The Productivity Effects of Wetland Restoration: Evidence from Agricultural Fields in Wisconsin

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Abstract

Optimizing payments for ecosystem services can increase agricultural resiliency to climate-related risks and shocks. I leverage remote-sensed yield data to evaluate the field-level productivity effects of voluntary wetland restoration. Using a regression discontinuity framework, I find that wetland easements retire land that is low yielding, 60-70% of mean yields. Further, I find evidence that wetland easements benefit surrounding production within a few kilometers by mitigating extreme weather conditions. Easements have the largest externality effects in areas with open fields, open water, and during extreme rain events. These results call for attention to the opportunity costs and beneficial externalities of land conservation programs and provides insight into where future wetland restoration may be optimal.

1 Introduction

From early settlement to the present day, over half of the original wetlands in the contiguous United States have been drained for residential, commercial, and agricultural development (McCorvie and Lant 1993; Tiner 1984). Out of its original 87 million hectares of wetlands, the USA has drained 54%, primarily for agricultural use. Beginning in the 1970s, the perception of wetland habitats shifted from nuisances to vital ecosystems that provide beneficial services such as flood protection, wildlife habit, pollutant filtration, and carbon sequestration. Understanding the economic impacts of wetlands is crucial in light of the recent Supreme Court hearing that narrowed protections granted to thousands of acres of wetland (Sackett v. EPA, 598 U.S. 21-454 (2023)).

The Agricultural Conservation Easement Program (ACEP), formally the Wetland Reserve Program, is a program offered by the Natural Resources Conservation Service (NRCS) of the United States Department of Agriculture (USDA) to restore wetlands through easement contracts. The right to crop on a field is purchased from landowners, and the NRCS restores the land to its original wetland state. As of 2020, there are over three million acres of permanent NRCS wetland easement in the US. In the state of Wisconsin, the focus of this study, there are 68,650 wetland easement acres. In comparison, about 14 million acres in Wisconsin are used for agricultural production. This analysis examines the effects of wetland easements on agricultural productivity and aims to inform future conservation efforts.

The fundamental research questions asked here include: 1) What are the costs to producers of switching from agricultural production to conservation (i.e. what is the forgone production and which land is being selected into the program)? 2) Are there external production benefits of conservation easements? 3) When and where are production spillovers concentrated? Measuring the relationship between conserved ecosystems and agricultural systems is critical in understanding the extent that that conservation agriculture can address climate risk, improve sustainability, and increase farm profitability in the long-run. This analysis offers insight into the private cost of conservation efforts and the ensuing public benefits.

One of the ecosystem benefits commonly associated with wetlands is flood mitigation. However, it is unclear how conserved wetlands impact neighboring field productivity. Wetlands alter water availability and flood patterns within the watershed (Acreman and Holden 2013; Bullock and Acreman 2003; Harvey et al. 2009). Wetlands are capable of storing flood waters during high runoff events such as rain storms and snow melt. Wetlands decrease both the rate and volume of floodwaters in the watershed. Wetlands store water during times of excess precipitation, recharge groundwater supplies, and then slowly release water back onto the

land—whether that is helpful or harmful to agricultural production at the field level is unknown.

In a previous study at the county level, I find that easements improve yields for corn, soybean, and wheat by reducing planting on unproductive cropland and changing the composition of land in production (Karwowski 2022). In this paper, I estimate the productivity effect of wetland easements at a finer resolution using novel remote sensing data in Wisconsin. I explore when and where easement restoration is most beneficial by identifying which mechanisms lead to the largest gains in agricultural productivity. I use satellite-based estimates of corn and soybean yields for agricultural fields (defined by USDA common land unit boundaries) from 2010-2019 to conduct my analysis. I quantify the forgone agricultural profits (the private costs) as well as the yield spillovers (the public benefits) of wetland easements.

Wisconsin is relevant for this analysis because of its agricultural prominence and high percentage of wetlands. Corn and soybeans are its highest-valued agricultural commodities after dairy and cattle. In 2022, Wisconsin produced over 500 million bushels of corn and 100 million bushels of soybeans. Wisconsin's geological and glacial history have given it a very diverse wetland landscape. Studying how wetland easements impact corn and soybean yields in Wisconsin is highly applicable to understanding the land use dynamics and interplay of wetland ecosystems and agricultural lands.

First, I measure the direct effects of easements by comparing fields enrolled in the wetland easement program with fields without easement to quantify the magnitude of potential yield loss. If the easement enrolled land had remained in production, what would yield gains be on that field? I estimate forgone productivity using a difference-in-differences approach and compare enrolled fields to all cropped fields in Wisconsin as well as a sub-sample of applicant fields (program applicants that were not selected to enroll). My results suggest that placing an easement on a field reduces corn yields by 61-90 bushels per acre and soybean yields by 21-31 bushels per acre. I also leverage the program ranking data to employ a regression discontinuity specification and identify a local average treatment effect. I estimate that easements decrease corn yields by approximately 83 bushels per acre and soybean yields by 31 bushels per acre. Measuring this direct effect uncovers the landowner's opportunity cost of placing land into an easement, or the value of agricultural production on that field.

For NRCS wetland easement programs, the payments for ecosystem services are based on the expected agricultural profits in the county. In Wisconsin, the past decade has seen average payments of $4,000 per acre while the average-yielding field has a present value of over $5,000 per acre. However, the present value calculations based on my estimated foregone yields ranges from $300-$3,000 per acre, and can even be negative at times. My empirical results suggest that current easement prices are inflated and that producers

would be willing to accept a lower price to retire their fields. Not only are easement enrolled lands low-yielding, my back-of-the-envelope calculations suggest that farming on these lands results in marginal profits. Placing land in easement may reduce net agricultural losses. Program cost-effectiveness could be increased if conservation agents used a reverse-auction strategy based on field-specific forgone yield to determine payments for ecosystem services.

