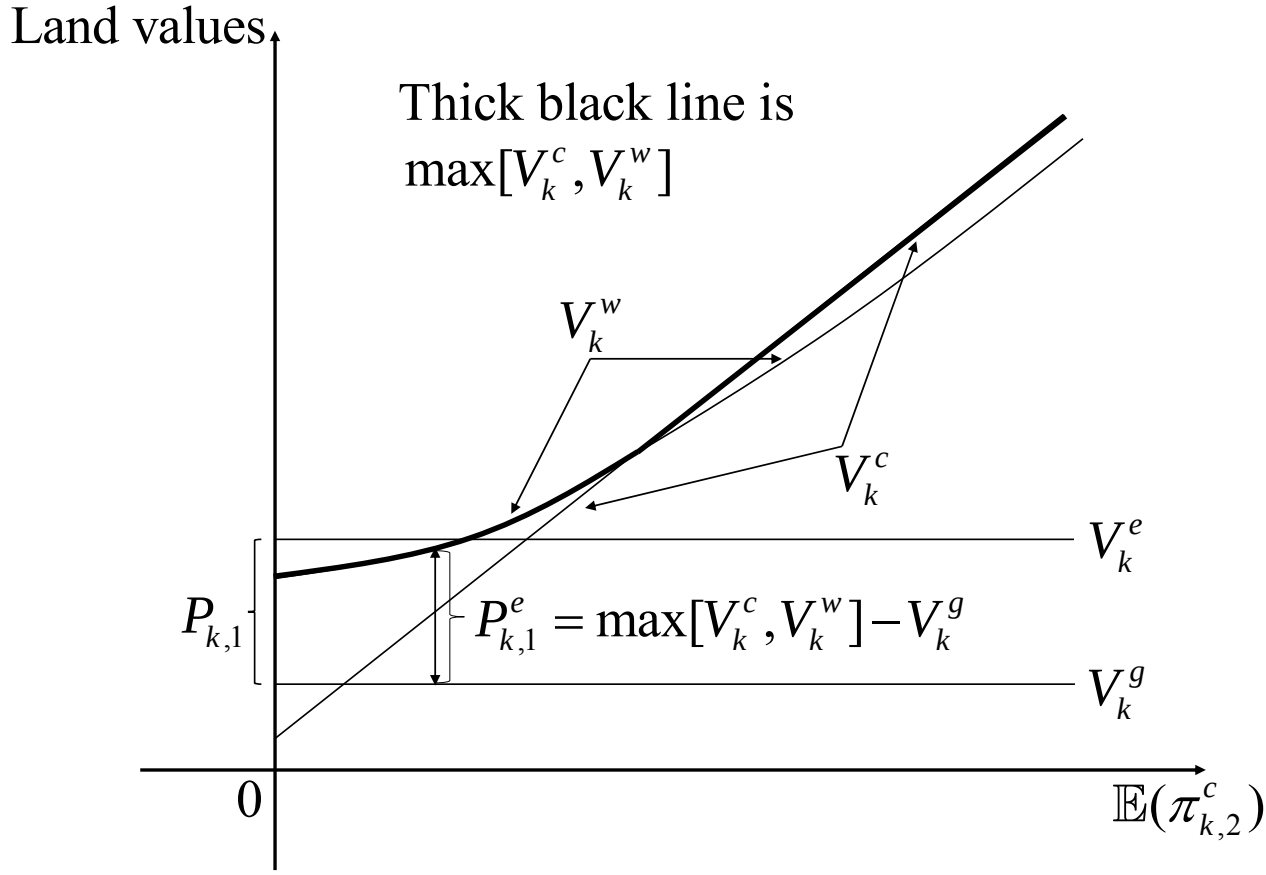

Figure 1. Land Values as the Mean of Cropping Returns Increases

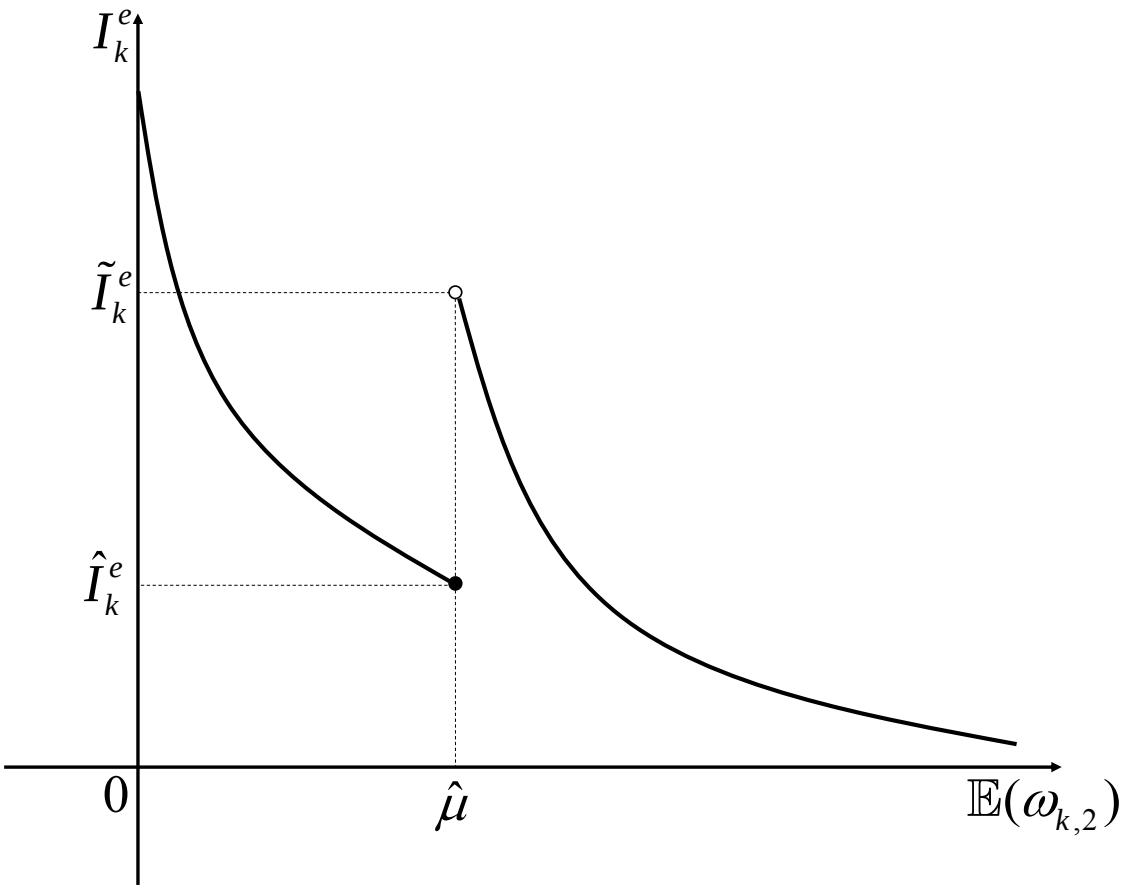

Figure 2. Easement Acquisition Index as the Mean of Return Differences (i.e., $\mathbb{E}(\omega_{k,2})$) Increases

