Grassland Easement Evaluation and Acquisition with Uncertain Conversion and Conservation Returns

Abstract: We develop an analytical framework to examine an agency's optimal grassland easement acquisition while accounting for landowners' optimal decisions under uncertainty in both conversion and conservation returns. We derive the value of "wait and see" (i.e., neither convert nor ease grassland) for landowners and find that grassland-to-cropland conversion probability and easement value vary in opposing directions when "wait and see" is preferred, indicating that a larger conversion probability does not necessarily imply a higher easement value. Our analysis shows that when conservation funds can be flexibly allocated across periods then the agency's optimal acquisition can be readily achieved by sorting land tracts according to their owners' optimal choices. When funds cannot be flexibly allocated across periods, we examine both a rational agency's and a myopic agency's decision problems. An acquisition index is developed to facilitate optimal easement acquisition.

Keywords: Acquisition, Conversion Risk, Cost Effectiveness, Easement, Environmental Benefits, Evaluation, Property Rights

JEL Classification: Q24, Q21, Q28, G12

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1 Introduction

Grassland ecosystems exist naturally on all continents except Antarctica. Human impacts, mainly through agricultural expansion and climate change, have put many grassland ecosystems at risk (White et al. 2000; Rashford et al. 2011; De Laporte 2013; Lark et al. 2020). Grassland protection has attracted much attention as numerous conservation programs have been developed and significant investments have been directed at grassland conservation (NFWF 2016). Easement contracts can be a means of precisely attenuating property rights through consensual and fair exchange; and hence are widely used to protect grasslands (Lawley and Towe 2014; Lawley and Yang 2015; Lawley and Towe 2019; Brasher et al. 2019; Anderson et al. 2021; Bennett et al. 2021). The U.S. Fish and Wildlife Service (USFWS) even views grassland easements as "the most cost-effective and socially acceptable means to ensure protection of important habitats" (USFWS 2011, p. 10). However, high crop returns since 2006 have imposed substantial financial pressures on easement acquisition in the North America Prairie Pothole Region (PPR). Walker et al. (2013) show that the average easement payment rate in the in the U.S. PPR almost quadrupled over 1998-2012, from $195/acre to $778/acre. With the rising agricultural land values (Davis 2020) and cropping enabling climate change (Muhammad et al. 2018; Zhang et al. 2020) in the North America PPR, grassland easement payment rate is only expected to increase. Therefore, easement evaluation and acquisition have attracted increasing attention (USGAO 2007; Walker et al. 2013; Braza 2017). For instance, Canada Grassland Projects Protocol, Ducks Unlimited Canada, and the Nature Conservancy of Canada all utilize grassland easement as one of their means to conserve grassland (Birds Canada 2020).

Evaluating efficiency of easement acquisition requires appropriate specification of associated environmental benefits and economic costs. It has been well-documented in the conservation literature that acquisition costs, grassland (or forestland)-to-cropland conversion probability, and environmental benefits should be taken into account when assessing conservation efficiency because they are closely interdependent due to the dynamic and stochastic nature of land-use decisions (Ando et al. 1998; Newburn et al. 2006; Wilson et al. 2006; Walker et al. 2013). However, as described in Walker et al. (2013), for easement acquisition these three components are often considered in isolation or are misidentified in the literature and in practice.

We develop an analytical framework that incorporates all three components. Specifically, in order to appropriately evaluate the costs and benefits of easement acquisition, the framework first derives the minimum easement payment that a landowner is willing to accept and the grassland conversion probability by solving landowners' stochastic and dynamic decision problem. Conversion probability is critical because it determines the expected environmental benefits due to easement acquisition (Braza 2017). Then, based on the conversion probability, easement payment, and easements' environmental benefits, we solve the easement agency's acquisition problem by developing acquisition indices that optimally rank grassland tracts under various budget constraint scenarios. To our best knowledge, such an analytical framework is missing in the existing literature.

Decisions pertaining to grassland easement involve land-use irreversibilities and uncertain returns. After signing an easement, landowners receive a lump-sum payment and perpetually forgo certain rights, including converting the land to crop production or draining any wetland.[1]

[1] We focus on the perpetual grassland easement contract because it is the main type of grassland easement contract and is generally preferred by the federal government (USGAO 2007).

Since easements prevent potential grassland conversions in uncertain future states of nature, a landowner may hesitate to place grassland under an easement unless sufficient payment is offered. 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."

In other words, while one generation of landowners forgoes the real option to convert their land it may only be in succeeding generation that the implications become material and these successors often feel aggrieved. While payment and how it is spent are unlikely to be the sole causes for grievance, a retrospective view (fair or not) among some that "Dad was had" will not endear the easement purchaser to local land owners. Approaches to evaluating land conversion and conservation incentives are mis-specified and likely do harm to community acceptance unless the approaches adequately account for the real option's value.

Appropriately specifying easement costs and benefits is necessary but not sufficient to improve easement efficiency. Studies have shown that the acquisition mechanism plays a critical role in improving conservation efficiency and cost-benefit analysis is advocated as a basic tool when prioritizing conservation activities (e.g., Arrow et al. 1996; Ando et al. 1998; Wilson et al. 2006; Murdoch et al. 2010; Ando and Mallory 2012; Miao et al. 2016). Although benefit-cost analysis has become increasingly accepted and incorporated into policy making, current USFWS easement acquisition procedures do not involve cost-benefit analysis as usually understood. As easement acquisitions often take place in uncertain and dynamic contexts, the challenge is to properly evaluate costs and benefits and incorporate them into one analytical framework.

A few studies examine efficiency of conservation acquisition in dynamic and stochastic frameworks (e.g., Costello and Polasky 2004; Wilson et al. 2006; Newburn et al. 2006; Underwood et al. 2009). However, none consider the dynamic and stochastic nature of landowners' decisions. Nor do they consider the option values of keeping land under the status quo (i.e., not conserved and not converted) that may affect the conservation payments acceptable to landowners. They treat conversion probability and conservation costs as fixed constants and ignore the economic mechanisms through which the conversion probability and acquisition costs are influenced. For instance, Costello and Polasky (2004) assume that conservation costs are the same across all protectable sites. Wilson et al. (2006) combine land area, Gross National Income, and Purchasing Power Parity to obtain land acquisition costs for parcels in the countries covered in their study. By using the hedonic approach, Newburn et al. (2006) estimate conversion probability and acquisition costs as functions of land characteristics such as slope, elevation, and micro-climate variables. Although convenient, these approaches disregard how conversion probabilities and acquisition costs are affected by the dynamic and stochastic forces that affect land use decisions. The present paper aims to fill this gap.

Although several other studies do account for the dynamic and stochastic nature of conservation decisions by using a real option approach (e.g., Tegene et al. 1999; Fackler et al. 2007; Miao et al. 2014; Shah and Ando 2016; and Di Corato and Brady 2019), they mainly focus on landowners' decision problems and do not consider the conservation agency's decision problem. Moreover, Tegene et al. (1999) and Fackler et al. (2007) do not consider uncertainty about returns from conservation, which may result in incorrect easement evaluation (Shah and Ando 2016). An exception is Vercammen (2019), who considers both a landowner's and an easement agency's decision problems under a dynamic stochastic framework. However, Vercammen focuses on donated easements and on the efficiency of easement tax credits as a tool to incentivize easement enrollment. Furthermore, he only considers conversion payment uncertainty and not uncertainty arising from conservation returns. In contrast, our study examines how the easement agency optimally spends an available budget on easements to maximize protected environmental benefits, while accounting for uncertainty about returns from both conversion and conservation. Lastly, Vercammen assumes a one-time opportunity to ease land whereas we admit timing flexibility.

The present study not only contributes to the conservation literature but also sheds lights on public policy designs for land conservation. Although it focuses on grassland conservation, its framework can be applied to studying other conservation cases, such as protecting forest and wetlands. Our analyses show that when the option value of converting the land is accounted for then grassland owners who are more likely to convert may be willing to accept a lower easement payment. This is because the option value dis-incentivizes immediate conversion and is part of the opportunity cost of easing the land in the present period. Therefore, it should be compensated by easement payments. If this option value falls then the conversion risk will rise and the easement payment will fall. This finding contradicts a prevalent belief in the conservation literature and practice that grasslands with higher conversion risk should be offered higher easement payments. It also underscores the importance of accounting for the option value when studying landowners' decision problems.

By solving the easement agency's optimal acquisition problem under various budget scenarios, this study provides easement agencies with a more structured framework for thinking through acquisition decisions and for improving acquisition efficiency. Our analyses show that if the easement agency can flexibly allocate the total available budget across periods then the optimal acquisition can be readily achieved by separating available land tracts into two groups based upon landowners' optimal land-use choices. This flexible allocation can be implemented by borrowing funds against its total budget or saving un-used funds for allocation in the next period. For instance, funds from the Land and Water Conservation Fund for the USFWS can be saved for future acquisitions (USGAO 2007). Moreover, the Wetlands Loan Act, established in 1961 and reauthorized multiple times through 1988, allowed the USFWS to obtain loans that were repaid by using Duck Stamp sales (USGAO 2007).[2]

In contrast to the flexible allocation scenario, the easement agency may face restrictions on allocating funds across periods. For instance, although the duck stamp funds can be saved indefinitely, the USFWS may have difficulties in borrowing funds and repaying them by using duck stamp funds (USGAO 2007). Moreover, duck stamps will not be charged at full price in one year unless prior year duck stamp funds are exhausted (USGAO 2007, p. 34), which incentivizes the agency to spend all Duck Stamp funds in a fiscal year. On the other hand, the USFWS has many landowners seeking to ease land at the prevailing terms (Walker et al. 2013). The agency has been witnessing grassland losses and might deem it irresponsible to withhold funds for future acquisition. Therefore, the USFWS may see little point in speculating that a commodity-related land price boom will pass or in collecting further information about future land-use decisions. If the easement agency has a fixed budget in each period that must be spent within the corresponding period, then it may acquire land tracts that would not be acquired when the agency can flexibly allocate budget across periods. Under the fixed budget scenario, decision problems for two agency types (i.e., rational and myopic) are discussed. The myopic agency's decision problem is of interest because it provides a heuristic acquisition mechanism that is

[2] In 2007 there was an effort sponsored by Senator Norm Coleman to reauthorize the Wetlands Loan Act (see https://www.congress.gov/bill/110th-congress/senate-bill/1641, accessed October 11, 2021). However, this effort was unsuccessful.

straightforward to implement in practice. Acquisition priority is analyzed based on an acquisition index for the myopic agency under the fixed budget scenario.

The rest of the article proceeds as follows. Section 2 describes the model setup. Section 3 presents a representative landowner's decision problem and analyzes how the optimal land-use decision and the minimum easement payment that the landowner is willing to accept are affected by changes in conversion and conservation returns. In Section 4 we examine the easement agency's decision problem under different budget scenarios and develop easement acquisition indices that rank grassland tracts. The last section provides some concluding remarks.

2 Model Setup

The analysis pertains to one easement agency and *K* grassland tracts, each grassland tract with a single owner denoted as $k \in \Omega \equiv \{1, \ldots, K\}$.[3] We consider a two-period framework where Figure 1 depicts the framework's timeline. In period one, grassland owners choose from three actions to maximize the net present values of expected profits from their lands. These are: *i*) convert to cropland (termed as "convert now"), *ii*) enroll in a permanent easement program (termed as "ease now"), and *iii*) keep under grass without easement (termed as "wait and see"). If "convert now" is taken in period one then the land generates crop returns in that period. However, if either "ease now" or "wait and see" is taken in period one then the land generates grazing returns in that period. Let $\pi_{k,t}^{i}$ denote landowner *k*'s return in period $t \in \{1, 2\}$ from land-use type $i \in \{c, g\}$, where *c* stands for cropping and *g* for grazing.

At the beginning of period one, cropping returns (i.e., $\pi_{k,1}^{c}$ $\pi_{k,1}^{g}$), and

[3] We understand that many easement agencies (e.g., private land trusts) exist in the land-conservation industry. However, studying coordination between easement agencies is beyond the scope of this paper. Instead, we refer readers to Albers and Ando (2003) and Albers, Ando, and Batz (2008) for this line of research.

θ_k) for land tract k in that period are certain and common knowledge for the easement agency and landowners. [4] Furthermore, the exact values of period-two returns for land tract k (i.e., $\pi^c_{k,2}$ and $\pi^g_{k,2}$) are unknown in period one but their joint cumulative distribution function, $G_k(\pi^c_{k,2}, \pi^g_{k,2})$, is common knowledge. Because cropping and grazing input and output prices are generally publicly available, and because soil and climatic attributes are readily retrievable, assuming that returns or return distributions are common knowledge is a reasonable approximation to reality.

In period one, before landowner k takes any actions the easement agency makes a take-it-or-leave-it easement offer, a lump-sum payment $P_{k,1} \geq 0$, to the landowner. We further assume that at the beginning of period one landowners know that if they choose "wait and see" in period one, then at the beginning of period two they will face a new easement offer, although the payments in the two offers may differ. Based on the easement offer, the deterministic returns in period one ($\pi^c_{k,1}$ and $\pi^g_{k,1}$), the one-time conversion cost (θ_k), her belief about period-two returns (i.e., $G_k(\pi^c_{k,2}, \pi^g_{k,2})$), and period-two easement payment, landowner k will choose one of three actions (i.e., "convert now," "ease now," and "wait and see") to maximize the expected net present value of returns from the land over the two periods.

At the beginning of period two, returns from cropping and grazing in that period (i.e., $\pi^c_{k,2}$

[4] Two-period frameworks with a similar timeline in information revelation and decision making are common in the literature (e.g., Arrow and Fisher 1974; Moledina et al. 2003; Miao et al. 2012). In practice landowners do not know the exact returns from a specific land use before they make the land-use decision due to the temporal gap between planting and harvesting. However, since land conversion and easement selection pertain to long-term land uses, if we view each period in the model as a multiple-year return regime then this simplified model can be a reasonable approximation of reality.

$\pi^{g}_{k,2}$) are realized.[5] If she converts in period one, then the land will continue under crop with cropping returns, $\pi^{c}_{k,2}$. That is, the grassland conversion is assumed to be irreversible.[6] If landowner *k* accepts the easement offer in period one, then in period two her land will continue under grass and receive period-two grazing returns, $\pi^{g}_{k,2}$. However, if the landowner chooses "wait and see" in period one then in period two she will choose between "convert now" and "ease now" under a new easement offer, $P_{k,2} \geq 0$. We assume that the one-time conversion cost, θ_k, is constant across the two periods.

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[5] Here we assume that uncertainty about period-two returns is completely resolved at the beginning of period two. Since the focus of our analysis is period-one decision problems, allowing some residual uncertainty in period two will only complicate the analysis without adding any new insights.

[6] We understand that a spectrum of irreversibility exists from completely irreversible to completely reversible depending on switching costs between land uses and on environmental benefits considered (Schatzki 2003; Song, Zhao, Swinton 2011). Therefore, we acknowledge that the irreversibility of grassland-to-cropland conversion is a strong and simplifying assumption. However, this assumption can be partially justified from two perspectives. First, restoring grasslands from croplands can be costly, particularly when underground drainage tiles have been installed or land has been elevated (Hansen et al. 2015), or when neighboring parcels have been converted (Arora et al. 2021). For instance, Phillips-Mao (2017) estimate that the restoration cost is about $1,506/acre. Therefore, in practice once grasslands are converted then the chances of them to be restored are small. Second, although for certain environmental benefits (e.g., habitat for ducks) restored grasslands may perform as well as native grasslands, from the perspective of protecting ecosystem services, this irreversibility assumption can be partially justified based on the fact that native grassland, once converted, is almost impossible to be fully re-established within a reasonable time. For instance, De et al. (2020) document that the soil organic carbon in the re-established grassland can only reach no more than 70% of the soil organic carbon in the native grassland even after 40 years of grassland re-establishment. Based on a meta-analysis, Ren et al. (2016) show that biodiversity and ecosystem service on restored grassland are about 17% and 28% lower than those in native grassland, respectively. Therefore, in practice once grasslands are converted then restoration to their earlier state is unlikely. We acknowledge that the first perspective is more relevant to a landowner's decision problem and the second is more relevant to a social planner's decision problem. The irreversibility assumption is adopted in many studies on developing agricultural land into urban uses (e.g., Capozza and Helsley, 1990; Wu and Irwin, 2008). For studies that consider reversibility, we refer readers to Dixit (1989), Miao et al. (2014), and Ch. 7 in Dixit and Pindyck (1994).