Second, I identify spillover effects on agricultural fields surrounding easements. Here, I define spillover effects as the effect that wetland easements have on surrouding croplands due to restoration-caused changes in water storage and water flow. The NRCS designs wetlands to minimize any spillover effects.[1] However, my findings suggest that wetland easements alter the hydrology and correspondingly, the productivity of surrounding fields.

I use a dynamic difference-in-differences strategy to compare yields before and after easement restoration on surrounding lands over time. Leveraging variation in easement timing and the exogeneity of neighbor restoration decisions, I causally identify easement spillover effects by comparing fields within an easement buffer with fields outside of the buffer as well as fields not yet within a restored easement buffer. I employ the Sun & Abraham (2021) estimator to account for staggered timing in easement restoration. I find that easements have the largest effect on fields within a 3-kilometer buffer. Notably, corn yields see increases of 2-5 bushels per acre while soybean yields are insignificantly impacted or experience small negative effects of 0.5-1 bushel per acre. Wetland easements have significant externalities beyond the fields under easement. To my knowledge, this is the first study that quantifies these spillover effects at the field level at a broad scale.

Third, I explore the mechanisms driving these spillover effects and highlight the conditions under which spillovers are amplified. I find that land use, precipitation levels, and soil characteristics can heighten or dampen spillover effects. Wetland easements that exist in areas with a higher proportion of fallow, forage, and open water experience yield increases. When precipitation levels are high during the planting and harvest season, wetland easements improve surrouding yields. Areas that experience more extreme rainfall during the spring and fall may benefit from additional wetland restoration. Lands with a high soil water content and low flood risk conditions also experience the highest productivity benefits from wetland easements.

This work contributes to a number of different strands of literature: 1) understanding the values and pricing

[1] According to the NRCS Conservation Practice Standard (Code 657), the work associated with restoring the wetland shall not adversely affect adjacent properties unless agreed to by signed written agreement or easement. The general hydrological effects of the restoration including the impacts on downstream hydrographs, volumes of surface runoff, and groundwater resources due to changes of water use and movement are considered during the planning phase of the restoration.

of conserved lands, 2) highlighting the effects of wetland habitats on flooding, and 3) quantifying land use externalities with satellite data.

Initially, a core contribution of this paper is documenting the selection effect of lands in the wetland restoration program: lands that apply to the easement programs are lower yielding than the average cropland parcel. Not only do I show this selection exists, I also mitigate the selection to uncover causal effects with my identification strategies. There is anecdotal evidence of this selection from policy directors but here I showcase the magnitude of the selection effect. Generally, lands that are put into easement have lower production value compared to croplands that do not enter easement programs. Understanding the opportunity cost of retiring land from production reveals the producer's minimum payment that they are willing to accept to enter the wetland easement program. Program cost-effectiveness could be improved by setting easement payments closer to the expected returns of the individual parcel that applies. More land could then be put towards wetland easement, resulting in an increase in ecosystem benefits.

Identifying the extent of the selection effect adds to the literature that seeks to understand how easements impact land value and vice versa. Many papers on easements quantify how property restrictions affect land value. There are a number of studies that evaluate the impact of easements on land sales prices and generally find a land discount on easement enrolled lands (Brown 1976; Shoemaker 1989; Nickerson and Lynch 2001; Shultz and Taff 2004; Kousky and Walls 2014; Lawley and Towe 2014). For instance, Anderson et al. (2008) identify a price discount of 35-50% on fields with easements in Wisconsin. However, Richardson et al. (2022) find that wetland restorations actually increase nearby property values by 6-10% in Arkansas. My approach looks beyond land sales and instead focuses on the flow of profits (or lack thereof) that can be derived from the land. Studying yields and quantifying the value of easements through that income channel provides an alternative measure of the land value and right to crop.

Another vein of the easement literature analyzes the incentives for putting land into conservation, as well as resulting landowner benefits. Parker (2004) finds that land is conserved through easements when transaction costs are low and gains from landowner specialization are high. Conservation easements, especially from private land trusts, have outpaced the more traditional acquisition of land outright, since they allow more value to be extracted from the land (Parker and Thurman 2019). The divided ownership contract allows for the conservation of environmental amenities while allowing landowners to benefit from the land (primarily through recreation, hunting, and fishing). Another key benefit of easements for landowners is the savings on income taxes from reduced land value (Parker and Thurman 2018). Anderson and King (2004) find that the most important drivers behind conserving land are private benefits rather than the desire to provide a public

good. The prior easement literature has mostly focused on identifying private landowner effects. My work emphasizes public benefits of the wetland easement programs by quantifying their unintended consequences.

Specifically, I estimate the ecosystem benefits of wetland easements on surrouding agricultural fields. Wetlands are unique ecosystems with the potential to alter the water availability and flood damages of crops in surrouding areas. To the extent the farmer owns surrounding land, this benefit helps make up for the foregone crop income from the easement. To the extent this land is owned by others, it is a positive externality and presumably part (but not all) of the social benefit that the program is paying for.

This work complements the ecosystem benefits literature that quantifies the impact of conserved habitats in regards to flood attenuation. Kousky and Walls (2014) find that buffers of forested land and green space can help communities avoid flood damages in residential areas, especially in the face of climate change. Floodplain restoration mitigates residential flood damages, particularly during hurricane events (Watson et al. 2016; Gourevitch et al. 2020). Brody et al. (2007) study how the lack of natural infrastructure due to increased residential development exacerbates flooding in watersheds along the coast. More recently, Taylor and Druckenmiller (2022) estimate that the loss of a hectare of wetland costs between $1,840-$8,000 in flood insurance losses. My paper provides an alternative estimate of the flood mitigation benefits of wetlands in a rural setting.

There is another branch of literature that analyzes how nature-based solutions can improve agricultural landscapes. Schulte et al. (2017) calculate the ecosystem benefits of prairie strips on corn and soybean lands with a small loss in yields. Needelman et al. (2007) study how drainage ditches provide a solution to flooding, similar to that provided by wetlands, by removing surface water during flood events and lowering water tables between events to reduce crop stress. The Conservation Reserve Program also plays a role in restoring floodplains and reducing flood risk. In a simulation study in Iowa and Missouri, Jobe et al. (2018) find that CRP acreage reduces flood velocities and potential damages. In my previous work (Karwowski 2022), I find evidence that easements increase average yields and decrease losses from excess moisture, disease and pests; I also find evidence suggesting that a spillover effect exists beyond the field with easement. In this paper using field-level data, I am able to identify when and where these indirect effects occur. The knowledge that wetland easements impact the yields and risk of surrouding lands can be integrated into Risk Management Agency insurance rate setting policies to account for this externality.