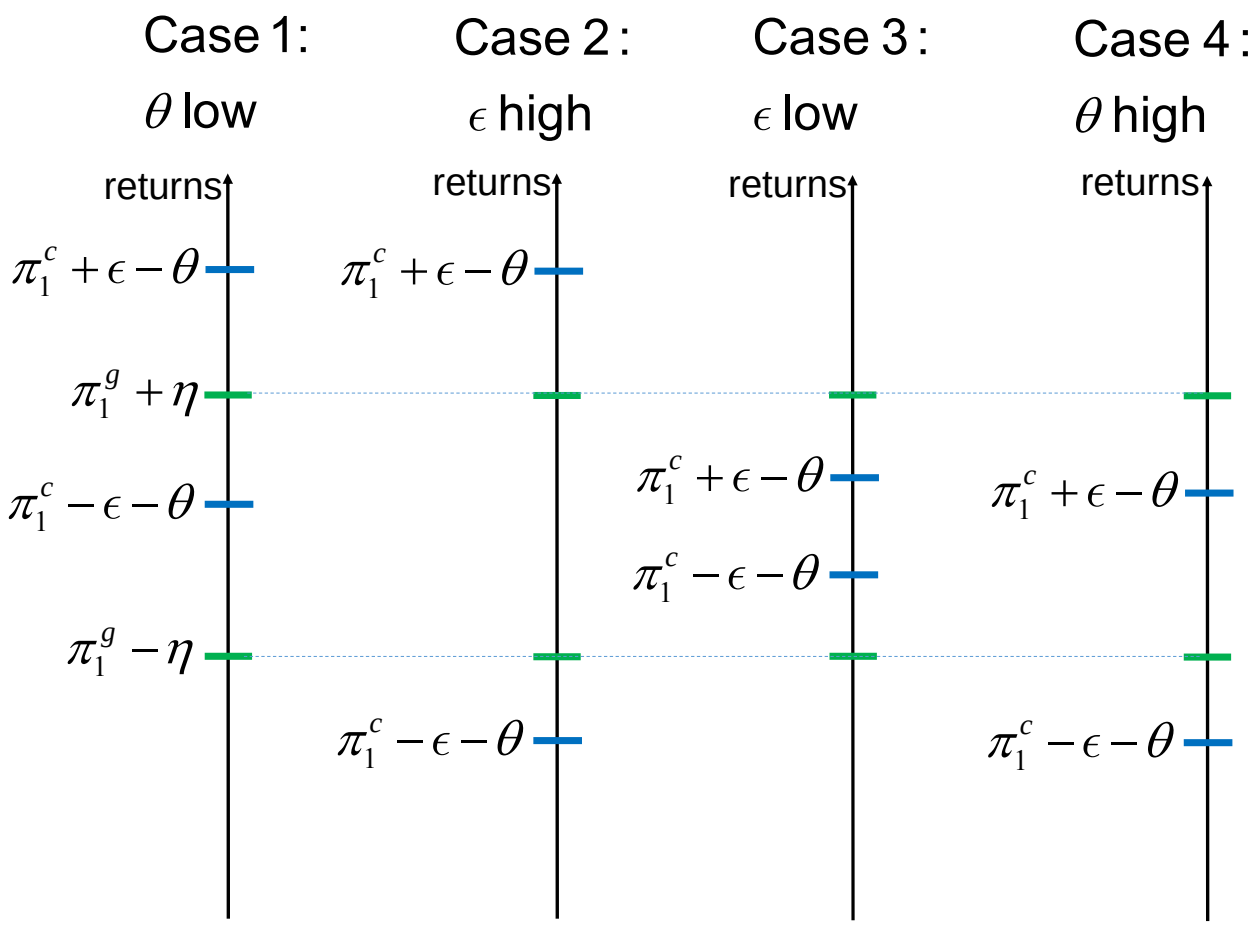

Figure 3. Four Cases for the Relationship between Returns from Cropping and from Grazing in Period Two