Let b_k be per-period environmental benefits of grassland tract *k*. For simplicity we assume that the environmental benefit of grassland do not vary across periods. It is straightforward to incorporate a changing environmental benefit in the model. However, doing so will not add much more insight we seek to provide.[7] Without loss of generality, we assume that once grassland is converted then its environmental benefits become zero. The easement agency, with complete and perfect information on the landowners' decision problem, maximizes environmental benefits from easement acquisition under a budget constraint. Total expected environmental benefits from protected grassland are not necessarily the same as benefits brought by an easement's acquisition. This is because, even without an easement, the grassland may remain unconverted and generate the same environmental benefits (Braza 2017). Therefore, conversion probability is critical when evaluating easement acquisition benefits (Newburn et al. 2005, 2006; Merenlender et al. 2009).[8] Were one grassland tract not converted in either period even without an easement, then conserving it would not generate any additional environmental benefits. Moreover, following Vercammen (2019), we assume that the easement agency only pays the minimum easement payment that a landowner is willing to accept.

Our analytical framework is not meant to capture every aspect of the easement acquisition process. Instead, we use a simplified and tractable model to highlight a central issue: Acquisition benefits, acquisition costs, and conversion probability are interrelated so that policy prescriptions

[7] We acknowledge that the environmental benefit of a grassland tract can be affected by the land use of its neighboring tracts. For simplicity, however, we do not consider spatial connectivity in this paper and refer readers to Arora et al. (2020) for a detailed study on this matter.
[8] A few previous studies acknowledge that environmental benefits may not be correctly measured (e.g., Murdoch et al. 2010; Miao et al. 2016). However, the idiosyncratic measurement errors considered in those studies differ from the mis-specification of environmental benefits and easement costs in the present study. The present study addresses structural mis-specification of benefits and costs caused by neglecting the decision context's dynamic and stochastic nature.

which do not capture these interrelations need to be interpreted with caution. In order to focus on this central issue, we have made a few simplifying assumptions as discussed above. In what follows we analyze the landowner and the easement agency decisions, as well as factors that may influence their decisions. Since the easement agency's payment and acquisition depend on landowners' optimal choice, we discuss landowners' decision problem first.

3. A Landowner's Decision Problem

Let V_k^c, V_k^e, and V_k^w be the expected values of tract *k* over the two periods when its owner takes actions "convert now," "ease now," and "wait and see" in period one, respectively. Then based on the model setup, we have

$$\begin{cases} V_k^c = \pi_{k,1}^c - \theta_k + \beta \mathsf{E}(\pi_{k,2}^c), \\ V_k^e = \pi_{k,1}^g + P_{k,1} + \beta \mathsf{E}(\pi_{k,2}^g), \\ V_k^w = \pi_{k,1}^g + \beta \mathsf{E}\{\max[\pi_{k,2}^c - \theta_k, \pi_{k,2}^g + P_{k,2}]\}, \end{cases} \tag{1}$$

where $\beta \in [0,1]$ is a discount factor and $\mathsf{E}(\cdot)$ is the expectation operator over the information available at the beginning of period one. The "wait and see" action keeps open the option to exchange one income flow (with cropping net of conversion cost) for another (with grazing and easement payment) and considers the possibility of new information in period two.

Let $V_k^g \equiv \pi_{k,1}^g + \beta \mathsf{E}(\pi_{k,2}^g)$ denote value of tract *k* were the land to be placed under grass in both periods but without any easement payment. We can see that V_k^g is always no larger than V_k^w because $\pi_{k,2}^g \le \max[\pi_{k,2}^c - \theta_k, \pi_{k,2}^g + P_{k,2}]$ for any $P_{k,2} \ge 0$. Intuitively, from a landowner's perspective, committing to conserving the land in both periods when no compensation is provided for such a commitment is no better than keeping open the option to convert. The overall problem for landowner *k* is to identify

$$V_k^* = \max[V_k^c, V_k^w, V_k^e], \tag{2}$$

which can be solved by first making pairwise comparisons between V_k^c, V_k^w, and V_k^e, and then linking these comparisons to identify V_k^*.

3.1 Comparison I: "Wait and See" vs. "Ease Now"

We define $\Delta_k^{w,e}$ as the difference between V_k^w and V_k^e. By equation (1) we obtain

$$\Delta_k^{w,e} \equiv V_k^w - V_k^e = -P_{k,1} + \beta \mathsf{E}(\max[\omega_{k,2} - \theta_k, P_{k,2}]), \tag{3}$$

where $\omega_{k,t} \equiv \pi_{k,t}^c - \pi_{k,t}^g$, $t \in \{1, 2\}$. Let $\hat{\theta}_k$ be the value of conversion cost such that $\Delta_k^{w,e} = 0$. Since $\Delta_k^{w,e}$ decreases in θ_k, whenever $\theta_k < \hat{\theta}_k$ then the value of "wait and see" exceeds that of "ease now." The reason is as follows. A decrease in conversion cost will increase the value of "wait and see" by increasing potential returns in period two, but it has no effect on the value of "ease now" because once a grassland tract is eased then conversion costs become irrelevant.

3.2 Comparison II: "Convert now" vs. "Wait and See"

If $\theta < \hat{\theta}_k$ then "wait and see" dominates "ease now" and the landowner chooses between "convert now" and "wait and see." Letting $\Delta_k^{c,w}$ denote the difference between land values from taking these two actions, then by equation (1) we have

$$\Delta_k^{c,w} \equiv V_k^c - V_k^w = \omega_{k,1} - \theta_k - \beta \mathsf{E}(\max[-\theta_k, -\omega_{k,2} + P_{k,2}]). \tag{4}$$

Let $\hat{\omega}_{k,1}^{c,w}$ $\Delta_k^{c,w} = 0$, i.e., $\hat{\omega}_{k,1}^{c,w} =$ $\theta_k + \beta \mathsf{E}(\max[-\theta_k, -\omega_{k,2} + P_{k,2}])$. Clearly, if $\omega_{k,1} > \hat{\omega}_{k,1}^{c,w}$

$0 < d\hat{\omega}_{k,1}^{c,w} / d\theta_k < 1$ and $d^2\hat{\omega}_{k,1}^{c,w} / d(\theta_k)^2 > 0$, indicating that $\hat{\omega}_{k,1}^{c,w}$

increases in θ_k

θ_k

"wait and see". The higher the conversion cost, the more likely that the conversion may not occur in period two. Consequently a larger increase in $\hat{\omega}_{k,1}^{c,w}$ is needed to equate V_k^c and V_k^w for each unit of increase in θ_k, and so the relationship between θ_k and $\hat{\omega}_{k,1}^{c,w}$ is convex.

3.3 Comparison III: "Convert Now" vs. "Ease Now"

If $\theta > \hat{\theta}_k$ then "ease now" dominates "wait and see" and therefore the choice facing the landowner is between "convert now" and "ease now." The difference between land values from "convert now" and "ease now" is given by

$$\Delta_k^{c,e} \equiv V_k^c - V_k^e = \omega_{k,1} - \theta_k - P_{k,1} + \beta \mathsf{E}(\omega_{k,2}). \tag{5}$$

Define $\hat{\omega}_{k,1}^{c,e}$ as the value of $\omega_{k,1}$ such that $\Delta_k^{c,e} = 0,$ i.e., $\hat{\omega}_{k,1}^{c,e} = \theta_k + P_{k,1} - \beta \mathsf{E}(\omega_{k,2})$. It is readily checked that to offset a one-unit increase in conversion cost so that the landowner remains indifferent between "convert now" and "ease now," a one-unit increase in the first-period return difference between cropping and grazing is needed. Clearly, if $\omega_{k,1} > \hat{\omega}_{k,1}^{c,e}$ then "convert now" is more profitable than "ease now."

3.4 Landowner's Optimal Choice

Figure 2 summarizes the landowner's optimal choice based upon the three pairwise comparisons discussed above. In Figure 2, the horizontal axis is the one-time grassland-to-cropland conversion cost, θ_k

$\omega_{k,1}$. From Comparison I we know that $\omega_{k,1}$

$\Delta_k^{w,e} = 0$ is vertical and intersects the θ_k axis at $\hat{\theta}_k$. Figure 2

where $\theta_k < \hat{\theta}_k$ also depicts $(\theta_k, \omega_{k,1})$ $\Delta_k^{c,w} = 0$ (i.e., $V_k^c = V_k^w$). Above the line

$\Delta_k^{c,w} = 0$ the landowner will choose “convert now” (i.e., $V_k^c \geq V_k^w$) whereas below the line she will choose “wait and see” (i.e., $V_k^c < V_k^w$). The right part (i.e., $\theta > \hat{\theta}_k$) of Figure 2 depicts the choice between “convert now” and “ease now” in $(\theta_k, \omega_{k,1})$ space. Above the line $\Delta_k^{c,e} = 0$ the landowner’s choice is to “convert now” whereas below the line the choice is to “ease now.”

Overall, the $(\theta_k, \omega_{k,1})$ space in Figure 2 are divided into three areas, at the top the landowner’s optimal choice is “convert now” (i.e., $V_k^* = V_k^c$); at the lower left, “wait and see” (i.e., $V_k^* = V_k^w$); and at the lower right, “ease now” (i.e., $V_k^* = V_k^e$). Figure 2 shows that pairs of $(\theta_k, \omega_{k,1})$ supporting the action “convert now” are those with relatively low conversion cost and high period-one return differences. Moreover, given the same conversion costs, as crop prices increases we will see more “convert now” actions. This is consistent with the fact that increasing amounts of grasslands on the edge of the U.S. Western Corn Belt were converted over 2007-2012 (Lark, Salmon, and Gibbs 2015; Wang et al. 2018; Alemu et al. 2020). Pairs of $(\theta_k, \omega_{k,1})$ supporting the action “wait and see” have low conversion cost and low period-one return differences, which is intuitive because low conversion cost encourages retaining the option to convert whereas a low difference in returns discourages “convert now.” Pairs with high conversion cost and low return differences support choosing “ease now.”

3.5 Conversion Probabilities and Minimum Easement Payments

As we have discussed in the Introduction, conversion probabilities should be appropriately accounted for when evaluating environmental benefits due to grassland easement. Were there no easement acquisition, then the conversion probability in period one would be determined by the comparison between land values from “convert now” (i.e., V_k^c V_k^w

V_k^c and V_k^w can be determined based on

θ_k) and on the differences between crop and grazing returns (i.e., $\omega_{k,t}$).

Therefore,, in the absence of easement payment the conversion probability in period one, i.e., $\Pr(V_k^c \geq V_k^w)$, degenerates to either 0 or 1.[9] That is, if $V_k^c \geq V_k^w$ then the grassland tract *k* will be converted in period one whereas if $V_k^c < V_k^w$ then not. For land tracts with $V_k^c < V_k^w$, if there is no easement offer in period two then the period-two conversion probability, when viewed in period one, is $\Pr(w_{k,2} \geq \theta_k)$, i.e., conversion occurs in period two whenever the period-two return difference between cropping and grazing is no smaller than the conversion cost.

Let $P_{k,t}^e$ be the minimum easement payment that landowner *k* is willing to accept in period $t \in \{1,2\}$. Hereafter for expositional simplicity we term $P_{k,t}^e$ as the "minimum easement payment." Clearly, if "convert now" or "ease now" is chosen in period one then $P_{k,2}^e$ is irrelevant. However, if "wait and see" is chosen, then the value of $P_{k,2}^e$ will be determined at the beginning of period two and will depend on the comparison between realized period-two conversion returns (i.e., $\pi_{k,2}^c - \theta_k$) and grazing returns (i.e., $\pi_{k,2}^g$). Specifically, if $\pi_{k,2}^c - \theta_k \geq \pi_{k,2}^g$ then $P_{k,2}^e = \pi_{k,2}^c - \theta_k - \pi_{k,2}^g = \omega_{k,2} - \theta_k$. If $\pi_{k,2}^c - \theta_k < \pi_{k,2}^g$ then $P_{k,2}^e = 0.$ So we have

$$P_{k,2}^e = \max[\omega_{k,2} - \theta_k, 0]. \tag{6}$$

[9] By relaxing the assumption that period-one returns and the one-time conversion cost are certain, we can obtain a non-degenerate period-one conversion probability. Moreover, even though some key economic drivers of land conversion considered in the paper (e.g., commodity prices and input costs) are public information, in reality the landowners have private information about their land productivity under various uses and their decisions are also determined by non-pecuniary factors such as their personal preferences for the amenity value of grasslands. Therefore, another way to obtain a non-degenerate period-one conversion probability is to add an error term into the equations in expression (1) where the error term captures non-pecuniary factors or conversion idiosyncrasies, following the same spirit of random utility maximization framework (McFadden, 1973). However, such relaxation will obscure the insights we provide in the study while not in any way negating them.

Note that when compared with the situation in which easements are absent, the period-two minimum easement payment does not increase land value from "wait and see" and hence does not affect the magnitude of the minimum easement payment in period one. This is because the magnitude of $P_{k,2}^{e}$ is only sufficient to bridge the gap between crop returns and grazing returns in period two. It does not increase the maximum returns the landowner could potentially obtain.

The value of $P_{k,1}^{e}$ depends on the comparison between V_k^g (i.e., value of "grazing always without easement") and the higher of V_k^c and V_k^w described in equation (1). That is,

$$P_{k,1}^{e} = \max[V_k^c, V_k^w] - V_k^g = \max[V_k^c - V_k^g, 0] + \max[V_k^w - V_k^g - \max(V_k^c - V_k^g, 0), 0]. \tag{7}$$

Item A in the Supplemental Information (SI) shows details on obtaining equation (7). The minimum easement payment in period one, $P_{k,1}^{e}$, equals the value of the option to convert grassland tract *k* to cropping in that period, because placing tract *k* under an easement is perpetually foregoing the option to crop the land. Expression $\max[V_k^c - V_k^g, 0]$ can be viewed as the intrinsic value of the option (i.e., returns from exercising the option in period one). Expression $\max[V_k^w - V_k^g - \max(V_k^c - V_k^g, 0), 0]$ can be viewed as the time value of the option (i.e., incremental returns from keeping the option open instead of exercising it in period one). The option value is the sum of the intrinsic value and the time value. In $(V_k^c, P_{k,1}^{e})$ space, Figure 3 depicts the minimum easement payment being interpreted as an option value, in which the thick black line is the minimum easement payment. When $V_k^c < V_k^w$ then the time value is strictly positive and consequently the option value is $(V_k^w - V_k^c) + (V_k^c - V_k^g) = V_k^w - V_k^g$. That is, for land tracts with $V_k^c < V_k^w$, part of the minimum easement payment is the time value. When $V_k^c \geq V_k^w$, however, then the time value becomes zero and the option value equals the intrinsic value.[10]

All else equal, a lower conversion cost (or a higher period-one return difference, $\omega_{k,1}$) will incentivize conversion and increase the minimum easement payment. The conversion cost is not only affected by technology advances (e.g., herbicide Roundup® that removes grass more efficiently and at lower cost), but also by the general economic environment (e.g., interest rates) and government regulations (e.g., Endangered Species Act and Safe Harbor Agreements). Also, a rich set of policy instruments in U.S. agriculture can influence crop returns. In addition to the crop insurance programs that may change the distribution of crop returns, and hence the distribution of $\omega_{k,t}$, some commodity programs such as Price Loss Coverage and Agriculture Risk Coverage established in the 2014 Farm Bill will also stabilize crop returns (Coppess and Paulson 2014).[11] Therefore, landowners making conversion decisions and agencies making easement acquisition choices should benefit from a better understanding of how these programs

[10] A net present value (NPV) approach that simply compares the values from "convert now" (i.e., V_k^c) and from "grazing always without easement" (i.e., V_k^g) would only capture the intrinsic value of the option and overlook its time value when evaluating easements. This indicates that the NPV approach may underestimate the minimum easement payment that a landowner is willing to accept and result in rejected easement offers. A landowner who has a strictly positive time value will retain the land under grass in period one. This may explain why many landowners place their grasslands under neither easements nor cropping (Magedanz 2004; Gattuso 2008). Item B of the online SI provides a numerical example of time value, intrinsic value, and period-one grassland easement payment under various scenarios about one-time grassland-to-cropland conversion cost and cropping-grazing return differences (see Figures S1 to S3). The example shows that the time value can be up to $100/acre, depending on the magnitude of period-one return differences. The time value first rises and then declines as the period-one return differences increases from negative to positive. The time values reach the highest when the period-one return differences are positive but close to zero (Figure S1).