Lastly, this paper leverages satellite data to highlight the regions and fields in which wetland easements procure the most beneficial agricultural spillovers. I identify the mechanisms through which the agricultural ecosystem benefits are heightened and dampened thanks to the abundance of satellite data available on land

use, weather, and soil characteristics. I find that areas with higher proportions of open water and open fields experience larger spillovers, especially during heavy rainfall periods. Prioritizing easements in these types of environments may increase future ecosystem benefits.

An absence of available data on crop yields at the field level have made this type of program evaluation difficult. Remote sensed data has allowed for a large scale impact evaluation of the wetland conservation programs. Recently, researchers have turned to satellite Landsat data to estimate crop yields, damages, field health, and recovery rates (Di et al. 2017; Tapia-Silva et al. 2011; Kang and Özdoğan 2019). Only a handful of economists have used satellite data to understand how innovations impact field productivity (Jain et al. 2019; Burke and Lobell 2017). My work will allow us to not only better understand the heterogeneity of easement agricultural spillovers, but exemplify how to use satellite data to analyze land-use policy.

This work is timely considering recent land conservation efforts. To mitigate the effects of climate change, 95 countries worldwide agreed to conserve 30% of the Earth's lands and oceans by 2030. In January 2021, the US initiated federal efforts to achieve the"30 by 30" initiative. The Inflation Reduction Act dedicated billions towards agricultural conservation in the next decade. Understanding the costs and benefits of wetland restoration to the agricultural sector will allow for more effective conservation pricing, selection, and public good.

The remainder of this paper is organized as follows. Section 2 provides background on the wetland easement programs as well as some insights into how wetlands alter flood and water patterns. I lay out a theoretical framework in section 3 that considers the optimal price of easements. In section 4, I discuss the empirical strategy and describe the models and assumptions in detail. Section 5 provides an overview of the data. Section 6 discusses results while section 7 concludes. Figures and results are compiled at the end of the paper.

2 Background

2.1 Water, Crops, and Wetlands

Flooding is one of the most damaging and costly natural disasters both in the US and globally, especially for agricultural systems (Watson et al. 2016). Flooding occurs when water exceeds the capacity of its channel network and inundates nearby areas (O'Connell et al. 2007). Excess precipitation decreases commodity

yields (Perry et al. 2020) and reduces land value (Hodge 2021). Flooding has led to billions of dollars in crop insurance indemnities from failed planting as well as delayed planting (Boyer et al. 2022). Many of these agricultural flood losses occur in the eastern half of the United States on wetlands that have been converted to croplands.

It is commonly touted that wetlands have the potential to serve as flood protection by storing water and acting as natural buffers. Wetlands have "sponge-like" capabilities that store water during wet periods and release water during dry periods. However, digging deeper into the hydrological literature presents limited evidence of a generalizable wetland effect on flooding (Acreman and Holden 2013). There is substantial heterogeneity in flood mitigation potential, depending on wetland type, topography, location, vegetation cover, slope, soil characteristics, saturation conditions, rainfall, and management. In a review of literature, Bullock and Acreman (2003) indicate that 80% of studies find evidence that wetlands reduce flooding, while 40% of studies actually find evidence that wetlands increase flooding.

How can floods be altered by wetlands? Wetlands can influence the rate of rise of floodwater, lag time between rainfall and flood peak, flood peak levels, and total volume of water (Acreman and Holden 2013). Wetland hollows, or depressions, may offer water storage that reduces peak flows and the resulting volume of flood waters downstream. Wetland soils can also store excess precipitation and slow the rate of water flow under the surface. However, if the wetland hollows are full and its soils are already saturated, then wetlands will not store water but instead act as sources of flood runoff. They will increase water flow, enable the rapid transfer of water downstream, increase the size of the flood, and reduce the time between rainfall and flood peak. Vegetation also have an influence on the degree of flood attenuation. Wetland vegetation, especially trees and shrubs, provides natural friction that decreases the speed of floodwaters (Harvey et al. 2009; Thomas and Nisbet 2007). In sum, wetlands impact the pathways and availability of water on surrounding lands that affects crop productivity.

There are a few ecological and hydrological studies that evaluate the effects of restored wetlands. Sonnier et al. (2018) examine two NRCS restored wetland easements in central Florida, dubbed the South Marsh and East Marsh. After restoration, the South Marsh exhibited a significant increase in the number of flooded days per year and the median water table. Notably, areas outside of the East Marsh easement experienced fewer flooded days per year and a lower water table, suggesting that the easement retained surface flow that would have flooded adjacent pastures prior to restoration. A main goal of USDA restoration programs is to avoid off-site impacts; yet, this does not always seem to be the case. Acreman and Holden (2013) point out that hydrological effects may not appear within a few years of restoration due to the initial degradation of

the wetland structure during drainage. The absence of long-run monitoring systems has led to a gap in our understanding of long-run restoration effects (Acreman and Holden 2013; Holden et al. 2011).

2.2 Wetland Policy

There is a long history of wetland drainage in the United States, dating back to colonial America (Dahl and Al Lord 1982). In the early 1600s, the area that we recognize as the contiguous US encompassed over 215 million acres of wetland. Of those original wetlands, only 100 million acres remain today (Tiner 1984; McCorvie and Lant 1993). Wetlands were often regarded as inconveniences —impeding travel, development, and production. As technological advances such as dredges, plows, rakes, and cultivators expanded, wetlands were drained and converted into productive agricultural lands. Rapid population growth and increased food demand accelerated wetland destruction. The Swampland Acts of 1849, 1850, and 1960 granted large amounts of federal lands to states if they spurred drainage of wetlands for settlement (Edwards and Thurman 2022). Edwards and Thurman (2022) estimate that drainage resulted in a 13-30% increase in agricultural land values, totaling $7-17 billion USD (2020 dollars). It was not until the second half of the 20th century that the perception around wetlands changed. Protections were put in place to disincentivize the destruction of wetlands and efforts were put forth to protect these valuable ecosystems.