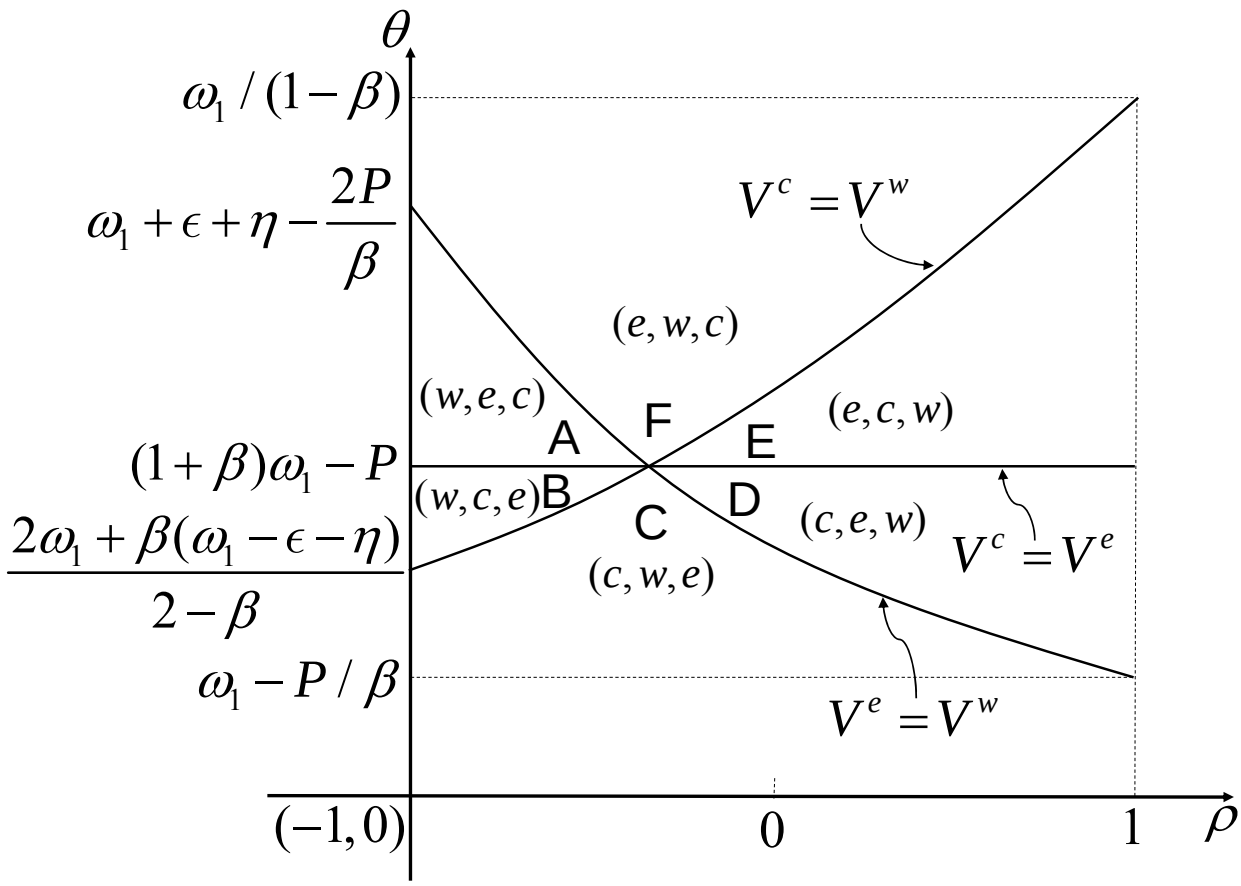

Figure 4a. Relationships between V^e, V^c, and V^w under Case 1 in the ρ-θ Space

Note: The vectors in areas A to F indicate relationship between V^e, V^c, and V^w. For example, (w,e,c) stands for $V^w > V^e > V^c$.