[11] Tax credit for easement donation may be viewed as a type of easement payment because it is a major incentive to place land under conservation easement (Gattuso 2008). However, since tax credits are mainly associated with easement donations rather than acquisitions, we do not examine their impact. We refer readers to Vercammen (2019) and Parker and Thurman (2019) for a detailed examination of easement tax credit provisions.

would potentially alter their decision environment. Next we examine how changes in period-two returns will affect the conversion probability and the minimum easement payments in period one.

3.6 Effects of Changes in Risk

We are particularly interested in risk attributes of period-two returns and associated risk interventions because returns can be volatile and risk interventions have policy implications (Miao, Hennessy, and Feng 2014). We proceed by focusing on the effects of changes in period-two return difference, $\omega_{k,2}$ in the sense of Rothschild and Stiglitz's (1970) mean preserving contraction (MPC). We do so because MPC is a common measure of changes in risk. In Item C of the SI we also discuss the effect of risk intervention policies in the form of crop insurance programs as the crop insurance program has become the principal means through which many countries mitigate cropping's downside risk and supports agricultural incomes. We show that the crop insurance program likely increases both conversion probability and minimum easement payment in period one (see Item C in the SI for details).[12]

If $\omega_{k,2}$ $\omega_{k,2}$ becomes less risky), then the value of $\mathsf{E}(\max[\omega_{k,2}-\theta_k, P_{k,2}])$

$\max[\omega_{k,2}-\theta_k, P_{k,2}]$ with respect to $\omega_{k,2}$. Therefore, in order to maintain $\Delta_k^{w,e}=0$, the value of θ_k should decrease and hence the line $\Delta_k^{w,e}=0$ will shift leftward (see Figure 4). From equation

[12] In Item C of the online SI we also provide a detailed analysis regarding the effects of three other stochastic orders related to period-two returns. They are: first-order stochastic dominance (FOSD), second-order stochastic dominance (SOSD), and supermodular order (SO). The FOSD and SOSD are of interest because they are also common measures of changes in risks. Furthermore, agricultural policies such as price support programs and the crop insurance program may alter crop return distributions in the sense of FOSD or SOSD. SO reflects changes in the interdependence between two random variables (Meyer and Strulovici 2015). It is studied because cropping and grazing returns are closely interdependent and are simultaneously influenced by economic and environmental shocks such as exchange rate volatility, energy price spikes, and droughts.

(7) we can see that although a change in the MPC sense does not affect the intrinsic value of the conversion option (i.e., $V_k^c - V_k^g$), it reduces the option's time value (i.e., $\max[0, V_k^w - V_k^c]$) and thus the minimum easement payment, making exercising the option in period one more appealing (i.e., increasing conversion probability). In sum, we conclude that:

Remark 1. *Whenever* $V_k^w \geq V_k^c$, *then an increase in* $\omega_{k,2}$ *in the MPC sense* (*i.e.,* $\omega_{k,2}$ *becomes less risky*) *will decrease the minimum easement payment and weakly increase the period-one conversion probability. Whenever* $V_k^w < V_k^c$, *then an increase in* $\omega_{k,2}$ *in the MPC sense does not affect the minimum easement payment or period-one conversion probability.*

The underlying intuition for Remark 1 is as follows. The option value of un-eased grassland dis-incentivizes immediate conversion or easement and is part of the opportunity cost of easing the land in the present period. Therefore, it should be compensated by easement payments. If the option value falls then the conversion risk will rise and the easement payment will fall. One should note that this option value arises from uncertainty about future cropping and grazing returns, and therefore exists for each grassland parcel. Although changes in the $\omega_{k,2}$ in the MPC sense only affects the easement payment or conversion probability via affecting this option value when $V_k^w \geq V_k^c$, the numerical example discussed in Item B of the SI shows that under about half of the 150 return-difference scenarios $V_k^w \geq V_k^c$ occurs (see Figure S4), indicating that the opposing changes in easement payment and conversion probability caused by changes in the riskiness of period-two return difference ($\omega_{k,2}$) applies to a large portion of land parcels. This opposing change has been ignored in the previous conservation literature in part because the "wait and see" option has been omitted when considering landowners' conversion decisions. Previous studies (e.g., Newburn et al. 2006; Visconti et al. 2010) usually presume conversion probability and conservation payment to be positively correlated. However, when the option value of converting is accounted for then this presumption may become misleading and may potentially prevent the easement agency from obtaining the full environmental benefits of easement acquisition.

Note that relaxing the grassland-to-cropland conversion irreversibility assumption will increase net present value of economic returns from ‘convert now.’ This is because the reversibility of grassland-to-cropland conversion will allow landowners to obtain the higher of cropping returns and grazing returns (net of cropland-to-grassland conversion costs) in period two. However, such a relaxation does not affect the net present returns from ‘wait and see’ and ‘ease now’ for a given easement payment (i.e., V_k^e and V_k^w in equation (1)). Therefore, we can see that relaxing the assumption will weakly increase period-one grassland easement payment because $P_{k,1}^e = \max[V_k^c, V_k^w] - V_k^g$. However, the key insights provided by Remark 1 would remain the same. That is, it is still the case that when $V_k^w \geq V_k^c$, then the easement payment and conversion probability change in opposing directions. This is because in this case any decrease in V_k^w will decrease the easement payment but increase the probability of grassland conversion.

4 Agency’s Decision Problem

The agency will account for easement payment, conversion probability, and environmental benefits associated with each grassland tract when optimally acquiring easements. Because restrictions might be placed upon the agency’s conservation resources, we consider two possible budget scenarios. We label the first budget scenario as “flexible allocation,” under which the agency can allocate its aggregate budget across the two periods without any restrictions. We label the second budget scenario as “pay-as-you-go,” under which the agency has a fixed budget for each period and cannot borrow or save funds across periods. Before analyzing the agency’s problem under the two budget scenarios, we first evaluate the environmental benefits due to easement acquisition.

4.1 Environmental Benefits due to Easement Acquisition

Parallel to the landowners' decision problem, we define B_k^c, B_k^e, and B_k^w as the expected environmental benefits of land tract *k* over the two periods when its owner chooses "convert now", "ease now," and "wait and see" in period one, respectively. Specifically, we have,

$$\begin{cases} B_k^c = 0, \\ B_k^e = (1+\beta)b_k, \\ B_k^w = b_k + \beta b_k[\Pr(\omega_{k,2} < \theta_k) + \Pr(\omega_{k,2} \geq \theta_k \text{ and } z_{k,2} = 1)], \end{cases} \tag{8}$$

where $z_{k,2}$ is an indicator of whether acquisition of tract *k* occurs in period two, with $z_{k,2} = 1$ indicating that the acquisition occurs in period two and $z_{k,2} = 0$ indicating no period-two acquisition of tract *k*. The indicator $z_{k,2}$ is defined only under "wait and see" and is a random variable because whether a tract is to be eased in period two depends on the realization of the tract's returns in that period. In equation (8), B_k^c and B_k^e are self-evident based on our assumptions about environmental benefits whereas B_k^w needs some explanation. When the "wait and see" action is chosen by landowner *k* in period one, then land tract *k* will be under grass in period one and generate environmental benefit b_k in that period. In period two, if land tract *k*'s conversion is unprofitable (i.e., $\omega_{k,2} < \theta_k$) or its conversion is profitable but it is acquired under an easement (i.e., $\omega_{k,2} \geq \theta_k$ and $z_{k,2} = 1$), then it provides environmental benefit b_k in period two as well. Therefore, under the "wait and see" action, the expected environmental benefits of land tract *k* over the two periods are $b_k + \beta b_k[\Pr(\omega_{k,2} < \theta_k) + \Pr(\omega_{k,2} \geq \theta_k \text{ and } z_{k,2} = 1)]$.

Based upon equation (8), we can readily obtain the expected environmental benefits secured

$\Delta_{k,1}^{B}$. Specifically, we have

$$\Delta_{k,1}^{\mathrm{B}} = \begin{cases} B_k^e - B_k^c = (1+\beta)b_k, & \text{if } V_k^c \geq V_k^w \\ B_k^e - B_k^w = \beta b_k \Pr(\omega_{k,2} \geq \theta_k \text{ and } z_{k,2} = 0), & \text{if } V_k^c < V_k^w. \end{cases} \tag{9}$$

Equation (9) states that acquiring a tract with $V_k^c \geq V_k^w$ secures full potential environmental benefits provided by the land. If a tract with $V_k^c < V_k^w$ will not be acquired in period two for sure (e.g., a zero period-two budget resulting in $\Pr(\omega_{k,2} \geq \theta_k \text{ and } z_{k,2} = 0) = \Pr(\omega_{k,2} \geq \theta_k)$) then acquiring this tract in period one will secure environmental benefits at $\beta b_k \Pr(\omega_{k,2} \geq \theta_k)$. However, if it will be acquired in period two for sure (e.g., an unlimited period-two budget resulting in $\Pr(\omega_{k,2} \geq \theta_k \text{ and } z_{k,2} = 0) = 0$) then acquiring this tract in period one does not secure any extra environmental benefits.[13]

A static approach that does not account for conversion probability or "wait and see" views the entire environmental benefits from the grassland across both periods, i.e., $(1+\beta)b_k$, as benefits obtained by the easement acquisition. It over-estimates the environmental benefits due to an easement acquisition in that, even without easement, the landowner may choose the "wait and see" action in period one and the land would still generate environmental benefit b_k in that period as well as $\beta b_k[\Pr(\omega_{k,2} < \theta_k) + \Pr(\omega_{k,2} \geq \theta_k \text{ and } z_{k,2} = 1)]$ in period two (see equation (8)). That is, the option value from "wait and see" incentivizes the landowner to keep the land under grass but not place it under easement. Consequently, even without an easement, some environmental benefits of grassland are maintained due to this option value, which should not be counted as the environmental benefits secured by easement acquisition.

[13] We acknowledge that this is true only if an eased grassland tract does not generate any environmental benefit spillovers into neighboring tracts.

Environmental benefits due to easement acquisition that occurs in period two are

$$\Delta^{\mathrm{B}}_{k,2} = \begin{cases} b_k, & \text{if } \omega_{k,2} \ge \theta_k; \\ 0, & \text{if } \omega_{k,2} < \theta_k. \end{cases} \tag{10}$$

That is, in period two if the return difference between cropping and grazing is no smaller than the one-time conversion cost (i.e., $\omega_{k,2} \ge \theta_k$) then without easement acquisition the landowner will convert the grassland. In this case, the environmental benefits secured by period-two acquisition is b_k. When $\omega_2 < \theta$, however, the environmental benefits secured by the period-two acquisition is zero because the landowner will not convert the grassland even if there is no easement.

4.2 Acquisition under the "Flexible Allocation" Budget Scenario

Define $\mathscr{P}(\Omega)$ as the set of all subsets of set Ω. Recall that $\Omega \equiv \{1,...,K\}$ is the set of land tracts available at the beginning of period one. The agency's purpose is to maximize expected gain in environmental benefits from easement acquisition for a given budget by optimally selecting a subset of land tracts $h_t \in \mathscr{P}(\Omega)$ in period $t \in \{1,2\}$:

$$\begin{aligned} &\max_{h_1 \in \mathscr{P}(\Omega)} \sum\nolimits_{k \in h_1} \Delta^{\mathrm{B}}_{k,1} + \beta\, \mathsf{E}(\max_{h_2 \in \mathscr{P}(\Omega - h_1)} \sum\nolimits_{k \in h_2} \Delta^{\mathrm{B}}_{k,2}) \\ &\text{s.t.} \quad \sum\nolimits_{k \in h_1} P^{\mathrm{e}}_{k,1} + \beta \sum\nolimits_{k \in h_2} P^{\mathrm{e}}_{k,2} \le M, \end{aligned} \tag{11}$$

where $\Delta^{\mathrm{B}}_{k,t}$

$\Gamma^c \equiv \{k \mid V^c_k \ge V^w_k\}$ and $\Gamma^w \equiv \{k \mid V^c_k < V^w_k\}$. To reflect the fact that land available is far more than land that can be eased due to the budget constraint, we assume that the aggregate easement budget can only cover a portion of land tracts in Γ^c or Γ^w, which ensures interior solutions for the agency's optimization problem.

Land tracts with $V_k^c < V_k^w$ will be under grass anyway in period one and provide the same period-one environmental benefits as if they were eased in that period. Being able to allocate funds across the two periods, the agency has the option of acquiring land tracts with $V_k^c < V_k^w$ in either period. However, the agency will be better off if it defers acquisition for such land tracts until period two. Because in period two the easement acquisition decisions are made after crop returns and grazing returns are realized, deferring the acquisition of land tracts with $V_k^c < V_k^w$ to period two retains the option to acquire these tracts but the option will be exercised only if the agency has no better choices of tracts available in period two. Intuitively, if a decision can be deferred until more information is available then the quality of decision made will improve and the Type I error (i.e., the agency does not ease a tract that should be eased) and Type II error (i.e., the agency eases a tract that should not be eased) rates will fall. Therefore, under the "flexible allocation" budget, land tracts to be eased in period one must have $V_k^c \geq V_k^w$, that is, $h_1 \subseteq \Gamma^c$. An index can be used to assist in period-one easement acquisition:

$$I_{k,1} = \frac{\Delta_{k,1}^{\mathrm{B}}}{P_{k,1}^e}\Big|_{V_k^c \geq V_k^w} = \frac{(1+\beta)b_k}{\omega_{k,1} + \beta\,\mathrm{E}(\omega_{k,2}) - \theta_k}, \tag{12}$$

where $P_{k,1}^e$ is valued based on equation (7). The index numerator is the increase in environmental benefits due to easement acquisition and the denominator is the minimum easement payment. The agency will acquire available land tract $k \in \Gamma^c$ in period one with the highest $I_{k,1}$ until the budget allocated to period one is exhausted.[14]

[14] Note that among the available land in period two, tracts with unprofitable conversion in

Optimal fund allocation across periods will be achieved by equating the marginal expected environmental benefit obtained by acquisition in periods one and two. Suppose $r \in \Omega$ is the land tract with the lowest index acquired in period one and $s \in \Omega$ is the land tract with the lowest index acquired in period two. Note that the value of *s* is a random variable when viewed from period one as under each realization of returns the tracts to be acquired in period two may differ. Then the optimal budget allocation is such that $I_{r,1} = \mathsf{E}(I_{s,2})$. Clearly, all else equal, when the period-one return difference, $\omega_{k,1}$, increases for all land tracts (e.g., due to a crop price boom), then the acquisition index in period one will decline (equivalent to a lower marginal environmental benefit per dollar). Under this situation the agency should allocate less funds to period one and more to period two. That is, *ceteris paribus*, if a period experiences commodity-related land price boom, then instead of adding acquisition funds in that period, the agency should reduce acquisition funds for that period. This conclusion holds even if the agency receives a larger acquisition budget due to this land price boom. Since the rate of land conversion generally increases during commodity price booms an intuitive suggestion for protecting grassland is to increase acquisition funds in these periods. However, this suggestion would only reduce the aggregate efficiency of easement acquisition.