The Clean Water Act of 1972 limited development on wetlands. Section 404 of the Clean Water Act required authorization from the Army Corps of Engineers to dredge or fill wetlands for real estate, water resource projects, infrastructure, mining, or industrial activities. For unavoidable impacts, compensatory mitigation was required to replace the loss of the wetland in the watershed. However, the Sackett vs. EPA ruling (2023) changed wetland federal protection: only wetlands that directly adjoin navigable bodies of water became eligible for Clean Water Act Protection.

In an effort to reduce wetland degradation and loss in an agricultural setting, the federal government enacted the Swampbuster provision as part of the Food Security Act of 1985. This provision dissuaded producers from draining land. The provision did not protect all wetlands from farming (wetlands that had already been drained were exempt); rather, it prevented the conversion of wetlands into workable cropland through draining, dredging, filling, or leveling (Gelso et al. 2008). Producers that drained wetlands were precluded from participating in any USDA program benefits, including loans, subsidies, crop insurance, and price support. Thereafter, the US began actively restoring degraded wetlands and even creating new ones through various wetland easement programs.

The NRCS aims to restore, enhance, and create wetlands through its wetland easement programs. The programs are funded through the Farm Bill but implemented at the state level. The state NRCS departments decide which lands to purchase and place under easement, and also restore and manage existing easements. In 1990, as part of the Food, Agriculture and Trade Act, the Wetland Reserve Program (WRP) was initiated to provide landowners with the incentive to restore farmed wetlands. The Emergency Wetland Reserve Program (EWRP) was authorized in 1993 to restore land in the Midwest after widespread flooding. The Emergency Watershed Protection Program-Floodplain Easement (EWPP-FPE) is a similar program that conserves floodplains in an effort to reduce flood losses. After 2014, the NRCS re-compiled its programs under the Wetland Reserve Easements component of the Agricultural Conservation Easement Program (ACEP-WRE). This paper analyzes all of these wetland easements programs.

Wetland restoration is a time-consuming process that can take years to complete. NRCS agents, not the landowner, are in charge of restoration. Undesired species (invasive species, nuisance species, and noxious species) are removed and desired species are planted. Efforts are made to restore the soil conditions and hydric functions to support the growth of wetland vegetation. Structures that impede water flow such as diversions, dikes, and levees are dislodged. The drainage patterns are modified to restore stream connectivity and restore the wetland hydrology. A central goal of the wetland restoration is to create a habitat that supports the native bird, fish, and wildlife species.

The easements subsidize producers while also providing a public good. Under easements, producers voluntarily limit future use of the land while retaining ownership. An easement is a permanent contract in which the producer sells their right to farm and develop on the easement enrolled land. The producer controls access, conveys title, and retains the rights to quiet enjoyment, undeveloped recreational uses, subsurface resources, and water. The landowner is paid based on an appraisal, or, more often, the geographical area rate cap (GARC). The GARC increased steadily from \$800/acre to \$5,190/acre in Wisconsin from 1990 to 2021. In the period of interest for this study, from 2010-2019, the average GARC was \$4,371. The payment to the landowner is the same regardless of the land quality.

To be eligible for easement, certain criteria need to be met by the participant and the land. Eligible fields must be on private land, owned by the applicant for at least seven years, and have the potential to be restored. The land needs to be one of the following: farmed or converted wetlands, croplands subject to flooding, riparian areas that link wetland areas, or adjacent lands that present ecological benefits. The landowner's adjusted gross income must be below \$1 million USD.[2] Landowners submit applications to their

[2]This threshold does not exclude many farmers from the program. Based on the Agricultural Resource Management Survey (ARMS), the average income for Wisconsin farm operators was \$98,353 in 2016-2020 and only 7% of farmers had sales above

nearest Farm Service Agency for specific fields to be considered for easement projects. Farmers may enroll for multiple different reasons: they are tired of constant flooding on their fields, they find themselves in debt, they hope to retire, or they find that alternative adaptation measures to continue production are expensive (for instance, buying new tiling on a field to reduce flooding can be very costly).

Typically, the Wisconsin NRCS department receives 50-200 applications each year. The NRCS then scores and ranks applicant parcels on a variety of attributes. The criteria are laid out in detail in the data section of this paper. The ranking sheet was pre-approved by a state technical committee that included input from farmers, nonprofits, and public forums. States were in charge of their own ranking systems until 2020, when the ranking became centralized at the national level.

After ranking, the state NRCS department chooses the highest-ranked applicant parcels to participate in the easement program. The number of projects and acres that are selected depends on the budget. Some projects are rejected because they do not meet the program intent or goals; often, these parcels are on forested land rather than floodplain or wetland. The NRCS chooses applicants that are ranked highest and continues down the list until funding for projects runs out. Sometimes, they skip a certain project and move to the next one, depending on the project costs and their budget.

The NRCS then presents the farmer with the price that they will pay for the easement. This price is usually equal to the geographical area rate cap, but it can also be decided by a land appraisal or landowner offer. The farmer has three options after receiving notice of acceptance in the program: (1) they can enroll in the easement program, (2) they can cancel and withdraw from the process, or (3) they can defer their application to a future period and re-apply. Some producers decide not to sign the contract because the payment is too low. Other times, potential easement applicants drop out after the parcel changes ownership or the land becomes protected under a different conservation agreement. There are also cases where the land is deemed ineligible after the farmer accepts the offer; for example, access rights to the land are limited because of pre-existing utility or railroad contracts on the land.