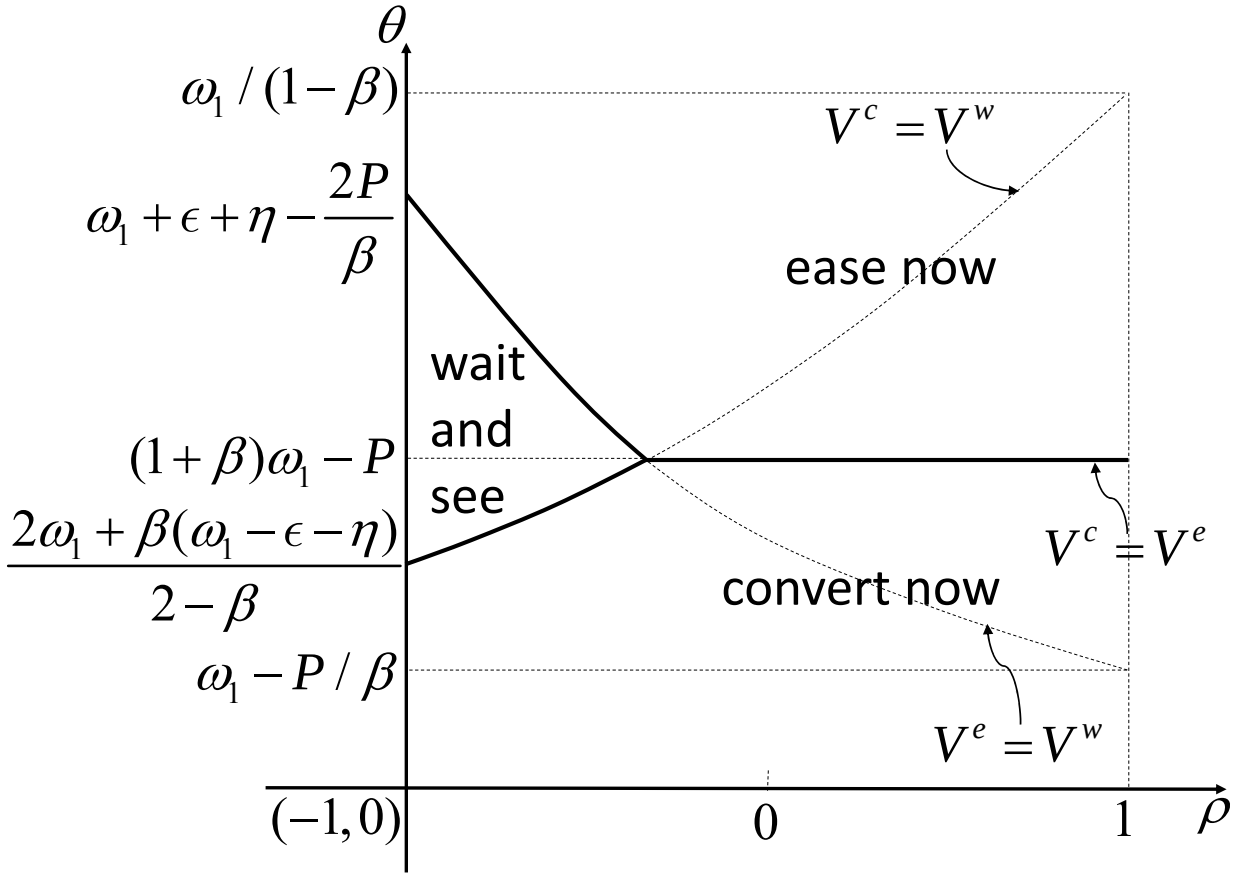

Figure 4b. A Cleaner Version of Figure 4a

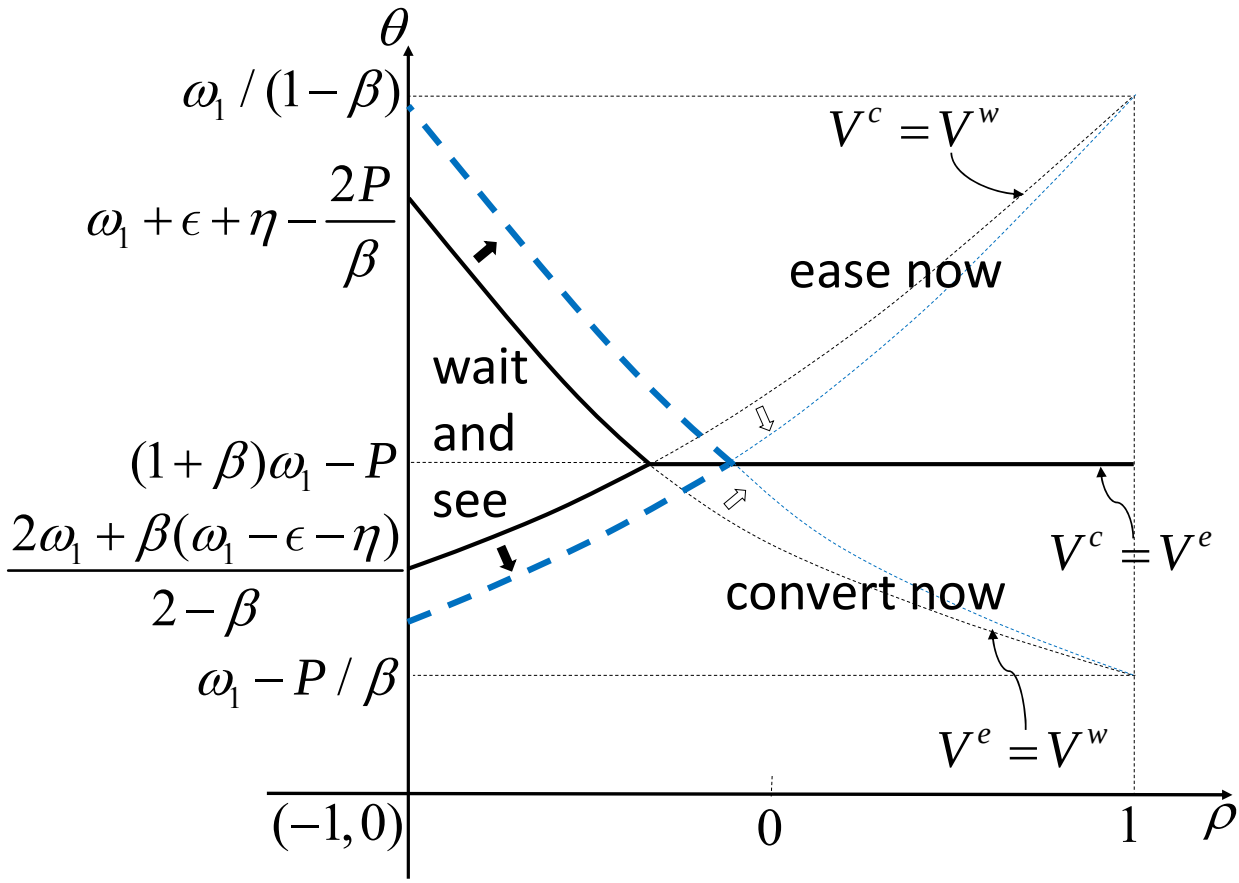

Figure 5. Effects of an Increase in the Variance of Cropping Returns or Grazing Returns