We summarize the discussion as the following remark:

Remark 2. (Sorting effect of information) *For a grassland tract with value from "convert now" smaller than that from "wait and see" in period one (i.e.,* $V_k^c < V_k^w$

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that period (i.e., $\omega_{k,2} \le \theta_k$) will not be acquired as they will remain unconverted anyway. The optimal acquisition strategy in period two is to acquire land with the highest index (or benefit-over-cost ratio), as described in the following equation, among available land until the budget is exhausted (Miao et al. 2016): $I_{k,2} = \Delta_{k,2}^{\mathrm{B}} / P_{k,2}^{e} = b_k / (\omega_{k,2} - \theta_k)$ for $\omega_{k,2} > \theta_k$.

$V_k^c \geq V_k^w$ in period one that have the highest index, $I_{k,1}$, until the budget allocated to period one is exhausted. The optimal budget allocation is such that $I_{r,1} = \mathrm{E}(I_{s,2})$. When period-one return difference, $\omega_{k,1}$, increases for all land tracts, all else equal, funds allocated to period one should be reduced.

Remark 2 significantly simplifies the agency's optimization problem in (11) due to the sorting effect of information, which arises from the time value of the option to convert. Note that $V_k^c < V_k^w$ holds only if time value, $\max[V_k^w - V_k^g - \max(V_k^c - V_k^g, 0), 0]$, is great than zero. Intuitively, for land tracts with $V_k^c < V_k^w$, their time value "buys" the right to make better informed decisions at a later period. Remark 2 signifies that the easement agency should account for the value of "wait and see" and separate the land into two groups according to the "convert now" and "wait and see" values. Without appropriately identifying their "wait and see" values, the agency may suffer from Type I and Type II errors in easement acquisition.

4.3 Acquisition under "Pay-as-you-go" Budget Scenario

Under this budget scenario, the agency cannot allocate funds across the two periods. However, it can still determine the period in which land tracts with $V_k^c < V_k^w$ may be acquired. As will be shown later in this subsection, the solution to a rational agency's optimal acquisition problem under "pay-as-you-go" is not as straightforward as that for the acquisition problem under "flexible allocation." Therefore, in this subsection we also consider a more tractable approach, one where the myopic agency maximizes the expected environmental benefits from each period without considering the possibility of future acquisition. A heuristic acquisition strategy that is straightforward to apply is then derived from this myopic agency's optimization problem.

4.3.1 Rational Agency

Under a "pay-as-you-go" budget scenario, a rational agency's decision problem is:

$$\begin{gathered}\max_{h_1 \in \mathcal{P}(\Omega)} \sum_{k \in h_1} \Delta^{\mathrm{B}}_{k,1} + \beta \mathsf{E}(\max_{h_2 \in \mathcal{P}(\Omega - h_1)} \sum_{k \in h_2} \Delta^{\mathrm{B}}_{k,2}) \\ \text{s.t.} \quad \sum_{k \in h_1} P^{\mathrm{e}}_{k,1} \le \bar{M}_1 \text{ and } \sum_{k \in h_2} P^{\mathrm{e}}_{k,2} \le \bar{M}_2,\end{gathered} \tag{13}$$

where $\bar{M}_t \ge 0$ is an exogenously determined fixed budget for period $t \in \{1, 2\}$. The two separate budget constraints in optimization problem (13) indicate that funds in each period cannot be reallocated to the other period. Again, a backward induction approach can be used to solve problem (13). The approach is presented in the SI, Item E, where we also discuss some necessary conditions that the optimal solution to problem (13) must satisfy. The optimal solution of (13) is not straightforward to achieve in practice because the optimal acquisition in period one requires knowledge of the probability that a tract satisfying $V^c_k < V^w_k$ is eased in period two. The probability is determined by the easement budget and by tract ranking among all available land tracts in period two under each realization of returns. Obtaining a joint distribution of returns for thousands of land tracts to determine the acquisition probability for a land tract in a future period may be infeasible in practice. Therefore, in what follows we propose a heuristic acquisition approach that is derived from an optimal decision problem of a myopic agency who maximizes expected environmental benefits due to easement acquisition in each period and does not consider the possibility that land tracts can be eased in the future. Myopia has been considered in a few existing land management studies. For example, to simplify their land acquisition decision problem, Wilson et al. (2006) assume a myopic conservation planner who maximizes conservation gains or minimizes conservation losses in each period with a fixed per-period budget. They find that conservation allocation results under a myopic planner are reasonable approximations to those under a rational planner.

4.3.2 Myopic Agency

Under the "pay-as-you-go" budget, a myopic agency's decision problem can be written as,

$$\begin{cases} \max_{h_1 \in \mathscr{P}(\Omega)} \sum_{k \in h_1} \tilde{\Delta}^{\mathrm{B}}_{k,1} & \text{s.t.} \quad \sum_{k \in h_1} P^{\mathrm{e}}_{k,1} \le \bar{M}_1, \quad \text{for period one} \\ \max_{h_2 \in \mathscr{P}(\Omega - h_1)} \sum_{k \in h_2} \Delta^{\mathrm{B}}_{k,2} & \text{s.t.} \quad \sum_{k \in h_2} P^{\mathrm{e}}_{k,2} \le \bar{M}_2, \quad \text{for period two,} \end{cases} \tag{14}$$

where $\tilde{\Delta}^{\mathrm{B}}_{k,1} = (1+\beta) b_k$ whenever $V^c_k \ge V^w_k$ and $\tilde{\Delta}^{\mathrm{B}}_{k,1} = \beta b_k \Pr(\omega_{k,2} \ge \theta_k)$ whenever $V^c_k < V^w_k$.

Following Miao et al. (2016) and using easement payment in equation (7), we construct an acquisition index, $\tilde{I}_{k,1}$, to rank easement acquisition in period one. Specifically,

$$\tilde{I}_{k,1} = \frac{\Delta^{\mathrm{B}}_{k,1}}{P^{\mathrm{e}}_{k,1}} = \begin{cases} \dfrac{(1+\beta) b_k}{\omega_{k,1} + \beta \mathsf{E}(\omega_{k,2}) - \theta_k} & \text{if } V^c_k \ge V^w_k; \\ \dfrac{b_k}{\mathsf{E}(\omega_{k,2} - \theta_k \mid \omega_{k,2} > \theta_k)} & \text{if } V^c_k < V^w_k. \end{cases} \tag{15}$$

Clearly, all else equal, any land tract with a higher environmental benefit, b_k, should be ranked higher. When $V^c_k \ge V^w_k$ then land tract with a higher conversion cost, θ_k, or a lower period-one return difference, $\omega_{k,1}$, should be ranked higher in acquisition because the minimum easement payment is lower. For land tracts with $V^c_k \ge V^w_k$ only the first, instead of any higher, moment of $\omega_{k,2}$ affects the index. Consequently, actuarially fair crop insurance will not affect the acquisition index for those tracts. Subsidized crop insurance will increase the average returns, and hence reduce the acquisition index. The 2014 Farm Bill's Sodsaver Provision reduces the crop insurance premium by 50 percentage points for the first four years of agricultural production on land converted from grassland in six states of the United States.[15] Therefore, when

[15] These six states are Iowa, Minnesota, South Dakota, North Dakota, Nebraska, and Montana.

compared with states not covered by the provision, grasslands covered under Sodsaver will have a higher acquisition index and therefore should be given higher acquisition priority. Since subsidy is proportional to insurance premium in the U.S. crop insurance program, land tracts with high premiums will receive larger premium subsidies. This implies that, all else equal, the subsidized crop insurance will cause tracts having higher risk in cropping returns, and so higher premiums, to rank lower in easement acquisition than tracts having lower cropping risk. Since land with riskier cropping production is often environmentally sensitive (Miao et al. 2016), subsidized crop insurance may leave land with high yield risk but larger environmental benefits uneased.

Equation (15) also show that whenever $V_k^c < V_k^w$ then the index numerator is the environmental benefits in period two and the denominator is the expected easement payment conditional on conversion being profitable. In this case, the impact of the conversion cost and return distribution changes on the acquisition index is ambiguous without possessing further information on the distribution of the difference in period-two returns, $\omega_{k,2}$.[16]

Figure 5 depicts the relationship between period-one acquisition index, $\tilde{I}_{k,1}$

$\omega_{k,1}$. Since whenever $V_k^c < V_k^w$

$V_k^c < V_k^w$ is horizontal. When

$V_k^c \geq V_k^w$ $\omega_{k,1}$. Note that when $\omega_{k,1}$ equals $\hat{\omega}_{k,1}^{c,w}$, which is the period-one return difference that equates V_k^c and V_k^w, then the index jumps from $\tilde{I}_k'$ to $\tilde{I}_k''$

[16] The precise distribution shift in $\omega_{k,2}$ that increases the value of $\mathsf{E}(\omega_{k,2} - \theta \mid \omega_{k,2} > \theta)$ and hence decreases the index is the mean residual life order, which is described in Item F of SI.

$\omega_{k,1}$ increases to $\hat{\omega}_{k,1}^{c,w}$ then the environmental benefit increase due to easement acquisition jumps from $\beta b_k \Pr(\omega_{2,k} \geq \theta_k)$ to $(1+\beta)b_k$ (see equation (9)) whereas the easement payment increases continuously (Figure 3). This benefit discontinuity results from accounting for "wait and see" in easement valuation and from the binary nature of the conversion decision. Figure 5 shows that acquisition priority should be placed on land tracts with $\omega_{k,1}$ value just marginally higher than $\hat{\omega}_{k,1}^{c,w}$. Grasslands on the edge of the Corn Belt can be viewed as this kind of land because they are marginal land that may be converted when crop returns are high but remain under grass when crop returns are low (Wright and Wimberly 2013).

For land tracts with "convert now" preferred to "wait and see" (i.e., $V_k^c \geq V_k^w$), then acquisition priorities decrease as the period-one return difference, $\omega_{k,1}$, increases because the larger the value of $\omega_{k,1}$ the higher the minimum easement payment. Typically higher quality land has higher return difference due to its higher mean cropping returns. Based on Figure 5, we can conclude that among land tracts with $V_k^c \geq V_k^w$, all else equal, high quality land tracts should have lower acquisition priority. However, among land tracts with $V_k^c < V_k^w$, land quality need not be considered when prioritizing easement acquisition in period one because whenever $V_k^c < V_k^w$ then the period-one return difference is irrelevant to easement payment in period one (see equation (7) and Figure 3). We can summarize the above discussion as the following remark.

Remark 3. *Suppose a myopic agency under the "pay-as-you-go" budget considers multiple grassland tracts. All else equal, i) acquisition priority should be placed on tracts with the period-one return difference,* $\omega_{k,1}$

$\hat{\omega}_{k,1}^{c,w}$

with $\omega_{k,1} < \hat{\omega}_{k,1}^{c,w}$, the period-one return difference needs not be considered; iii) when $\omega_{k,1} > \hat{\omega}_{k,1}^{c,w}$, land tracts with higher $\omega_{k,1}$ values should receive lower acquisition priority.

Figure 6 depicts iso-index curves for equation (15) in (θ_k, b_k) space. Its Panel (a) presents the iso-index curves for grassland tracts with $V^c \geq V^w$ while holding constant the expected value of aggregate return differences in the two periods (defined as $\delta_k \equiv \omega_{k,1} + \beta \mathsf{E}(\omega_{k,2})$). It is readily checked that the absolute value of an iso-index curve slope is acquisition index value divided by $1+\beta$. Therefore, as an iso-index curve tilts upward while the right end of the curve remains fixed at point $(\delta_k, 0)$, then the associated index value increases.[17] As environmental benefit, b_k, or one-time conversion cost, θ_k, increases, the iso-index curves have larger index values, indicating higher acquisition priority (Panel (a)). Panel (b) in Figure 6 depicts the iso-index curves when $V^c < V^w$ where we assume that $\mathsf{E}(\omega_{k,2} - \theta_k \mid \omega_{k,2} > \theta_k)$ increases in θ_k at a decreasing rate.[18] In this case, as b_k remains constant and θ_k increases, the iso-index curves have smaller index values.

Under the "Pay-as-you-go" budget scenario, because the agency cannot allocate its budget across the two periods, in each period the agency will exhaust the budget it receives in that period. If easement budget increases in a period but nothing else changes, then the agency will be

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[17] When $\theta_k = \delta_k$ and $V_k^c \geq V_k^w$ then the acquisition index in equation (16) is not defined. Furthermore, because $V^w \geq V^g \equiv \pi_{k,1}^g - \beta \mathsf{E}(\pi_{k,2}^g)$, one can readily check that whenever $V^c \geq V^w$ then $\omega_{k,1} + \beta \mathsf{E}(\omega_{k,2}) - \theta_k \geq 0$. Consequently, all the iso-index curves converge on point $(\delta_k, 0)$ from the left but will never reach it. As the total return difference across the two periods, δ_k, increases, the bundle of iso-index curves simply shifts rightward in parallel manner.

[18] Without knowing the specific distribution of $\omega_{k,2}$, we cannot determine the shape of its mean residual life function or the impact of conversion costs on the acquisition index. For further discussion about the shapes of mean residual life functions, we refer readers to Finkelstein (2002) and Guess and Proschan (1988).

able to purchase more easement in that period, following the parcel ranking suggested by the model. If both land values and easement budget increase in economic booms, then the effect of increased budget on easement acquisition could be weakened or even eliminated by the increased land values. This suggests that the “Pay-as-you-go” budget scenario would suffer from efficiency loss when compared with the “flexible allocation” budget scenario. This efficiency loss might be mitigated when easement agencies may have various funding sources that are not closely related to land markets (e.g., duck stamp sales for USFWS).

Clearly, for the same net present value of budget across the two periods, the optimization problem (13) outcome is no better than the problem (11) outcome; and problem (14) no better than (13). This indicates that acquisition efficiency loss may result from being unable to allocate funds across periods or from ignoring the probability that a land tract can be eased in future periods. The magnitude of the loss is determined by a) the specific funds distribution across the two periods under “pay-as-you-go;” and b) the distribution of land values across all tracts from taking the “convert now” action and taking the “wait and see” action. In reality, grassland easement funds are limited and can only acquire a small portion of available land tracts. Moreover, the index curve discontinuity feature as shown in Figure 5 suggests that land tract index values with $V_k^c < V_k^w$ may be systematically smaller than those for land tracts with $V_k^c \geq V_k^w$. Therefore, we do not expect that the efficiency loss due to myopic agency is significant when compared with a rational agency under the “pay-as-you-go” budget. However, the efficiency difference between the outcomes under the “flexible allocation” and “pay-as-you-go” budget scenarios may be large.