Applications that are not selected roll over to the next application period and can be selected in the future. Applicants that are not selected in a certain year often keep their application active and continue to roll it over in future sign-ups. Based on interviews with policy directors, it is most often the case that farmers continue to crop on the land if they are not selected. Enrolling land in easement means that producers forgo future potential profits on that land from planting crops.

$500,000 (Deller 2022).

3 Analytical Model

Farmer's problem

I develop a theoretical model to draw intuition about easement implementation and optimal NRCS pricing strategy. This model considers the decision-making processes for a representative farmer and conservation agent. The farmer is a rational agent that chooses whether to leave their field in agricultural production or enroll in the easement program. The conservation agent chooses which land to place under easement and sets the price of easements. The conservation agent's goal is to maximize the environmental benefits of the land. I compare the current pricing strategy of the conservation agent with a price discrimination strategy to show the additional value that the conservation agent could gain. I also add to the model by considering the spillover impacts of easements on surrounding fields. This is a one-period model that does not consider leaving the land fallow, nor the option value of waiting to enroll in the program. For more comprehensive theoretical frameworks on the easement decision-making process, see Miao et al. (2016) for a discussion of option value and dynamics and see Parker and Thurman (2018) to consider the role of development income and tax benefits.

I start by considering land area L that is divided into field parcels l_i. Each field is the same size and $i = 1, 2, , ..., N$. In this scenario, each field is owned by one farmer. Each field differs in its agricultural yields (y_i), costs of planting (c_i), and potential environmental benefits (b_i). I assume there is one commodity type that can be produced and the price of the commodity p is determined by the market.

The farmer makes land use decisions that will maximize their profits. The farmer determines what to do with each field l_i and the decision for each field is independent of the other fields. The farmer can put field l_i into agricultural production ($e_i = 0$) or they can enroll the land in the easement program ($e_i = 1$). For each field in agriculture, the farmer makes a profit based on the commodity price (p), yield (y_i), and cost (c_i), where field-specific profits equal $py_i - c_i$. When a field is put into easement, the farmer receives a payment of r_i for retiring the land from agricultural production. The farmer chooses e_i={0,1} for each l_i to maximize profits. To solve the farmer's problem, I set up an unconstrained maximization problem and take a first-order condition.

$$max_{e_i=\{0,1\}} \ (py_i - c_i)(1 - e_i) + r_i e_i$$

$$[e_i] : py_i - c_i = r_i$$

$$e_i^f = \begin{cases} 1 & \text{if } py_i - c_i \leq r_i \\ 0 & \text{if } py_i - c_i > r_i \end{cases}$$

The farmer will ease field i when the retirement payment is greater than or equal to the agricultural profits of a field. When the retirement payment is less than the agricultural profits, the farmer will use the field for agricultural production. This model also informs us of the qualities of land that are more likely to be placed under easement. Land with lower yields and higher costs of planting are more likely to be put under easement. This highlights the selection bias of lower value land into the easement program.

Conservation agent's problem

The conservation agent maximizes environmental benefits subject to their budget constraint. These benefits are idiosyncratic to a field and can include potential ecological benefits such as reduced soil erosion, sequestered carbon, reduced greenhouse gases, wildlife habitat, wildlife diversity, and improved local water quality. The conservation agent chooses which fields to enroll $e_i = \{0, 1\}$, while simultaneously choosing the price to offer a farmer to retire that field r_i. The conservation agent is also subject to total budget T. I assume that the budget is positive $T > 0$ and that the conservation agent cannot exceed the budget $\sum_i^N r_i e_i \leq T$. I can write out the conservation agent's objective function as a constrained maximization problem.

$$max_{r_i, e_i = \{0,1\}} \sum_i^N b_i e_i + \lambda \sum_i^N (T - r_i e_i)$$

$$[e_i] : b_i = \lambda r_i$$

$$[r_i] : \lambda e_i = 0$$

$$[\lambda] : T = \sum_i^L r_i e_i$$

$$e_i^c = \begin{cases} 1 & \text{if } \frac{b_i}{r_i} \geq \lambda \\ 0 & \text{if } \frac{b_i}{r_i} < \lambda \end{cases}$$

The conservation agent will place an easement on field i when the benefit-to-cost ratio of that field exceeds the shadow price. The shadow price λ represents the marginal benefit of relaxing the budget constraint, or the associated change in environmental benefits when the budget is increased by one unit. The conservation agent will enroll the fields with the highest benefit-cost ratio first and will continue to enroll the most beneficial fields until the budget T is depleted.

What price r_i does the conservation agent set for each easement? The conservation agent wants to minimize the price offered for the easement while ensuring that the farmer will accept the retirement payment and ease the field. The farmer will not enroll a field unless the easement payment exceeds or equals the expected agricultural profits. The optimal solution would be for the conservation agent to set each $r_i = py_i - c_i$. Then, the conservation agent could rank fields by the benefit-to-cost ratio $\frac{b_i}{py_i - c_i}$ and enroll fields until the budget is exhausted.

$$e_i^* = \begin{cases} 1 & \text{if } \frac{b_i}{py_i - c_i} \geq \lambda \\ 0 & \text{if } \frac{b_i}{py_i - c_i} < \lambda \end{cases}$$

This model predicts that fields with ample environmental benefits and low agricultural productivity are the most likely to retire from agricultural production. The fields with high benefit-cost ratios will go into easement first. If the price of the commodity increases, then fields are less likely to be placed under easement because the opportunity cost is higher. Or, if the cost of production increases—for example, if the price of labor or other inputs increases—then more fields would enter the easement program.