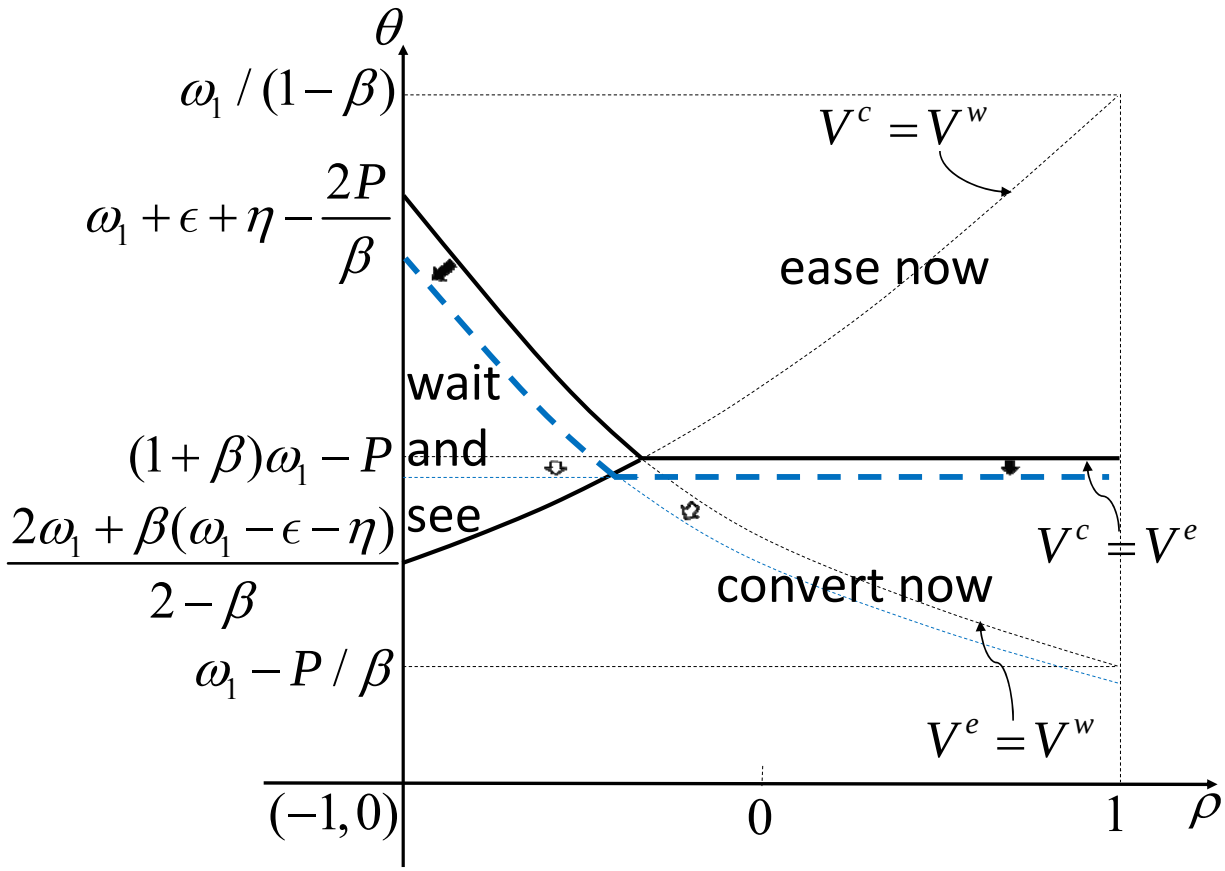

Figure 6. Effects of an Increase in Easement Payment

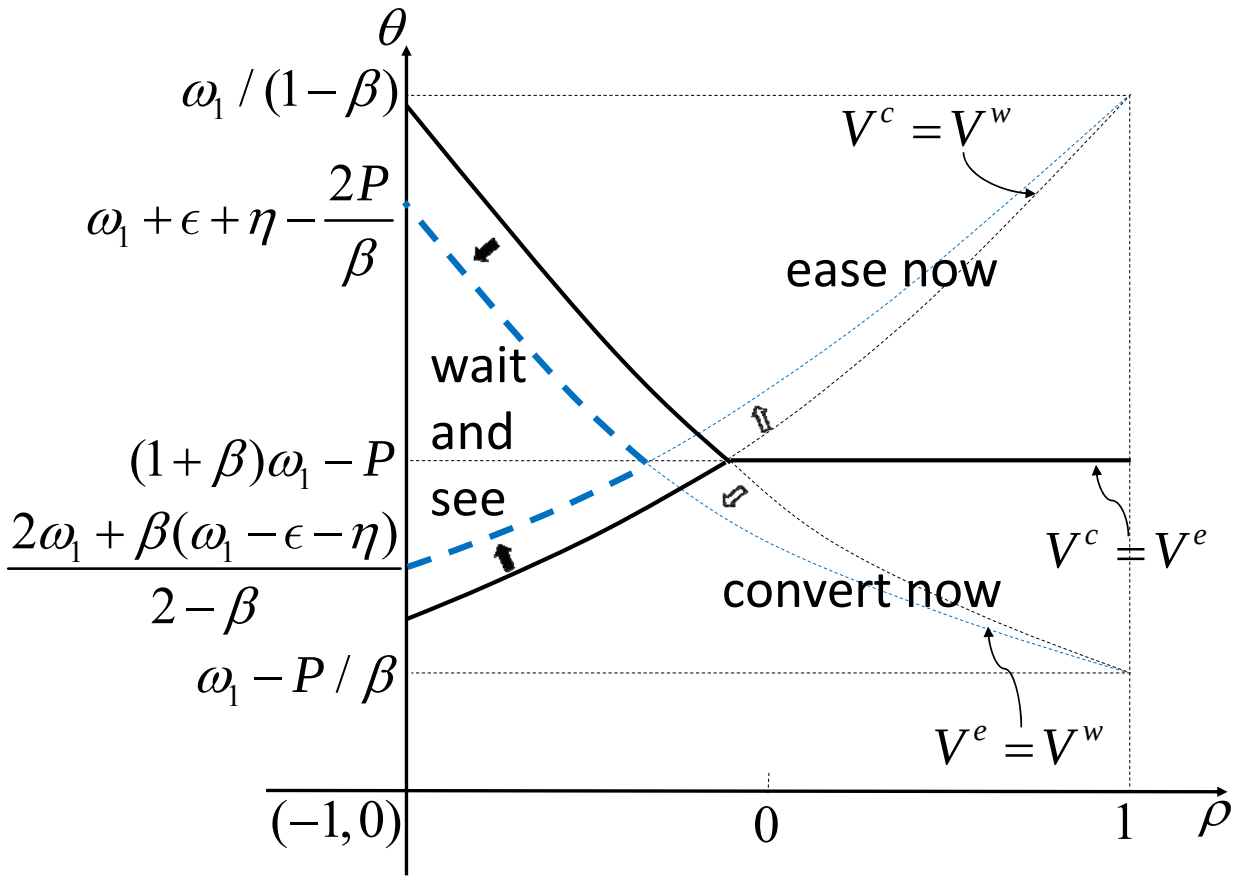

Figure 7. Effects of Actuarially Fair Crop Insurance

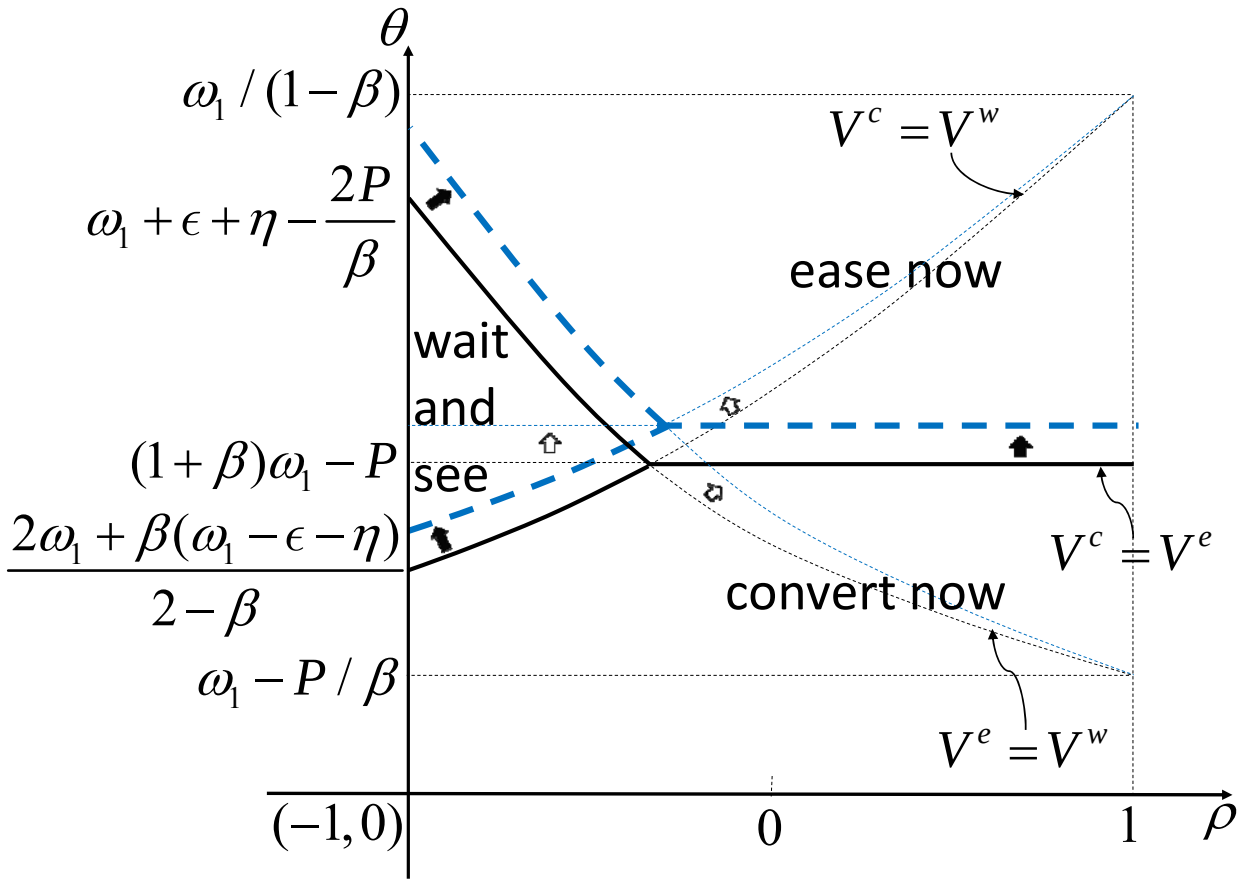

Figure 8. Effects of Subsidized Crop Insurance

Supporting Information for "Grassland Easement Evaluation and Acquisition: an Integrated Framework"

Item A.

In this item we show how to obtain equation (13), the value of $V^w(\pi_1^c, \pi_2^c)$ under the four cases specified in equation (11).

Case 1. $\pi_1^c + \epsilon - \theta > \pi_1^g + \eta$ and $\pi_1^c - \epsilon - \theta > \pi_1^g - \eta$

Under this case,

$$
\begin{aligned}
& V^w(\pi_1^c, \pi_1^g) \\
&= \pi_1^g + \beta \mathbb{E}\{\max[\pi_2^c - \theta, \pi_2^g]\} \\
&= \pi_1^g + \beta\{0.25(1+\rho)(\pi_1^c - \epsilon - \theta) + 0.25(1-\rho)(\pi_1^g + \eta) + \\
&\quad 0.25(1-\rho)(\pi_1^c + \epsilon - \theta) + 0.25(1+\rho)(\pi_1^c + \epsilon - \theta)\} \\
&= \pi_1^g + \beta\{0.25(1+\rho)(\pi_1^c - \epsilon - \theta) + 0.25(1-\rho)(\pi_1^g + \eta) + 0.5(\pi_1^c + \epsilon - \theta)\} \\
&= \pi_1^g + \beta\{(0.75 + 0.25\rho)\pi_1^c + 0.25(1-\rho)(\pi_1^g + \eta) + 0.25(1-\rho)\epsilon - (0.75 + 0.25\rho)\theta\} \\
&= \pi_1^g + 0.25\beta[(3+\rho)(\pi_1^c - \theta) + (1-\rho)(\pi_1^g + \epsilon + \eta)].
\end{aligned}
$$

It is readily checked that $\partial V^w / \partial \epsilon \geq 0$, $\partial V^w / \partial \eta \geq 0$, $\partial V^w / \partial \theta < 0$. Further, by Assumption 1 we have

$$
\begin{aligned}
& \frac{\partial V^w(\pi_1^c, \pi_1^g)}{\partial \rho} \\
&= \beta\{0.25\pi_1^c - 0.25(\pi_1^g + \eta) - 0.25\epsilon - 0.25\theta\} \\
&= 0.25\beta\{(\pi_1^c - \epsilon - \theta) - (\pi_1^g + \eta)\} \\
&< 0.
\end{aligned}
$$

Case 2. $\pi_1^c + \epsilon - \theta > \pi_1^g + \eta$ and $\pi_1^c - \epsilon - \theta < \pi_1^g - \eta$