5 Conclusions

We develop an analytical framework to better understand economic determinants of conversion choices and the effective use of easement dollars. Fully understanding the evaluation and acquisition of easements is necessary as their use increases. Two key features of our framework are that it examines *i*) landowners' conversion trade-offs when admitting "wait and see" strategies and better reflects a landowner's decision in an environment with uncertainty; and *ii*) an easement agency's optimal acquisition problem that accounts for landowners' conversion trade-offs. These features allow us to study dynamic interrelations between benefits, costs, and conversion probability that have not been examined by the existing literature. Based on a two-period model, we find that for land tracts with "wait and see" value larger than that the "convert now" value the conversion probability and the minimum easement payment may vary in opposing directions. This finding indicates that simply offering larger easement payments to grasslands with higher conversion probability may not achieve the optimal easement acquisition outcome. The easement agency should consider the time value that the "wait and see" action provides to landowners. In practice, this requires that the easement agency use information about one-time conversion costs and expected differences in returns form cropping and grazing.

Our analyses show that when the easement agency is able to allocate funds across periods, then in period one the agency should only acquire land tracts whose owners select "convert now." However, when the easement agency has a fixed budget for each period, then a rational agency's optimal easement acquisition is complicated. We therefore develop a straightforward easement acquisition index based upon a myopic easement agency's decision problem. The acquisition index incorporates land tracts' environmental benefits, conversion costs, and return distributions, indicating that to reach the intended environmental benefits from easement acquisition the agency should use much more information than just environmental benefits.

This study has simplified the complex decision environment to manifest qualitative results and some aspects of the framework can be expanded for future research. First, discussions with easement managers in the U.S. Prairie Pothole Region point to strategic issues when purchasing easements. Arora et al. (2021) also show that due to the spillover effect of conversion and conservation (i.e., conversion of one grassland tract prompts conversions of neighboring grassland tracts and conservation of one grassland tract may conserve neighboring grassland tracts), conservation parcels should be strategically targeted and the strategy that maximizes environmental benefits ‘explicitly’ conserved per dollar may not be efficient. In terms of environmental benefits, it is generally believed that a contiguous parcel provides larger environmental benefits than do fragmented parcels with the same total area (Diamond 1975; Williams et al. 2005; Wimberly et al. 2018). For simplicity our model does not consider the clustering benefits of grassland conservation. Expanding the current model to include spatial spillover and clustering benefits may be a fruitful direction for future research.

Second, the irreversibility assumption of grassland-to-cropland conversion can be refined so that the framework developed in the current study can be applied to analyzing easement of other types of private lands for environmental services. The most direct way of doing so is to address the fact that not all private land conversions are irreversible in regard to profit possibilities. In addition, were a distinction to exist between reversibility in regard to profit possibilities and irreversibility in regard to ecological outcomes that society values then optimal policy would have to account for the distinction. Any such distinction might allow for a clearer understanding of appropriate roles for property right attenuation approaches to ecosystem management. A standard Pigouvian tax on conversion might be appropriate were economic consequences and ecological consequences of comparable reversibility but perpetual easements may better match policy goals when the only irreversibility applies to the provision of non-market goods and services.

Finally, landowners' characteristics such as age, education level, and credit constraint situations may play an important role in determining their land-use decisions. For instance, retiring livestock farmers may be more interested in easing their grassland so that the land will be preserved as it is while beginning grassland owners may benefit from the lump-sum easement payment to mitigate their credit constraint. Some non-pecuniary factors also affect how landowners value their land (Yu and Belcher 2011). All these factors make landowners' evaluation of their land private information. Examining private information about landowner preferences is beyond the scope of this present study and can be a direction for future research. Ferraro (2008) proposes three approaches for conservation agency to reduce landowners' information rent: use observable landowner attributes to refine the distribution of landowners' private returns; allow landowners to select from a list of screening contracts; and conduct conservation auctions under which competition between landowners reduces their information rents. Augmenting the current model with these approaches is another direction for further research.

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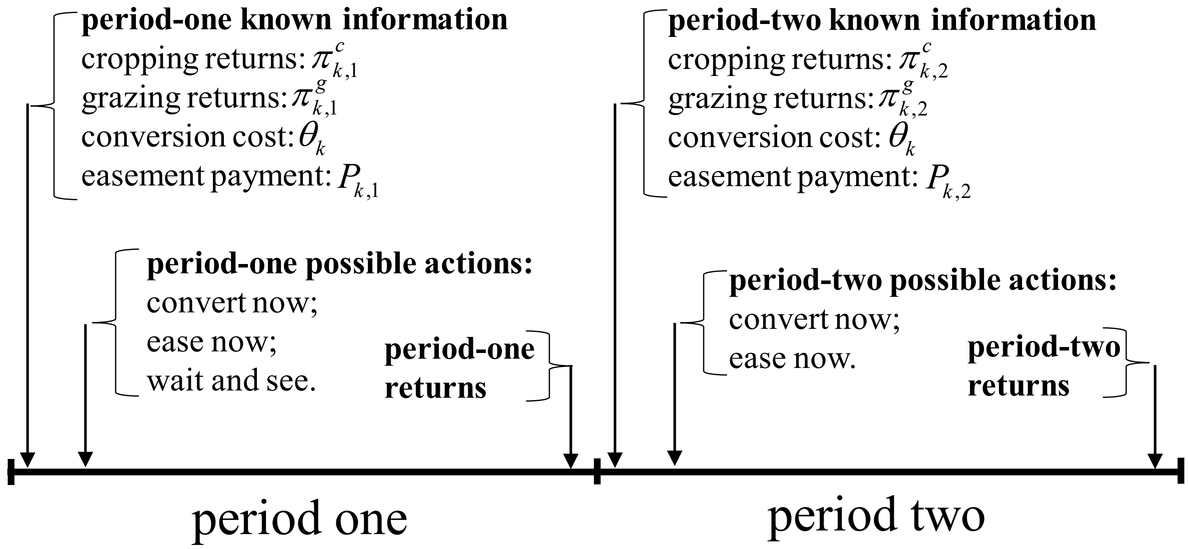

Figure 1. Model timeline

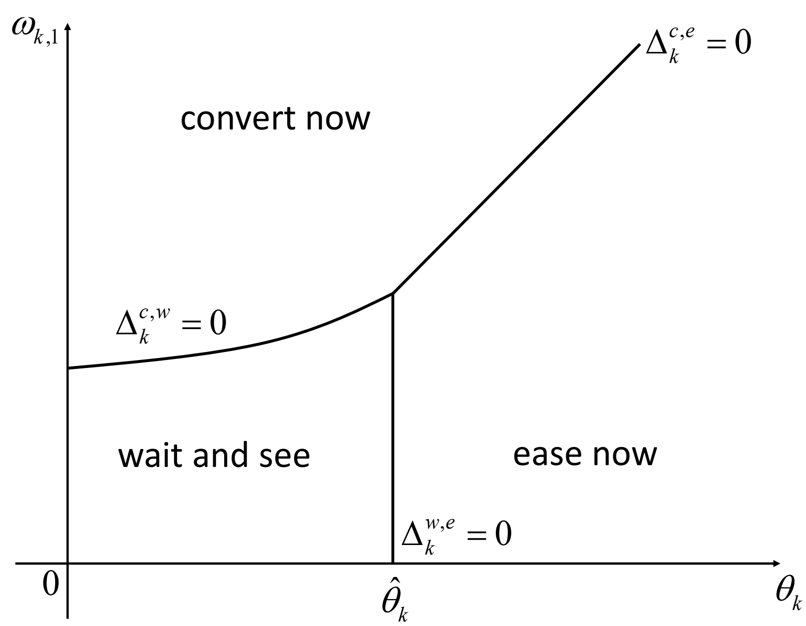

Figure 2. Period-one optimal actions in $(\theta_k, \omega_{k,1})$ space

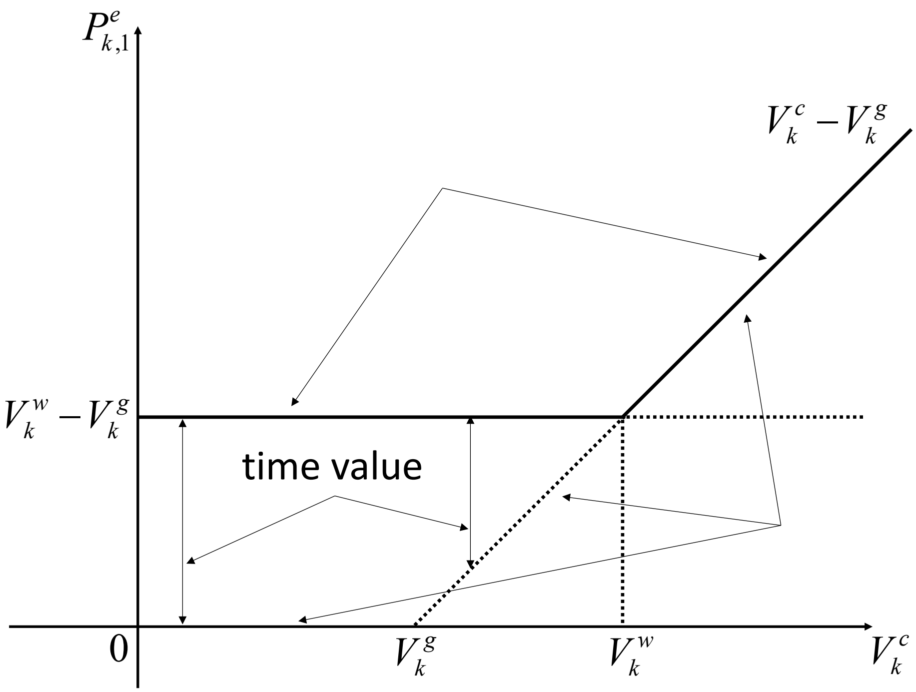

Figure 3. A Graphical Presentation of the Minimum Easement Payment

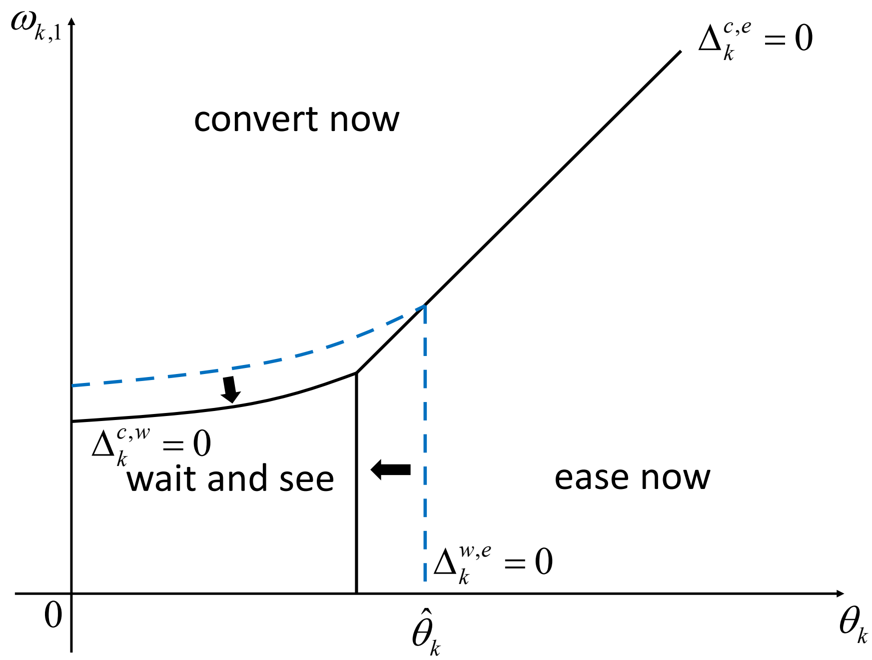

Figure 4. Impact of an increase in $\omega_{k,2}$ in the sense of mean preserving contraction on period-one optimal action

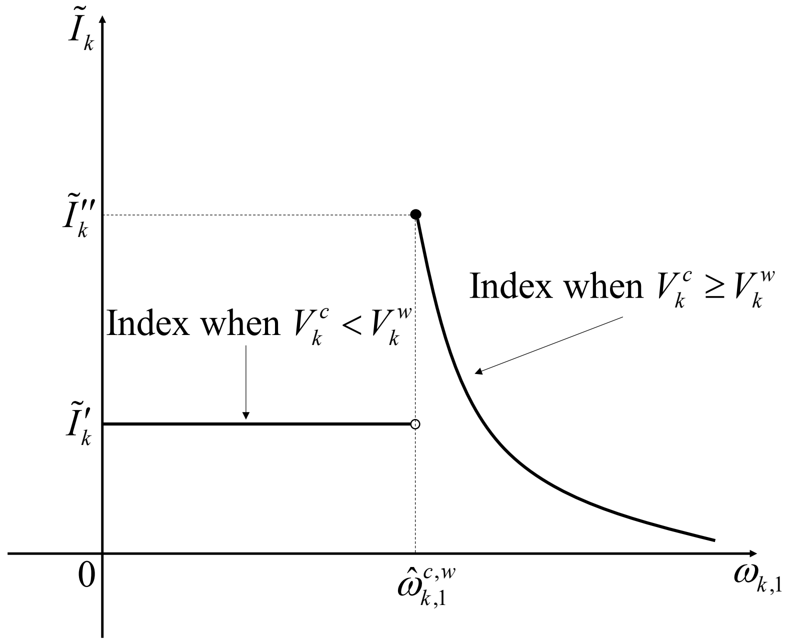

Figure 5. Easement acquisition index with "pay-as-you-go" as the Period-one Return Difference Increases (Myopic Agency)

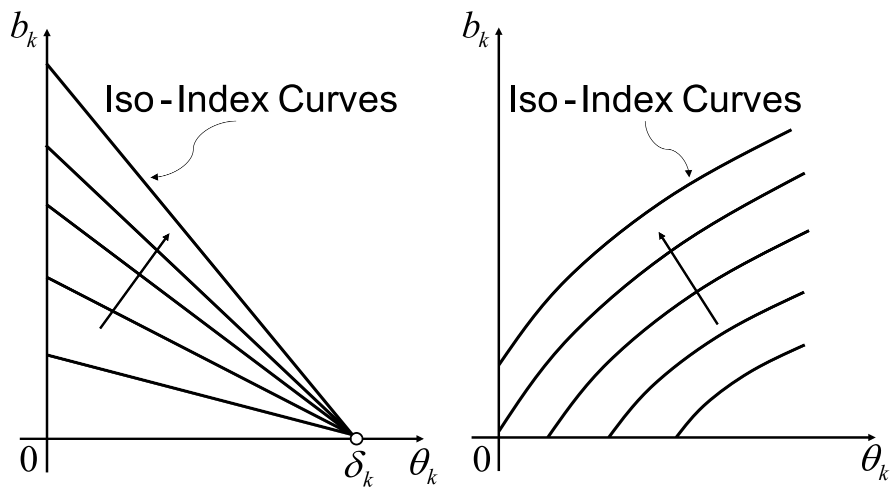

Figure 6. Iso-Index curves under the "pay-as-you-go" budget scenario for a myopic agency when $V_k^c \geq V_k^w$ (Panel a) and when $V_k^c < V_k^w$ (Panel b) Note: the straight arrows in the graphs show directions such that index value increases.

Supplemental Information for "Grassland Easement Evaluation and Acquisition Criteria with Uncertain Conversion and Conservation Returns" (to be available online only)

Item A.