However, the conservation agent does not set the price of easement equal to the field-specific forgone yields. It is most often the case that the easement payment is equal to the geographical area rate cap. This can be interpreted as the average land value in a county. The conservation agent sets the price equal to the average land value in L. I call this price $\bar{r}$. The conservation agent uses the average expected agricultural profits for all N fields to determine $\bar{r} = \frac{1}{N} \sum_i^N py_i - c_i$. When the conservation agent sets the price equal to the average expected profits of all the land, the fields that are below average in term of agricultural profits are the ones that will retire. The farmers derive a higher producer surplus since they would have been willing to accept a lower price. This also means that the budget will be depleted at a faster rate and fewer fields will be put under easement. This leads to lower total benefits for the conservation agent.

$$e_i^* = \begin{cases} 1 & \text{if } \frac{b_i}{\frac{1}{N} \sum_i^N py_i - c_i} \geq \lambda^* \\ 0 & \text{if } \frac{b_i}{\frac{1}{N} \sum_i^N py_i - c_i} < \lambda^* \end{cases}$$

Figure 1 translates the model to a graph format to juxtapose the conservation agent's pricing strategies. The left-hand side of the figure models the conservation agent's decision to set the retirement price equal to the average profits of all the land ($\bar{r}$). The right-hand side of the figure models a price discrimination strategy in which the agent sets the price of the easement equal to a specific field's forgone yields ($r_i = py_i - c_i$). The price discrimination strategy allows the conservation agent to acquire more easements and increase the total

ecological benefits for the same budget. When the price is set to $\bar{r}$, the producer surplus of the farmer is positive. When the price is equal to forgone yields, the producer surplus is driven down to zero. The price discrimination strategy allows the conservation agent to increase the total benefits of the program.

Considering spillover effects

The baseline model implicitly assumes that easement enrolled land does not impact surrounding agricultural fields. However, easements may impact nearby fields through their water-storing capacity. Restoring land into a wetland or floodplain changes the watershed topography and can lead to the easement acting as a "sink," where water pools onto the land with an easement. Excess water upstream from the easement, instead of pooling on agricultural lands, now streams to the restored wetland or floodplain. The easement could also impact flooding downstream by changing the rate of flow and volume of water on lands downstream of the easement. This upstream and downstream effect could change water availability and water pooling on surrounding croplands. This could lead to improved or worse yields on agricultural lands near easements. I expand the farmer's objective model by considering how easement spillover effects change the farmer's easement decision-making process.

In this version, the farmer owns more than one field. I model the spillover effect as spy_j, where $j \neq i$, $e_i = 1$, and s can be positive or negative. The spillover s represents the change in yields following wetland restoration due to changing hydrological conditions on surrounding lands. The spy_j term represents changes in profits from the spillover effects. Since the farmer is considering the fields they own, the farmer internalizes this spillover effect. These yield spillovers may change the number of fields that enroll in easement if s is large enough. I assume that easements do not impact the costs of producing on other fields.[3] Here, I model the farmer's problem and consider how the decision to ease field i is influenced by spillover effects on surrounding croplands j.

$$max_{e_i=\{0,1\}} \underbrace{(py_i - c_i)(1-e_i) + r_i e_i}_{\text{objective for field i}} + \underbrace{\sum_{j\neq i}^{n<N} (py_j + spy_j - c_j)(1-e_j)e_i + \sum_{j\neq i}^{n<N} r_j e_j}_{\text{spillover effect of field i on j}}$$

$$[e_i] : py_i - c_i = r_i + \sum_{j\neq i}^{n<N} (py_j + spy_j - c_j)(1-e_j)$$

$$e_i^s = \begin{cases} 1 & \text{if } py_i - c_i \leq r_i + \sum_{j\neq i}^{n<N} (py_j + spy_j - c_j)(1-e_j) \\ 0 & \text{if } py_i - c_i > r_i + \sum_{j\neq i}^{n<N} (py_j + spy_j - c_j)(1-e_j) \end{cases}$$

[3] I abstract away from potential cases in which adding an easement increases the cost of accessing neighboring fields, for example.

When the farmer takes into account the spillover effects of easements, their easement threshold changes. If there are zero spillovers, then the equations revert back to the original solution. If the spillover effect is positive ($s > 0$), then easement enrollment is more likely. If the spillover effect is negative, then the farmer is less likely to enroll fields into the easement program. If the spillover exists on fields that are not owned by the farmer who is considering the easement, the spillover effects become externalities.

4 Data and Descriptive Statistics

I compile data from a wide array of sources to build a panel data set. I aggregate pixel-level data with 30x30 meter resolution to the field level. My panel spans from 2010-2019. The panel has yearly field-level observations that represent the time frame from April to October (the main growing season). Summary statistics are displayed in Table 1 and 2.

a. The **Common Land Unit** database delineates fields with common owners, land uses, and land cover. The Common Land Unit (CLU) is described as an individual contiguous farming parcel by the USDA and is used by its agencies. The CLU is the smallest unit of land that has a permanent boundary. The shapefiles are provided by Geocommunity and represent 2008 borders. These shapefiles are cleaned to account for geospatial anomalies. Only CLUs with at least 10 acres of land are in the sample of interest. My main unit of analysis is at the common land unit level.

b. The **NRCS Easements Database** is the source for all the information on wetland restoration easements. The data spans from program inception in 1992 to 2020. Variables include program type, total acres enrolled, cropland acres enrolled, costs, and key dates in the process. The geospatial data identifying the easement locations are in a separate shape file; these are merged with the administrative data. In Wisconsin as of 2020, there were 694 easement projects of interest. These include easements in the ACEP-WRE program (35), EWPP-FPE (43), and WRP (616). Easements in Wisconsin cover 58 of the 72 counties. The acreage of easements within each county is shown in Figure 2. I exclude the counties that contain no easements in my analyses.

I overlay the common land unit shapefile with the easement shapefile to create easement treatment for each common land unit. If there is no easement on a field, easement treatment is 0 for that field. I create easement treatment variables that depend on the proportion of a field within the easement. I look at the effect of having at least 50% of a field in easement ($Easement > 50\%$). Figure 3 shows how easements can cover

multiple fields and are often clustered together.