Under this case,

$$
\begin{aligned}
&V^w(\pi_1^c, \pi_1^g) \\
&= \pi_1^g + \beta \mathbb{E}\{\max[\pi_2^c - \theta, \pi_2^g]\} \\
&= \pi_1^g + \beta\{0.25(1+\rho)(\pi_1^g - \eta) + 0.25(1-\rho)(\pi_1^g + \eta) + \\
&\quad 0.25(1-\rho)(\pi_1^c + \epsilon - \theta) + 0.25(1+\rho)(\pi_1^c + \epsilon - \theta)\} \\
&= \pi_1^g + \beta\{0.5\pi_1^g - 0.5\rho\eta + 0.5(\pi_1^c + \epsilon - \theta)\} \\
&= \pi_1^g + 0.5\beta(\pi_1^c + \epsilon - \theta + \pi_1^g - \rho\eta).
\end{aligned}
$$

It is readily checked that $\partial V^w / \partial \epsilon > 0$, $\partial V^w / \partial \rho < 0$, $\partial V^w / \partial \theta < 0$. Moreover, $\partial V^w / \partial \eta = -0.5\rho$. If $\rho > 0$ then $\partial V^w / \partial \eta < 0$. If $\rho < 0$ then $\partial V^w / \partial \eta > 0$. If $\rho = 0$ then $\partial V^w / \partial \eta = 0$.

Case 3. $\pi_1^c + \epsilon - \theta < \pi_1^g + \eta$ and $\pi_1^c - \epsilon - \theta > \pi_1^g - \eta$

Under this case,

$$
\begin{aligned}
&V^w(\pi_1^c, \pi_1^g) \\
&= \pi_1^g + \beta \mathbb{E}\{\max[\pi_2^c - \theta, \pi_2^g]\} \\
&= \pi_1^g + \beta\{0.25(1+\rho)(\pi_1^c - \epsilon - \theta) + 0.25(1-\rho)(\pi_1^g + \eta) + \\
&\quad 0.25(1-\rho)(\pi_1^c + \epsilon - \theta) + 0.25(1+\rho)(\pi_1^g + \eta)\} \\
&= \pi_1^g + \beta\{0.5\pi_1^c - 0.5\rho\epsilon - 0.5\theta + 0.5(\pi_1^g + \eta)\} \\
&= \pi_1^g + 0.5\beta(\pi_1^c - \rho\epsilon - \theta + \pi_1^g + \eta)\ .
\end{aligned}
$$

We can check that $\partial V^w / \partial \eta > 0$, $\partial V^w / \partial \rho < 0$, $\partial V^w / \partial \theta < 0$. However, $\partial V^w / \partial \epsilon = -0.5\rho$. If $\rho > 0$ then $\partial V^w / \partial \epsilon < 0$. If $\rho < 0$ then $\partial V^w / \partial \epsilon > 0$. If $\rho = 0$ then $\partial V^w / \partial \epsilon = 0$.