In this item we show why $P_{k,1}^{e} = \max[V_k^c - V_k^g, 0] + \max[V_k^w - V_k^g - \max(V_k^c - V_k^g, 0), 0]$ holds.

$$
\begin{aligned}
&\max[V_k^c - V_k^g, 0] + \max[V_k^w - V_k^g - \max(V_k^c - V_k^g, 0), 0] \\
&= \max[V_k^w - V_k^g, \max[V_k^c - V_k^g, 0]] \\
&= \max[V_k^w, \max[V_k^c, V_k^g]] - V_k^g \\
&= \max[V_k^w, V_k^c] - V_k^g \quad \text{(because } V_k^w \geq V_k^g\text{)} \\
&= P_{k,1}^{e}.
\end{aligned}
$$

Item B.

In this item we provide a numerical example of time value, intrinsic value, and period-one grassland easement payment under various scenarios about one-time grassland-to-cropland conversion cost and cropping-grazing return differences.

We calibrate the landowner's decision problem by using data obtained from various sources. First, we obtain the annual return difference between cropping and grazing from Arora et al. (2021). In their Table 4, Arora et al. (2021) provide return differences for 11 parcels in Stutsman County, North Dakota. These return differences range between -\$50/acre/year and \$99/acre/year across these 11 parcels. We adopt these two numbers as the lower bound and the upper bound respectively of the cropping-grazing return differences in our numerical example, and we then consider 150 return difference scenarios: {-50, -49, …, 0, …, 99}, where the unit of return difference is \$/acre/year. Or, equivalently, one can view these 150 scenarios as return differences for 150 different grassland parcels, which differ in their underlying productivities and therefore return differences.

Second, we construct two periods for our model timeline based on a temporal horizon from present to infinity. The first period covers the most proximate ten years of the temporal horizon, and the second period includes years 11 to infinity. Assuming an annual interest rate at 7% by following Miao et al. (2014), one can readily check that (1) the net present value (NPV) of a \$1/year annuity over the first 10 years is about \$7.5, (2) the NPV of \$1 in the 11th year is about \$0.51, therefore, we set $\beta = 0.51$, and (3) the NPV of a \$1/year annuity over years 11 to infinity is about \$7.8. We admit that this construction is somewhat arbitrary; however, it allows the returns from the two periods to have approximately equal weight when determining the values of landowners' actions. We further assume that the return difference over the first ten years (i.e., period one) is constant and certain, consistent with the model timeline described in Figure 1.

Third, we assume that the period-two *annual* return differences are normally distributed with mean equal to period-one annual return differences. The standard deviation of these normal distributions is calibrated based on annual cash rental rates for non-irrigated cropland and pasture/rangeland (data obtained from Appendix Table 3 in Davis (2021)). Specifically, we use the difference between annual cash rental rates for non-irrigated cropland and pasture/rangeland to approximate the return difference for cropping and grazing. We then use the standard deviation (calibrated at \$31.31/acre/year) of the return differences as the standard deviation of the aforementioned normal distributions. All the cash rental rates are converted to 2020 dollars by using the Gross Domestic Product Implicit Price Deflator. For simplicity we assume the annual return difference in period two, once realized, remains the same across all years in that period. Therefore, the period-two return difference is normally distributed with mean at

$d_1(1+r)/r$ $31.31\times(1+r)/r$, where $d_1 \in \{-50,-49,...,99\}$ is the *annual* return difference in period one and $r = 7\%$ is the interest rate.

Fourth, the one-time grassland-to-cropland conversion cost is obtained from Miao et al. (2014), Ransom et al. (2008), and Doidge et al. (2020). Miao et al. (2014) documented that the conversion cost can vary considerably depending on land conditions. If only a few runs of herbicide application are needed, then the cost can be as low as \$30/acre. However, if the land preparation involves removal of rocks, scrub, or even fences, then the cost can rise well beyond \$100/acre. Ransom et al. (2008) suggest that \$55/acre could be a reasonable estimate of average conversion costs of grassland in North Dakota. Doidge et al. (2020) report that the mean grassland-to-cropland conversion cost is about \$85.73/acre. In our numerical example, we therefore consider four levels of the one-time conversion cost (\$/acre) for each return difference scenario: 30, 55, 85, and 150.

With the above model calibration, here we provide detailed calculations under a specific scenario about return difference and conversion cost. Suppose the annual return difference of cropping and grazing is -\$0/acre/year and the one-time conversion cost is \$30/acre. We have

$$V^w - V^g = 0.51\times \mathrm{E}\{\max(0, \frac{d_2}{1-\frac{1}{1+0.07}} - 30)\} = 88.78$$

$$V^c - V^g = \sum_{t=1}^{10}(0\times\frac{1}{(1+0.07)^{(t-1)}}) - 30 + 0.51\times\frac{0}{1-\frac{1}{1+0.07}} = -30,$$

where $\mathrm{E}(\cdot)$ is the expectation operator and $d_2 \sim N(0, 31.31^2)$. Based on equation (7), we can then calculate the period-one easement payment value as

$$P_1^e = \max[V^c, V^w] - V^g = \max[V^c - V^g, V^w - V^g] = \max[54.5, -794.29] = 88.78.$$

Because the intrinsic value is $\max[0, V^c - V^g] = \max[0, -30] = 0$ and because the period-one easement payment value is the sum of intrinsic value and time value, in this case the time value is equal to the option value, \$88.78/acre.

The same calculation is conducted for all combinations of return differences and conversion costs. Results are summarized in Figures S1 to S3. We find that the time value can be up to about \$100/acre, depending on the magnitude of period-one return differences. The time value first rises and then declines as the period-one return differences increases from negative to positive. We can see that the time values reach the highest when the period-one return differences are positive but close to zero. This is intuitive because when cropping returns are close to grazing returns, then the existence of the one-time conversion cost will render 'wait and see' more appealing (i.e., high time value) whereas the time value will vanish if the return difference is extremely large or small. For instance, if the cropping returns are much higher than grazing returns in period one, then the land will be converted immediately and there is no value to hold the option of period-two conversion. As a result, the time value will be zero (see Figure S1). We also have checked that the time value is increasing in the standard deviation of period-two return differences. For instance, when the standard deviation is doubled, then the time value can be up to \$200/acre. When the standard deviation becomes 0, then the time value vanishes. The intrinsic value and the period-one easement value, on the other hand, weakly increase in the annual cropping-grazing return difference (see Figures S2 and S3). The kinks and non-differentiability at these kinks in Figures S1 to S3 arise from the nature of maximum functions in the expressions of time value, intrinsic value, and easement value.

Item C.

In this item we discuss how landowners' decisions are affected by changes in period two returns in the sense of first-order stochastic dominance (FOSD), second-order stochastic dominance (SOSD), and supermodular order (SO).

Changes in the Sense of FOSD

If $\omega_{k,2}$ undergoes an increase to $\omega'_{k,2}$ in the FOSD sense (i.e., for any increasing function $f(\cdot)$ inequality $\mathsf{E}[f(\omega'_{k,2})] \geq \mathsf{E}[f(\omega_{k,2})]$ holds), denoted by $\omega'_{k,2} \succ_{\text{FOSD}} \omega_{k,2}$, then we can check that the three iso-value lines (i.e., $\Delta_k^{c,e} = \Delta_k^{c,w} = \Delta_k^{w,e} = 0$) will shift rightward. Figure S5 shows that this change enlarges the "convert now" area and shrinks the "ease now" area, indicating an increase in the period one conversion probability. The effect on the "wait and see" area is ambiguous without further information about the distributions of $\omega_{k,2}$. This is because the "wait and see" action becomes more profitable when compared with "ease now" as potential returns from cropping increase relative to grazing returns. When compared with "convert now," however, "wait and see" assumes less appeal because the relative cropping profit increase in period two may not materialize. The net effect of an FOSD increase in $\omega_{k,2}$ on the "wait and see" area depends on the specific magnitude of these two opposing effects.

If $\omega'_{k,2} \succ_{\text{FOSD}} \omega_{k,2}$ then we have $\mathsf{E}(\max[\omega'_{k,2} - \theta_k, 0]) \geq \mathsf{E}(\max[\omega_{k,2} - \theta_k, 0])$ because $\max[\omega_{k,2} - \theta_k, 0]$ is an increasing function in $\omega_{k,2}$. Therefore, by equation (7) we know that the minimum easement payment, 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 grazing becomes relatively larger and hence the minimum easement payment that the landowner is willing to accept will increase. For future reference, we formalize the obvious inference as:

Remark S1. *When the period-two return difference, $\omega_{k,2}$, increases in the FOSD sense, then both the conversion probability and the minimum easement payment increase*.

This finding supports the assumption widely used in the conservation literature that grasslands with higher conversion probability should be offered higher easement payments (e.g., Newburn et al. 2006). Although intuitive, this assumption does not always hold. In what follows we show situations where conversion probability and minimum easement payment may vary inversely.

Changes in the Sense of SOSD

We adopt the standard probabilist's concept of SOSD (Gollier 2001, p. 42): if inequality $\mathsf{E}[f(\omega'_{k,2})] \geq \mathsf{E}[f(\omega_{k,2})]$ $f(\cdot)$, then $\omega'_{k,2}$ second-order stochastically dominates $\omega_{k,2}$, denoted by $\omega'_{k,2} \succ_{\text{SOSD}} \omega_{k,2}$. Hence, from equations (4) and (5) in the main text we can see that when $\omega_{k,2}$ undergoes an increase in the sense of SOSD, then the lines $\Delta_k^{c,w} = 0$ and $\Delta_k^{c,e} = 0$ will shift downward.[19] This indicates that "convert now" increases its value relative to those of "wait and see" and "ease now" under an SOSD change in $\omega_{k,2}$. As a result, the period-one conversion probability will increase. Intuitively, as uncertainty about the period-two return difference decreases, "wait and see" becomes less appealing when compared to "convert now." In the polar case where the period-two return difference is certain, then "wait and see" is meaningless and the landowner's period-one choice will be between "convert now" and "ease now." However, when $\omega_{k,2}$ undergoes an increase in the sense of SOSD, then the period-one minimum easement payment may increase or decrease. For instance, when $\omega_{k,2}$ undergoes an increase in the sense of FOSD, a special case of SOSD, then by Remark

[19] Note that in equation (4) in the main text we have $-\beta\mathsf{E}(\max[-\theta_k, -\omega_{k,2} + P_{k,2}]) = \beta\mathsf{E}(\min[\theta_k, \omega_{k,2} - P_{k,2}])$ where $\min[\theta_k, \omega_{k,2} - P_{k,2}]$ is increasing and concave in $\omega_{k,2}$.

S1 we know that the period-one minimum easement payment increases. When $\omega_{k,2}$ undergoes an increase in the sense of MPC, a special case of SOSD, then by Remark 1 in the main text we know that the period-one minimum easement payment decreases.

Remark S2. *When the period-two return difference, $\omega_{k,2}$, increases in the SOSD sense, then the period-one conversion probability increases. The effect on period-one minimum easement payment is ambiguous.*

Changes in the Supermodular Sense

We turn now to a consideration of how changes in covariation between crop returns and grazing returns are likely to affect the optimal action choice and the minimum easement payment. We use supermodular order as a measure of the covariation and define it as follows.

Definition S1: (Ch. 9 in Shaked and Shanthikumar 2007) *Define supermodular as 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, denoted by $(\varsigma_1'', \varsigma_2'') \succ_{\mathrm{SO}} (\varsigma_1', \varsigma_2')$, if, for any supermodular function $f(\varsigma_1, \varsigma_2)$, inequality $\mathrm{E}[f(\varsigma_1'', \varsigma_2'')] \geq \mathrm{E}[f(\varsigma_1', \varsigma_2')]$ holds.*

An example of a random variable pair that can be ordered in this sense is a pair of bivariate normal distributions that only differ in their correlation coefficient (see Example 9.A.20 in Shaked and Shanthikumar 2007). In this example, the distribution with the larger correlation coefficient is larger in the supermodular order.

Note that $-\max[\omega_{k,2} - \theta_k, P_{k,2}]$ $(\pi^c_{k,2}, \pi^g_{k,2})$

$\omega_{k,2} \equiv \pi^c_{k,2} - \pi^g_{k,2}$, we have $-\max[\omega_{k,2} - \theta_k, P_{k,2}] = -\max[\pi^c_{k,2} - \pi^g_{k,2} - \theta_k, P_{k,2}]$. Note that the function $\max[x, P_{k,2}]$ is convex in *x*, implying that $\max[\pi^c_{k,2} - \pi^g_{k,2} - \theta_k, P_{k,2}]$ has a non-positive second difference in the pair $(\pi^c_{k,2}, \pi^g_{k,2})$. That is, 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

$$\begin{aligned} &\max[\hat{\pi}^c_{k,2} - \hat{\pi}^g_{k,2} - \theta_k, P_{k,2}] - \max[\hat{\pi}^c_{k,2} - \tilde{\pi}^g_{k,2} - \theta_k, P_{k,2}] \\ &\leq \max[\tilde{\pi}^c_{k,2} - \hat{\pi}^g_{k,2} - \theta_k, P_{k,2}] - \max[\tilde{\pi}^c_{k,2} - \tilde{\pi}^g_{k,2} - \theta_k, P_{k,2}]. \end{aligned} \tag{SI-1}$$

Re-arranging terms in equation (SI-1) we obtain,

$$\begin{aligned} &-\max[\hat{\pi}^c_{k,2} - \hat{\pi}^g_{k,2} - \theta_k, P_{k,2}] - \max[\tilde{\pi}^c_{k,2} - \tilde{\pi}^g_{k,2} - \theta_k, P_{k,2}] \\ &\geq -\max[\hat{\pi}^c_{k,2} - \tilde{\pi}^g_{k,2} - \theta_k, P_{k,2}] - \max[\tilde{\pi}^c_{k,2} - \hat{\pi}^g_{k,2} - \theta_k, P_{k,2}]. \end{aligned} \tag{SI-2}$$

By Definition S1, equation (SI-2) implies that $-\max[\omega_{k,2} - \theta_k, P_{k,2}]$ is a supermodular function of $(\pi^c_{k,2}, \pi^g_{k,2})$. Similarly, we can show that $-\max[-\theta_k, -\omega_{k,2} + P_{k,2}]$ is a supermodular function of $(\pi^c_{k,2}, \pi^g_{k,2})$ as well. This finishes the proof.

Given that $-\max[\omega_{k,2} - \theta_k, P_{k,2}]$ $(\pi^c_{k,2}, \pi^g_{k,2})$

$(\pi^c_{k,2}, \pi^g_{k,2})$ in the supermodular sense will decrease the value of

$\mathsf{E}(\max[\omega_{k,2} - \theta_k, P_{k,2}])$ $\Delta_k^{w,e} = 0$ leftward (see equation (4)). Similarly, an increase in $(\pi^c_{k,2}, \pi^g_{k,2})$ in the supermodular sense will decrease the value of $\mathsf{E}(\max[-\theta_k, -\omega_{k,2} + P_{k,2}])$ and hence shift the $\Delta_k^{c,w} = 0$ curve downward (see equation (4)). Since an increase in $(\pi^c_{k,2}, \pi^g_{k,2})$ in the supermodular sense does not change $\mathsf{E}(\pi^c_{k,2} - \pi^g_{k,2})$, based on equation (5) we know that it will not affect the line $\Delta_k^{c,e} = 0$.[20] Figure S6 also depicts the impacts of an increase in $(\pi^c_{k,2}, \pi^g_{k,2})$ in the supermodular sense, from which we can see that the "convert

[20] Note that $\pi^c_{k,2} - \pi^g_{k,2}$ and $\pi^g_{k,2} - \pi^c_{k,2}$ are both supermodular functions. Therefore, it is readily checked that a supermodular order increase in $(\pi^c_{k,2}, \pi^g_{k,2})$ does not affect $\mathsf{E}(\pi^c_{k,2} - \pi^g_{k,2})$.

now" area expands and hence the conversion probability increases. The intuition is as the crop returns and grazing returns become more aligned with each other, the probability that the landowner will regret choosing "convert now" will decrease. Following the same intuition, from equation (7) we can see that an increase in $(\pi^c_{k,2}, \pi^g_{k,2})$ in the SO sense will decrease the minimum easement payment by reducing the time value of the conversion option, given that $-\max[\omega_{k,2} - \theta_k, 0]$ is a supermodular function of $(\pi^c_{k,2}, \pi^g_{k,2})$.[21] The following remark summarizes the subsection's discussion.