I also calculate the distance to the nearest easement for each common land unit within 40 kilometers. I use the centroid of the easement (not the fields with easement) and the centroid of the fields to calculate the distance of each field from its nearest easement. Figures 4 and 5 exemplifies the spatial extent of the easements and surrounding common land units in Avon and Burlington within 3 kilometers.

c. The **NRCS Easement Application Data** was provided by the Wisconsin state NRCS department in the form of an Application Detail Report. I was provided with the applicants that applied to the ACEP-WRE and WRP yearly from 2008-2021 as well as the 2009 and 2019 FPE applicants. The applicant observations that I kept in my applicant data subset include applicant statuses that were labeled as Canceled, Deferred, Draft, Eligible, Pending, or Archived. I also restricted my sample to observations that had valid latitudes and longitudes. I drop the observations that provide the same latitude and longitude for easement applications with different owners. I match applicant latitudes and longitudes with common land unit fields since applicant shapefiles do not exist. This method is imperfect, since the latitude and longitude allow me to match with one common land unit, but not with all the common land unit fields that were considered for easement.[4]

d. **Wisconsin Easements Ranking Data** was provided by the state NRCS after I became an Earth Team Volunteer in 2019. There are 110 applicant fields that were never placed under easement that I use as a counterfactual group. I have detailed information on the ranking and attributes of the easement enrolled fields and applicant fields. Fields for the wetland easements program are ranked on the following criteria: 1) acres of eligible land, 2) drainage conditions of the land over the past 10 years, 3) portion of hydric land that will be wetter after restoration, 4) water depth in June, 5) presence of native community in need of restoration, such as a fen, prairie remnant, or glade, 6) protection of WI special concern species, 7) protection of WI-threatened or endangered species, 8) protection of federally threatened or endangered species, 9) watershed waterfowl habitat conservation priority, 10) other wetlands within a one-mile radius, 11) other wetlands within a 1/2 mile radius, 12) impairment of water quality within the watershed, 13) proximity of cropland that would drain into wetland, 14) restoration cost estimates, 15) easement purchasing cost estimates, 16) long-term maintenance requirements such as a berm or pipe, 17) easement duration, 18) proximity to other easements or protected land, and 19) clear title and no presence of hazardous materials that will undermine the easement. Scores are out of 200. Criteria details and weighting have changed over the decades but the

[4]There are also 15 cases in which an applicant applied to an easement program more than once with the same field (either in different years for the same program, for both the WRP and EWPP programs, or for the same program in the same year but with a different number of acres). If they applied to a program more than once, I keep the observation with more information. If they applied for both programs in the same year, I keep the application with more details (such as cost and ranking). If they applied for the same program in the same year with a different acreage amount, I keep the one with the larger acreage.

main priorities have remained constant.

e. **Crop Yield Data**, created by Kang and Özdoğan (2019), estimates crop yields at the pixel level. An example of the raw yield predictions are shown in Figure 6. A random forest algorithm predicts yields for both corn and soybean crops. The machine-learning algorithm provides yield predictions for a field whenever a pixel within the field is classified as corn or soybean by the Cropland Data Layer. Each yield prediction is based on bushels per acre planted. If a field is placed in easement, and that part of the field had previously been cropped, I assume that the production for that now easement enrolled land is 0. Field-level agricultural data with known yields, USDA county-level yield data, and remotely sensed variables are used to train and test the prediction model. The attributes used to make these predictions are based on the literature (Kang and Özdoğan 2019). The accuracy of field-level agricultural productivity estimates ranges from 85-95%.

To analyze the extent that the satellite predictions are accurate, I compare the predictions with other yield prediction sources and publicly available NASS data. Density plots that display the yield distribution of corn and soybeans for all the fields in the data are shown in Figure 7. A common feature in most yield density plots are long tails. This is a factor that the satellite data is unable to capture; a limitation of the prediction algorithm is that it poorly predicts the lowest and highest yields. An in-depth discussion of the differences between actual yield data and simulated yield data can be found in the following articles(Sabini et al. 2017; Khaki et al. 2021; Wang et al. 2018). Similar to the literature findings, it seems that the satellite data I use are consistently underpredicting yields. The timelines in Figure 8 show that the corn and soybean predicted yields follow the same trends as the NASS data but are routinely below the actual data. This data limitation could mean that my regression estimates are biased towards zero. However, the alternative of using the satellite data is to rely on county-level data that is unable to provide insights into how easements affect production at the field-level.

f. The other data sets that provide control variables include the USDA Cropland Data Layer (USDA National Agricultural Statistics Service 2022), USDA Web Soil Survey (Soil Survey Staff, Natural Resources Conservation Service 2022), and PRISM Climate Group (Oregon State University 2022). These are primarily used to explore the mechanisms through which easement spillover effects occur.

5 Empirical Strategy

A variety of econometric methods are used to quantify the productivity effects of wetland easements. I run separate models for each commodity type, corn and soybeans. Each method is tailored to the particular research question and scope of analysis. My standard errors are clustered at the sub-watershed level in every specification.

5.1 What are the forgone yields of easements?

My first goal is to understand the direct field effects (i.e. what yields would have occurred had that particular field not been placed under easement). Enrolling land in easement mechanically decreases yields for that field since producers are no longer able to crop there. I focus on predicting forgone yields of the easement and determining whether producers would have gained profits on a field had it not been placed under easement. There are two counterfactual control groups that I investigate: all the cropped fields in Wisconsin that are at least 10 acres, and the applicant easement fields that were not selected into the program.

I uncover the direct effect of easements while dealing with the selection issue. It has been difficult to establish a causal estimate of easement effects due to the selection bias in easement program enrollment. The landowners that choose to apply for an easement and are selected into the programs are not random. Producers that are more likely to put land into easement favor conservation, believe that wetlands benefit farm operations, and oppose draining other wetlands for agricultural production (Wachenheim et al. 2019). The selected easement fields also differ from the average farmland parcel. Easement enrolled fields have higher flood risk, poorer soil quality, and are located in floodplains near other easements and protected land. To try and deal with the selection issue, I use a difference-in-differences and regression discontinuity approach with applicant data to identify the causal direct effect.