Case 4. $\pi_1^c + \epsilon - \theta < \pi_1^g + \eta$ and $\pi_1^c - \epsilon - \theta < \pi_1^g - \eta$

Under this case,

$$
\begin{aligned}
&V^w(\pi_1^c, \pi_1^g) \\
&= \pi_1^g + \beta \mathbb{E}\{\max[\pi_2^c - \theta, \pi_2^g]\} \\
&= \pi_1^g + \beta\{0.25(1+\rho)(\pi_1^g - \eta) + 0.25(1-\rho)(\pi_1^g + \eta) + \\
&\quad 0.25(1-\rho)(\pi_1^c + \epsilon - \theta) + 0.25(1+\rho)(\pi_1^g + \eta)\} \\
&= \pi_1^g + \beta\{0.25(1+\rho)(\pi_1^g - \eta) + 0.5(\pi_1^g + \eta) + 0.25(1-\rho)(\pi_1^c + \epsilon - \theta)\} \\
&= \pi_1^g + \beta\{(0.5 + 0.25(1+\rho))\pi_1^g + 0.25(1-\rho)\eta + 0.25(1-\rho)(\pi_1^c + \epsilon - \theta)\} \\
&= \pi_1^g + 0.25\beta[(3+\rho)\pi_1^g + (1-\rho)(\pi_1^c + \epsilon + \eta - \theta)].
\end{aligned}
$$

It is readily checked that $\partial V^w / \partial \epsilon \geq 0,\ \partial V^w / \partial \eta \geq 0,\ \partial V^w / \partial \theta < 0.$ Further, by Assumption 1 we have

$$
\begin{aligned}
&\frac{\partial V^w(\pi_1^c, \pi_1^g)}{\partial \rho} \\
&= \beta\{0.25\pi_1^g - 0.25\eta - 0.25(\pi_1^c + \epsilon - \theta)\} \\
&= 0.25\beta\{(\pi_1^g - \eta) - (\pi_1^c + \epsilon - \theta)\} \\
&< 0.
\end{aligned}
$$

Item B.

In this item we show that $\partial \tilde{\theta} / \partial \rho < 0$, $\partial^2 \tilde{\theta} / \partial \rho^2 > 0,\ \partial \hat{\theta} / \partial \rho > 0$, and $\partial^2 \hat{\theta} / \partial \rho^2 > 0$. By definition we know $\tilde{\theta}$ such that $V^e(\pi_1^c, \pi_1^g) = V^w(\pi_1^c, \pi_1^g)$. Specifically,

$$
\begin{aligned}
&V^g(\pi_1^c, \pi_1^g) = V^w(\pi_1^c, \pi_1^g) \\
&\Rightarrow \pi_1^g + \beta\pi_1^g + P = \pi_1^g + 0.25\beta\{(3+\rho)(\pi_1^c - \tilde{\theta}) + (1-\rho)(\pi_1^g + \epsilon + \eta)\} \\
&\Rightarrow 0.25\beta\{(3+\rho)(\pi_1^c - \tilde{\theta}) + (1-\rho)(\pi_1^g + \epsilon + \eta)\} - \beta\pi_1^g - P = 0 \\
&\Rightarrow \frac{\partial \tilde{\theta}}{\partial \rho} = \frac{(\pi_1^c - \epsilon - \tilde{\theta}) - (\pi_1^g + \eta)}{3+\rho} < 0 \qquad \text{by Assumption 1} \\
&\Rightarrow \frac{\partial^2 \tilde{\theta}}{\partial \rho^2} = \frac{-\frac{\partial \tilde{\theta}}{\partial \rho}(3+\rho) - [(\pi_1^c - \epsilon - \tilde{\theta}) - (\pi_1^g + \eta)]}{(3+\rho)^3} > 0.
\end{aligned}
$$

By definition we know $\hat{\theta}$ such that $V^c(\pi_1^c, \pi_1^g) = V^w(\pi_1^c, \pi_1^g)$. Specifically,

$$
\begin{aligned}
& V^c(\pi_1^c, \pi_1^g) = V^w(\pi_1^c, \pi_1^g) \\
& \Rightarrow \pi_1^c + \beta\pi_1^c - \hat{\theta} = \pi_1^g + 0.25\beta\{(3+\rho)(\pi_1^c - \hat{\theta}) + (1-\rho)(\pi_1^g + \epsilon + \eta)\} \\
& \Rightarrow \theta(1 - 0.25\beta(3+\rho)) - (\pi_1^c - \pi_1^g) - 0.25\beta(1-\rho)[(\pi_1^c - \pi_1^g) - (\epsilon + \eta)] = 0 \\
& \Rightarrow \frac{\partial\theta}{\partial\rho} = -\frac{-0.25\beta[(\pi_1^c - \epsilon - \hat{\theta}) - (\pi_1^g + \eta)]}{-1 + 0.25\beta(3+\rho)} \\
& \qquad = \frac{-0.25\beta[(\pi_1^c - \epsilon - \hat{\theta}) - (\pi_1^g + \eta)]}{1 - 0.25\beta(3+\rho)} \\
& \qquad > 0. \qquad \text{by Assumption 1}
\end{aligned}
$$

Moreover,

$$
\frac{\partial^2\hat{\theta}}{\partial\rho^2} = \frac{0.25\beta\frac{\partial\hat{\theta}}{\partial\rho}(1 - 0.25\beta(3+\rho)) + (0.25\beta)^2[(\pi_1^g + \eta) - (\pi_1^c - \epsilon - \hat{\theta})]}{(1 - 0.25\beta(3+\rho))^2} > 0.
$$

Item C.

In this item we specify conditions regarding *P* and other parameters (i.e., π_1^c, π_1^g, ϵ, η, and β) that support Figure 4a. Keep in mind that Figure 4a just depicts one possible shape and so leave much unstated. The shapes of $\bar{\theta}(\rho)$, $\tilde{\theta}(\rho)$, and $\hat{\theta}(\rho)$ in Figure 2 require specific relationships between the parameters (i.e., *P*, π_1^c, π_1^g, ϵ, η, and β). In what follows we discuss these relationships in detail.