Remark S3. *Suppose that the distribution of cropping returns and grazing returns undergoes an increase in the supermodular order sense. Then, all else equal, the period-one i) probability of conversion will weakly increase; and ii) minimum easement payment will weakly decrease.*

Remark S3 reveals another situation under which conversion probability and easement payment may vary in opposing directions. From Remarks 2 and S3 we can see that increases in returns in the MPC sense or the SO sense decrease the time value of the option to convert (i.e., $\max[0, V^w_k - V^c_k]$) but has no effect on the intrinsic value (i.e., $V^c_k - V^g_k$). In these cases, the conversion probability will increase and the minimum easement payment will decrease.

Effects of Risk Interventions

In terms of risk interventions' effect, we consider two types of insurance policies: free insurance with premium fully subsidized by the federal government and actuarially fair insurance without any premium subsidy.[22] Suppose that the insurance guarantees return amount *l*. Then crop

[21] Margrabe (1978) presents a numerical example where an increase in the correlation of returns between two assets lowers the value of the option to exchange the assets.
[22] Although available in the United States, livestock crop insurance products are not well established (Shields 2015). Therefore, for simplicity we do not consider insurance for grass-based outputs.

$\hat{\pi}^c_{k,2} = \max[l, \pi^c_{k,2}] \geq \pi^c_{k,2}$. Furthermore, let $\hat{\omega}_{k,2} \equiv \hat{\pi}^c_{k,2} - \pi^g_{k,2}$ be the return difference in period two between crop returns with fully subsidized insurance and grazing returns. Clearly, we have $\hat{\omega}_{k,2} \geq \omega_{k,2}$ and $\Pr(\hat{\omega}_{k,2} \leq b) \leq \Pr(\omega_{k,2} \leq b)$ for any $b \in \mathsf{R}$, which indicates that $\hat{\omega}_{k,2}$ first-order stochastically dominates $\omega_{k,2}$, denoted by $\hat{\omega}_{k,2} \succ_{\text{FOSD}} \omega_{k,2}$. Therefore, by Remark S1 in the online SI we know that fully subsidized crop insurance increases the period-one conversion probability and the minimum easement payment.

Let $\tilde{\pi}^c_{k,2}$ denote crop returns with actuarially fair insurance. Again, assume that the guaranteed return level is *l*. Then we have $\tilde{\pi}^c_{k,2} = \max[l, \pi^c_{k,2}] - \mathsf{E}(\max[l - \pi^c_{k,2}, 0])$. It is readily checked that $\tilde{\pi}^c_{k,2}$ second-order stochastically dominates (SOSD) $\pi^c_{k,2}$, denoted by $\tilde{\pi}^c_{k,2} \succ_{\text{SOSD}} \pi^c_{k,2}$.[23] In the case of fully subsidized crop insurance, we have shown that if $\hat{\pi}^c_{k,2} \succ_{\text{FOSD}} \pi^c_{k,2}$ then $\hat{\omega}_{k,2} \succ_{\text{FOSD}} \omega_{k,2}$. In the case of actuarially fair insurance, however, $\tilde{\pi}^c_{k,2} \succ_{\text{SOSD}} \pi^c_{k,2}$ does not necessarily imply that $\tilde{\omega}_{k,2} \succ_{\text{SOSD}} \omega_{k,2}$, where $\tilde{\omega}_{k,2} \equiv \tilde{\pi}^c_{k,2} - \pi^g_{k,2}$. It depends on the interdependence between $\pi^c_{k,2}$ and $\pi^p_{k,2}$. In the subsection below we provide two examples under which with an actuarially fair insurance we have $\omega_{k,2} \succ_{\text{SOSD}} \tilde{\omega}_{k,2}$ and $\tilde{\omega}_{k,2} \succ_{\text{SOSD}} \omega_{k,2}$, respectively, depending on the correlation between cropping and grazing returns in period two. We summarize the above discussion as the following remark.

Remark S4. *Fully subsidized crop insurance increases the conversion probability and*

[23] Here we adopt the SOSD concept from Gollier (2001, p. 42): if inequality $\mathsf{E}[f(\omega'_{k,2})] \geq \mathsf{E}[f(\omega_{k,2})]$ holds for any increasing and concave function $f(\cdot)$, then $\omega'_{k,2}$ second-order stochastically dominates $\omega_{k,2}$.

minimum easement payment in period one. The effect of actuarially fair insurance on the conversion probability and minimum easement payment depends on the interdependence between crop and grazing returns.

Given that U.S. farmers have free catastrophic coverage for insurable crops and that the overall average crop insurance premium subsidy rate for buy-up coverage (i.e., coverage level higher than catastrophic coverage) is above 60% (Shields 2015), we believe that the federal crop insurance would increase the conversion probability and the minimum easement payment.

Two examples of actuarially fair insurance

This Item includes two examples under which with an actuarially fair insurance $\omega_{k,2} \succ_{\text{SOSD}} \tilde{\omega}_{k,2}$ and $\tilde{\omega}_{k,2} \succ_{\text{SOSD}} \omega_{k,2}$ hold, respectively.

Example 1. Suppose $\pi^g_{k,2} = \pi^c_{k,2}$ $\pi^g_{k,2}$

$\pi^c_{k,2}$. Under this situation, $\omega_{k,2} = 0$ and $\tilde{\omega}_{k,2} \equiv \tilde{\pi}^c_{k,2} - \pi^g_{k,2} = \max[l - \pi^c_{k,2}, 0]$ $-\mathsf{E}(\max[l - \pi^c_{k,2}, 0])$. It is readily checked that $\mathsf{E}(\tilde{\omega}_{k,2}) = 0$. By Jensen's inequality, for any increasing and concave function, $u(\cdot)$, we have $\mathsf{E}(u(\omega_{k,2})) \geq \mathsf{E}(u(\tilde{\omega}_{k,2}))$, indicating that $\omega_{k,2}$ second-order stochastically dominates $\tilde{\omega}_{k,2}$. In this example actuarially fair insurance will enlarge the "wait and see" area while shrinking the "ease now" and "convert now" areas (Remark 2). The intuition is that when grazing returns are perfectly aligned with crop returns, then there is no point to "wait and see" because the difference between grazing returns and crop returns will not vary. Furthermore, if $\pi^g_{k,2} = \pi^c_{k,2}$ then based upon equation (1) grassland will not be converted in period two. The presence of actuarially fair insurance allows a positive probability that converting the grassland to crop land in period two is more profitable. In this case "wait and see" is more appealing to the landowner. Moreover, by Jensen's inequality and by equation (7), we can check that the minimum easement payment under $\omega_{k,2}$ is smaller than that under $\tilde{\omega}_{k,2}$. Therefore, in this example the availability of an actuarially fair insurance contract will decrease the conversion probability in period one, increase the minimum easement payment in period one, and increase the conversion probability in period two.

Example 2. Suppose $\pi^g_{k,2}$ and $\pi^c_{k,2}$ are statistically independent. Then the return difference under actuarially fair insurance with coverage l becomes $\tilde{\omega}_{k,2} = \pi^c_{k,2} - \pi^g_{k,2} + \max[l - \pi^c_{k,2}, 0]$ $-\mathsf{E}(\max[l - \pi^c_{k,2}, 0])$. For any increasing and concave function $u(\cdot)$, we have

$$\begin{aligned}&\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} u(\pi^c_{k,2} - \pi^g_{k,2} + \max[l - \pi^c_{k,2}, 0] - \mathsf{E}(\max[l - \pi^c_{k,2}, 0]))dG_1(\pi^c_{k,2})dG_2(\pi^g_{k,2}) \\ &\geq \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} u(\pi^c_{k,2} - \pi^g_{k,2})dG_1(\pi^c_{k,2})dG_2(\pi^g_{k,2}),\end{aligned} \tag{SI-3}$$

where $G_1(\pi^c_{k,2})$ and $G_2(\pi^g_{k,2})$ are the respective marginal distributions of $\pi^c_{k,2}$ and $\pi^g_{k,2}$. The inequality holds because for each fixed value of $\pi^g_{k,2}$ a risk averse landowner will prefer to have actuarially fair insurance on $\pi^c_{k,2}$. Therefore, we can conclude that when $\pi^g_{k,2}$ and $\pi^c_{k,2}$ are independent then $\tilde{\omega}_{k,2}$ second-order stochastically dominates $\omega_{k,2}$. Therefore, in this example, the presence of an actuarially fair insurance contract will enlarge the "ease now" and "convert now" areas but shrink the "wait and see" area. The intuition is that crop insurance decreases the crop returns risk while not affecting the interdependence between crop returns and grazing returns (recall that in this example the two returns are independent); therefore, it reduces the value of "wait and see." Consequently, the period-one conversion probability will increase. Moreover, based upon Jensen's inequality and equation (7) we can show that the minimum easement payment under $\tilde{\omega}_{k,2}$ is smaller than that under $\omega_{k,2}$. That is, in this example actuarially fair insurance decreases the minimum easement payment.

Item D.

This Item shows a procedure to solve problem (11) by using backward induction. In period two, the agency's decision problem is straightforward: by taking land tracts eased in period one, h_1, as given and after observing the realizations of crop returns and grazing returns in period two, the agency maximizes environmental benefits due to acquisition in period two by selecting tracts from available grassland tracts to exhaust the available budget in period two. The available grassland tracts in period two are those with $V_k^c < V_k^w$ but not eased in period one. Note that if grassland tracts with $V_k^c \geq V_k^w$ are not eased in period one, then they will be cropped in period one and will not be available for acquisition in period two. The available budget in period two, M_2, can be determined by equation $\sum_{k \in h_1} P_{k,1}^{\mathrm{e}} + \beta M_2 = M$. We denote the optimal land tract set to be eased in period two for a given h_1 as $\hat{h}_2(h_1)$. To obtain $\hat{h}_2(h_1)$, as shown in Miao et al. (2016), the agency simply enrolls grasslands with the highest ratio of increased environmental benefits due to easement acquisition over easement payment,

$$I_{k,2} = \frac{\Delta_{k,2}^{\mathrm{B}}}{P_{k,2}^{e}} = \frac{b_k}{\omega_{k,2} - \theta_k} \text{ for } \Delta_{k,2}^{\mathrm{B}} > 0, \tag{SI-4}$$

until the available period-two budget is exhausted. Tracts with $\Delta_{k,2}^{\mathrm{B}} = 0$ will not be considered for easement acquisition because no extra environmental benefit is secured by their acquisition. When analysis proceeds back to period one, then the easement agency will simply select h_1 to maximize $\sum_{k \in h_1} \Delta_{k,1}^{\mathrm{B}} + \beta \mathrm{E}(\sum_{k \in \hat{h}_2(h_1)} \Delta_{k,2}^{\mathrm{B}})$ under the aggregate budget M.

Item E.

This Item shows a procedure to solve problem (13) by using backward induction and discusses

$\bar{M}_2$, is no

longer determined by h_1. Therefore, in period two, by taking h_1 and $\bar{M}_2$ as given, the agency optimally select land tracts to ease according to $I_{k,2}$ in equation (SI-4) until the easement budget is exhausted. We denote the set of selected tracts in period two as $\tilde{h}_2(h_1, \bar{M}_2)$. When analysis proceeds to period one, then the easement agency will select h_1 to maximize $\sum_{k\in h_1} \Delta^{\mathrm{B}}_{k,1}$ $+\beta\,\mathrm{E}(\sum_{k\in\tilde{h}_2(h_1,\bar{M}_2)} \Delta^{\mathrm{B}}_{k,2})$ under the period-one fixed budget $\bar{M}_1$.

Unlike the optimal solution to problem (11) where land tracts with $V_k^c < V_k^w$ will not be eased in period one, for problem (13) the agency may find it optimal to acquire some land tracts with $V_k^c < V_k^w$ in period one because now the fund in period one cannot be saved for period two acquisition. For instance, if the fixed budget in period one is so large that the marginal environmental benefit from acquisition of tracts with $V_k^c \geq V_k^w$ in that period is low, then the agency may increase aggregate environmental benefits over the two periods by easing some land tracts with both $V_k^c < V_k^w$ and higher benefit-cost ratio in period one.

Define $\hat{B}^*_{\Omega_2}$

$\bar{M}_2$ from an available land tract set in period two, Ω_2.

Furthermore, let $\hat{h}_1^*$

$\bar{M}_1$. Then the set of land available to be eased in

period two is $\hat{\Omega}_2 = \Gamma^w - \hat{h}_1^*$.

$\grave{o}_{-j} = \hat{B}^{*}_{\hat{\Omega}_2} - \hat{B}^{*}_{\hat{\Omega}_2 - \{j\}}$ $\grave{o}_{-j} \geq 0$ because reducing available land tracts in period two cannot increase, and may decrease, the expected maximized environmental benefits in that period. Specifically, if a land tract $j \in \hat{\Omega}_2$ were to be eased in period one by using funds saved from dropping land tract $i \in \hat{h}_1^*$, then the expected environmental benefit gains from land tract *j* would be $\beta b_j \Pr(\omega_{j,2} \geq \theta_j) - \grave{o}_{-j}$; the expected environmental benefit loss from not acquiring tract *i* would depend on whether $V_i^c \geq V_i^w$ holds. If $V_i^c \geq V_i^w$ then the loss is simply $\Delta_{i,1}^{\mathrm{B}}|_{V_i^c \geq V_i^w}$ (see equation (9)). If $V_i^c < V_i^w$, however, then the loss is $\beta b_i \Pr(\omega_{i,2} \geq \theta_i) - \grave{o}_{-j+i}$, where $\grave{o}_{-j+i} = \hat{B}^{*}_{\hat{\Omega}_2 - \{j\} + \{i\}} - \hat{B}^{*}_{\hat{\Omega}_2 - \{j\}}$. So we have the following necessary conditions for $\hat{h}_1^*$ to be optimal:

Remark S5. *Set* $\hat{h}_1^*$ *is the optimal tract set to acquire in period one only if for any tracts* $i \in \hat{h}_1^*$ *and* $j \in \hat{\Omega}_2 = \Gamma^w - \hat{h}_1^*$ *the following conditions hold: i) if* $V_i^c \geq V_i^w$ *then* $\Delta_{i,1}^{\mathrm{B}}|_{V_i^c \geq V_i^w} \geq \beta b_j \Pr(\omega_{j,2} \geq \theta_j) - \grave{o}_{-j}$*; and ii) if* $V_i^c < V_i^w$ *then* $\beta b_i \Pr(\omega_{i,2} \geq \theta_i) - \grave{o}_{-j+i} \geq \beta b_j \Pr(\omega_{j,2} \geq \theta_j) - \grave{o}_{-j}$.

Remark S5 basically states that under the optimal solution switching land tracts between the two periods does not increase total benefits.

Item F.

In this item we define mean residual life order (MRLO) and how changes period-two return differences in an MRLO sense will affect a grassland tract's acquisition priority.

Definition S2: (Ch. 2 in Shaked and Shanthikumar 2007) *For a random variable X with support* Λ *and a finite mean, its mean residual life function is defined as*

$$q(t) = \begin{cases} \mathsf{E}(X - t \mid X > t), & \text{for } t \in \Lambda \\ 0, & \text{otherwise.} \end{cases} \tag{SI-5}$$

Let $\tilde{q}(t)$ *be the mean residual life function of another random variable,* $\tilde{X}$ *. If for every t the inequality* $\tilde{q}(t) \geq q(t)$ *holds then* $\tilde{X}$ *is greater than X in the sense of mean residual life order* (*MRLO*)*, denoted as* $\tilde{X} \succ_{\mathrm{MRLO}} X$.