Notice that if $P = 0$ then we always have $V^w(\pi_1^c, \pi_1^g) > V^e(\pi_1^c, \pi_1^g)$ in Case 1. This is because $V^w(\pi_1^c, \pi_1^g) = \pi_1^g + \beta\mathbb{E}\{\max[\pi_2^c - \theta, \pi_2^g]\} > \pi_1^g + \beta\mathbb{E}(\pi_2^g) = V^e(\pi_1^c, \pi_1^g)|_{P=0}$. Therefore, easement payment, *P*, must be sufficiently large that there exist some θ in Case 1 such that $V^w(\pi_1^c, \pi_1^g) = V^e(\pi_1^c, \pi_1^g)$.

Without loss of generality we assume that $\epsilon > \eta$. Based on equation (12) in the main text we

know that in Case 1 we must have $\theta \in \left(\delta-(\epsilon+\eta), \delta-(\epsilon-\eta)\right)$. When $\rho=1$ then $V^w(\pi_1^c, \pi_1^g) = \pi_1^g + \beta(\pi_1^c - \theta)$. In order to have $V^e(\pi_1^c, \pi_1^g) = V^w(\pi_1^c, \pi_1^g)|_{\rho=1}$ in Case 1, we must have $\tilde{\theta} = \delta - P/\beta \in \left(\delta-(\epsilon+\eta), \delta-(\epsilon-\eta)\right)$, which yields

Condition 1: $$P \in \left(\beta(\epsilon-\eta), \beta(\epsilon+\eta)\right).$$

In the main text we have shown that $\bar{\theta} = (1+\beta)\delta - P$. In order to make $\delta-(\epsilon+\eta) < \bar{\theta} < \delta-(\epsilon-\eta)$, we must have

Condition 2: $$P \in \left(\beta\delta+\epsilon-\eta, \beta\delta+\epsilon+\eta\right).$$

To ensure Conditions 1 and 2 hold simultaneously, we must have

Condition 3: $$\beta\delta+\epsilon-\eta < \beta(\epsilon+\eta).$$

When $\rho=-1$ then $V^w(\pi_1^c, \pi_1^g) = \pi_1^g + 0.5\beta(\pi_1^c + \epsilon - \theta + \pi_1^g + \eta)$. Therefore, $\tilde{\theta}|_{\rho=-1} = \delta+\epsilon+\eta-2P/\beta$. In Figure 2, $\tilde{\theta}|_{\rho=-1} > \bar{\theta} = (1+\beta)\delta - P$, which requires

Condition 4: $$P < \frac{\beta(\epsilon+\eta-\beta\delta)}{2-\beta}.$$

To ensure Conditions 1, 2, and 4 hold simultaneously we must have

$$\frac{\beta(\epsilon+\eta-\beta\delta)}{2-\beta} > \beta\delta+\epsilon-\eta,$$

which is equivalent to

Condition 5: $$\beta\delta+(\epsilon-\eta) < \beta\epsilon.$$

Now let us study the curve of $\hat{\theta}$. Recall that $\hat{\theta}$ is the conversion cost such that $V^c(\pi_1^c, \pi_1^g) = V^w(\pi_1^c, \pi_1^g)$. It is readily checked that $\hat{\theta}|_{\rho=1} = \delta/(1-\beta) > \delta-\epsilon+\eta$. On the other hand, $\hat{\theta}|_{\rho=-1} = [2\delta-\beta(\delta-\epsilon-\eta)]/(2-\beta)$. In Figure 2 we have $\hat{\theta}|_{\rho=-1} < (1+\beta)\delta - P$, which requires

Condition 6: $$P < (1+\beta)\delta - \frac{2\delta+\beta(\delta-\epsilon-\eta)}{2-\beta}.$$

In order to ensure the existence of P that satisfies Conditions 1, 2, 4 and 6, we must have

Condition 7: $$(1+\beta)\delta - \frac{2\delta + \beta(\delta - \epsilon - \eta)}{2-\beta} > \beta\delta + \epsilon - \eta.$$

We find that Condition 7 is equivalent to Condition 5:

$$\begin{aligned}
&(1+\beta)\delta - \frac{2\delta + \beta(\delta - \epsilon - \eta)}{2-\beta} > \beta\delta + \epsilon - \eta \\
&\Leftrightarrow \delta - \frac{2\delta + \beta(\delta - \epsilon - \eta)}{2-\beta} > \epsilon - \eta \\
&\Leftrightarrow 2\delta - \beta\delta - 2\delta - \beta(\delta - \epsilon - \eta) > (2-\beta)(\epsilon - \eta) \\
&\Leftrightarrow -2\beta\delta > 2\epsilon - 2\eta - \beta\epsilon + \beta\eta - \beta\epsilon - \beta\eta \\
&\Leftrightarrow \beta\delta + (\epsilon - \eta) < \beta\epsilon.
\end{aligned}$$

In sum, Conditions 1, 2, 4, 5, and 6 ensure shapes presented in Figure 2.

Item D.

This item shows how to obtain equation (16). According to equation (2), if $V^c \le V^w$ then the easement payments is $\beta\mathbb{E}(\max[\pi_2^c - \pi_2^g - \theta, 0])$. By following a similar procedure in Item B, we obtain:

$$\beta\mathbb{E}(\max[\pi_2^c - \pi_2^g - \theta, 0]) = \begin{cases} 0.25\beta[(3+\rho)(\pi_1^c - \pi_1^g - \theta) + (1-\rho)(\epsilon + \eta)] & \text{under Case 1} \\ 0.5\beta[(\pi_1^c + \epsilon - \theta) - (\pi_1^g + \rho\eta)] & \text{under Case 2} \\ 0.5\beta[(\pi_1^c - \rho\epsilon - \theta) - (\pi_1^g - \eta)] & \text{under Case 3} \\ 0.25\beta(1-\rho)[(\pi_1^c + \epsilon - \theta) - (\pi_1^g - \eta)] & \text{under Case 4.} \end{cases}$$

Then by equations (9) and (15) we can obtain equation (16):

$$I^e = \begin{cases} b/[(\pi_1^c - \pi_1^g - \theta) + (\epsilon + \eta)(1-\rho)/(3+\rho)] & \text{under Case 1} \\ b/[(\pi_1^c + \epsilon - \theta) - (\pi_1^g + \rho\eta)] & \text{under Case 2} \\ b/[(\pi_1^c - \rho\epsilon - \theta) - (\pi_1^g - \eta)] & \text{under Case 3} \\ b/[(\pi_1^c + \epsilon - \theta) - (\pi_1^g - \eta)] & \text{under Case 4.} \end{cases}$$

References

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