By Definition S2 and equation (15) we can readily reach the following conclusion:

Remark S6. *Suppose a myopic agency under the "pay-as-you-go" budget considers two grassland tracts, namely r and s, both with "wait and see" preferred in period one. All else equal, if* $\omega_{r,2} \succ_{\mathrm{MRLO}} \omega_{s,2}$ *then tract r should have lower priority for acquisition than tract s.*

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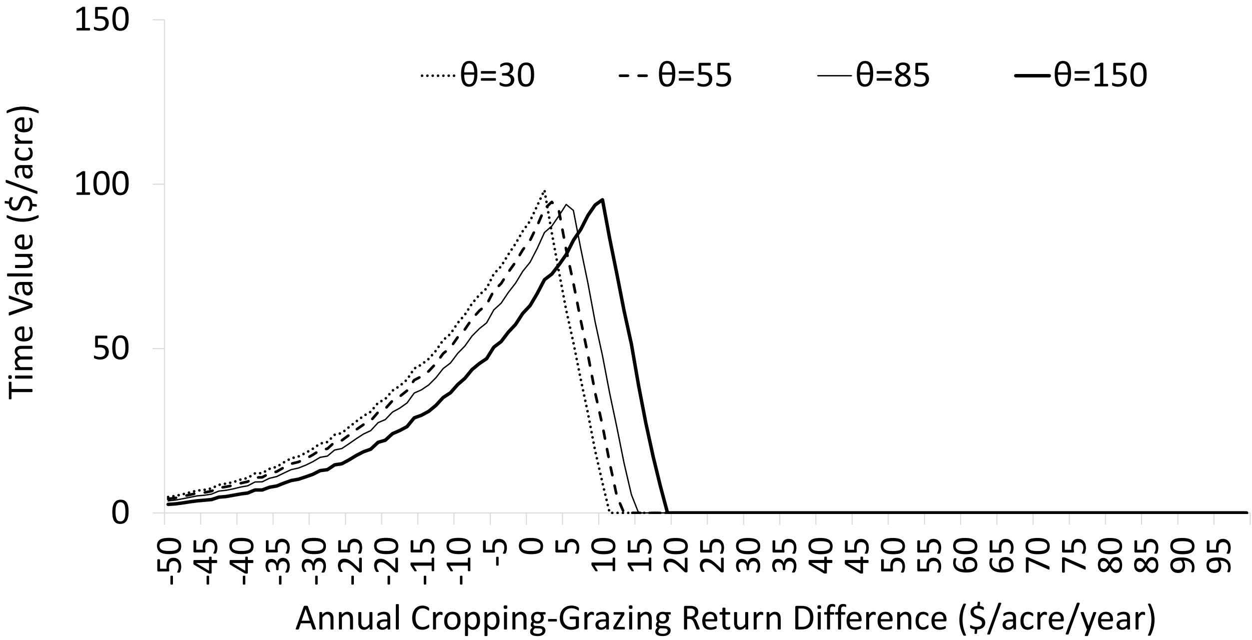

Figure S1. Time Value under Various Conversion Cost and Period-One Return Difference Scenarios

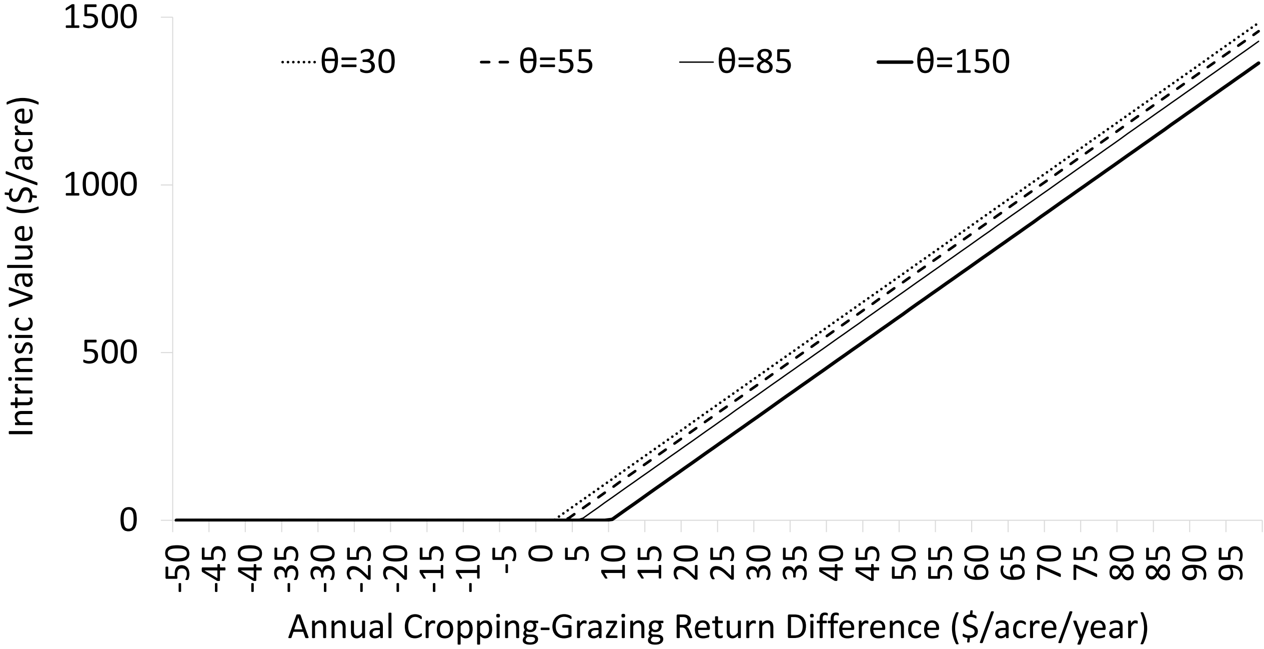

Figure S2. Intrinsic Value under Various Conversion Cost and Period-One Return Difference Scenarios

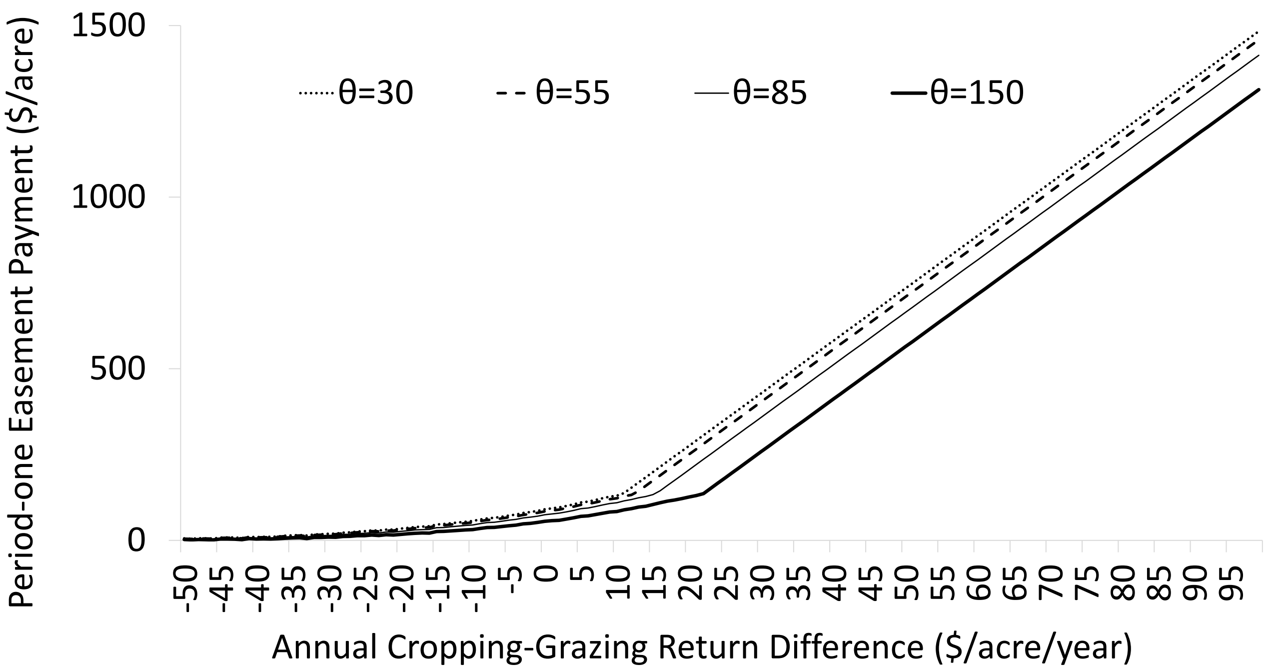

Figure S3. Period-One Grassland Easement Payment under Various Conversion Cost and Period-One Return Difference Scenarios

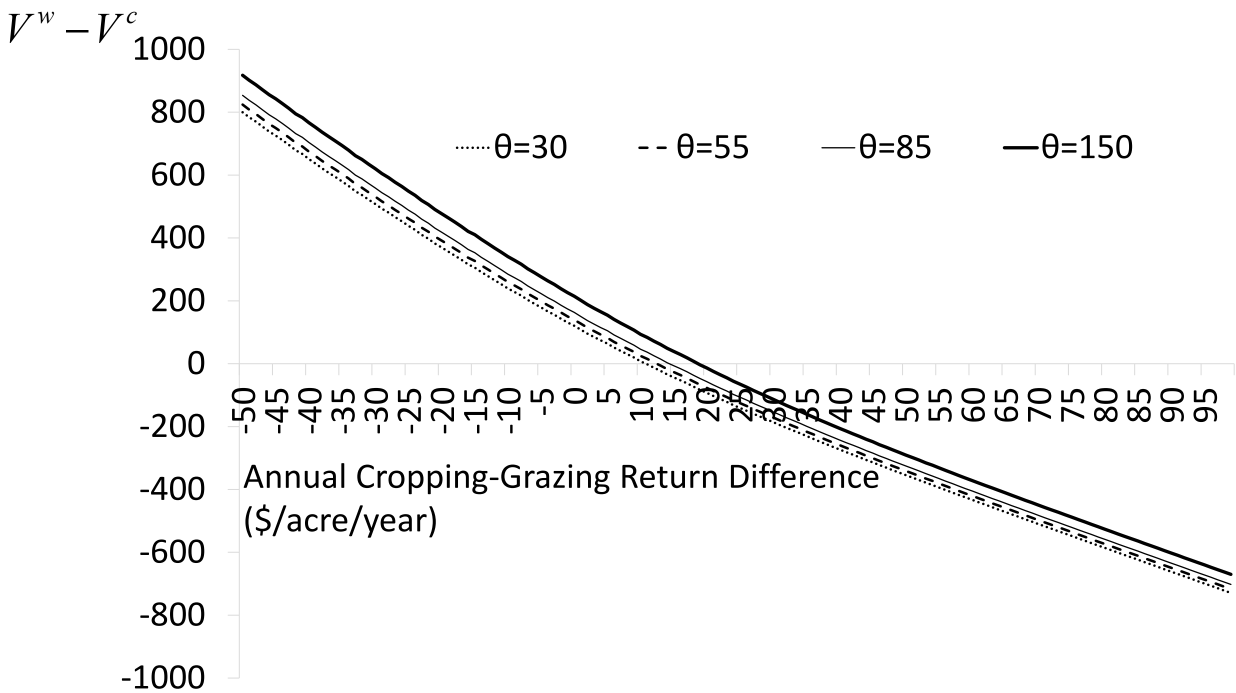

Figure S4. The value of $V^w - V^c$ under Various Conversion Cost and Period-One Return Difference Scenarios

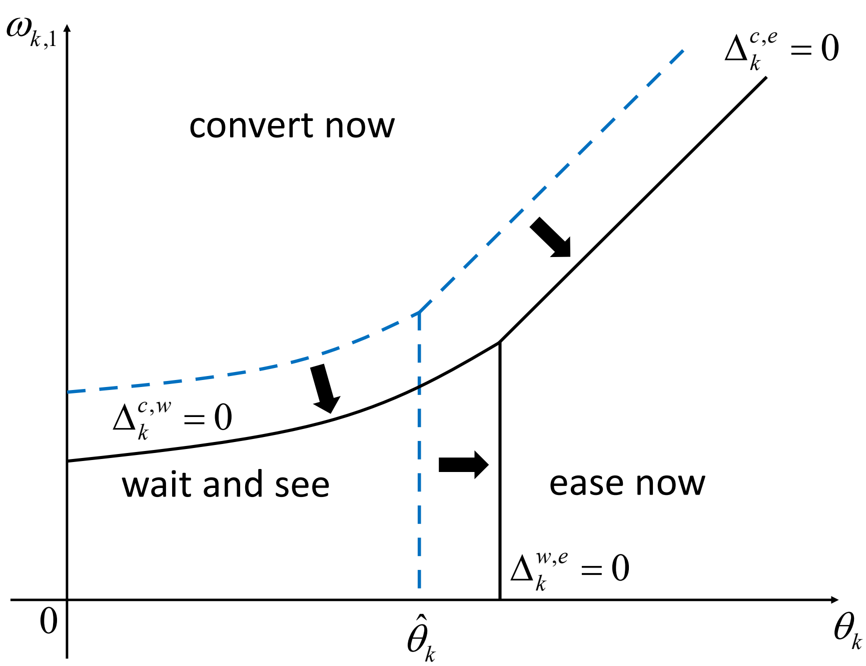

Figure S5. Impact of an increase in $\omega_{k,2}$ in the FOSD sense on period-one optimal action

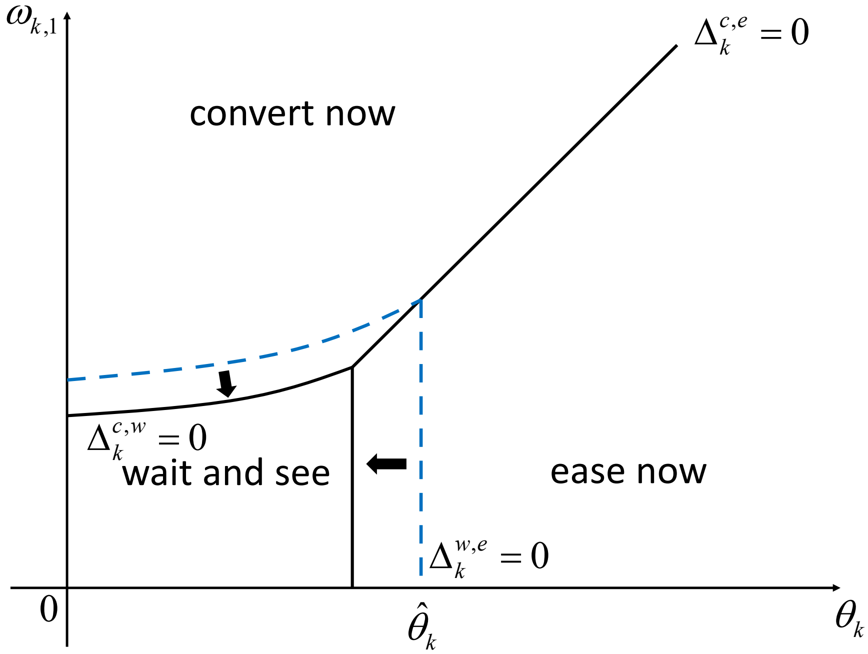

Figure S6. Impact of an increase in $\omega_{k,2}$ in the sense of supermodular order on period-one optimal action