5.1.1 Difference-in-differences

I use a difference-in-differences framework to identify the treatment effect of a wetland easement on own-field yields. The identifying assumption is that, after accounting for unit-specific and time-specific fixed effects, there are parallel trends for the yield outcomes of the treated units and control units. With the difference-in-differences approach, I use variation within fields to identify the impact of easements. My two-way fixed effects model looks at how $Easement_{it}$ treatment impacts yields at the yearly field level for

each commodity, Y_{it}. I include relevant control variables X_{it}, field fixed effects α_i, and year fixed effects δ_t. The included control variables are the precipitation levels, max temperature during the growing season, and extreme degree days from June, July and August.

$$Y_{it} = \beta Easement_{it} + \Gamma X_{it} + \alpha_i + \delta_t + \epsilon_{it} \tag{1}$$

5.1.2 Regression Discontinuity

To recover a causal estimate, my preferred specification is a Regression Discontinuity (RD) approach. The ranking process of easements lends itself to finding the Local Average Treatment Effect (LATE) through RD. I compare the easement fields that were funded before the budget cutoff was reached to those that were not funded because of the cutoff. This is much in the same spirit as the Greenstone and Gallagher (2008) study of Superfund sites. Their design is almost identical—the fund varies year to year, and sites are ranked. The top-ranked site gets priority and the conservation agent proceeds down the list until the budget is exhausted. The observations at the threshold will be comparable and would have had believably similar success in terms of easement impact and quality. I assume that the relationship between easement ranking and potential benefits from the easement does not vary discontinuously across the threshold. The underlying identifying assumptions are that 1) there is exogenous variation in treatment assignment at the threshold and 2) the applicant cannot change the ranking variable in a way that changes their treatment status.

Because of ranking data availability, I am only able to use 2013 and 2015 applicants and easements for this approach. There is a sharp cutoff for 2013 applicants at 70 points and for 2015 applicants at 60 points. I pool these two groups into one data set by normalizing the cutoff point to 0 to run a cumulative analysis. I estimate the treatment effect of easements by comparing the yields of the applicant and enrolled fields after the wetland easement has been restored. I assume that the restoration date for applicant fields is two years after the application date (the average time between application and restoration in this sample).

I implement the RD according to the best practice guide by Lee and Lemieux (2010). The outcome variables of interest continue to be yields for corn and soybean for a field. On the right-hand side of my equation, I include the ranking of each field (the running variable) in the year of application, less the cutoff, $Ranking_{it} - C_t$. Fields that are considered treated in this specification are those with rankings greater than the cutoff. Fields with rankings that are less than the cutoff are in the control group. The cutoff for each year is different and I define it as C_t. The probability of treatment changes from 0 to 1 at and beyond this threshold ranking.

The treatment variable of interest, $Easement_{it}$, represents the easement projects above the ranking cutoff.

$$Easement_{it} = \begin{cases} 0 & \text{if } Ranking_{it} \leq C_t \\ 1 & \text{if } Ranking_{it} \geq C_t \end{cases}$$

$$Y_{it} = \alpha_l + \beta Easement_{it} + f(Ranking_{it} - C_t) + \Gamma X_{it} + \epsilon_{it} \tag{2}$$

Essentially, the RD approach compares the untreated observations on the left side of the cutoff (l) with the treated observations on the right side of the cutoff (r). The treatment effect β captures the difference between the two intercepts at the cutoff point $\alpha_r - \alpha_l$. It is also considered best practice to include an interaction term between the treatment variable and the running variable to allow the regression function and slope to differ on both sides of the cutoff. I include the same control variables as in the difference-in-differences model as well a year variable to allow for general yield trends over time.

$$Y_{it} = \alpha_l + \beta Easement_{it} + \rho(Ranking_{it} - c_t) + \Gamma X_{it} + \epsilon_{it}$$

$$Y_{it} = \alpha_l + \beta Easement_{it} + \rho(Ranking_{it} - c_t) + \lambda Easement_{it} * (Ranking_{it} - c_t) + \Gamma X_{it} + \epsilon_{it}$$

The optimal bandwidth is derived using the data-driven Imbens and Kalyanaraman (2012) method which minimizes the mean-square error of the model. The optimal bandwidth is 20 for the corn data and 10 for the soybean data. I try a variety of alternate bandwidth specifications for robustness to check for results sensitivity.

5.2 What are the spillover effects of easements?

The second main research question asks how easements impact surrounding production. The hydrological literature and farmer anecdotes suggest that wetlands play a role in mitigating flood damages on surrounding lands. It is also possible that a wetland easement could increase flooding and reduce yields in adjacent fields, depending on its design. This ambiguity leads me to analyze how surrounding fields' agricultural yields change after wetland easement implementation.

5.2.1 Dynamic difference-in-differences

I analyze how wetland easements impact surrounding field yields using a dynamic difference-in-differences strategy. The main identifying assumption is that the treated and control units have parallel trends. Control groups vary from all cropped fields to not-yet-treated easement neighbors. Since it is likely that a nearby field has a different owner, neighboring easement treatment is reasonably exogenous. A field is considered treated in the periods following an easement restoration within a certain distance. I look at fields that are 1, 3, and 10 km from the restored easement. I use the period prior to treatment (-1) as the reference year.

$$Y_{it} = \sum_{\tau=-4}^{\tau=8} \beta_\tau EasementNearby_{i\tau} + \Gamma X_{it} + \alpha_i + \delta_t + \epsilon_{it} \tag{3}$$

I prefer an dynamic approach when looking at spillover effects because wetland easements can take a few years to integrate into the local ecosystem. Importantly, I make sure to account for common difference-in-differences problems that have recently been brought to the forefront of the econometric literature (Goodman-Bacon 2018; Callaway and Sant'Anna 2021; De Chaisemartin et al. 2019). The biggest criticism of a difference-in-differences design with staggered treatment timing is that the estimate does not represent the average treatment effect. Because of variation in treatment timing, the effect may be decomposed into the average treatment effect plus the bias from differential time trends (Goodman-Bacon 2018). Callaway and Sant'Anna (2021) discuss how traditional staggered difference-in-difference models that include post-treated outcomes in the control groups lead to biased coefficients. Therefore, I employ the Sun and Abraham (2021) specification to estimate dynamic treatment effects. This allows for calculation of heterogeneous treatment effects across different cohorts of treatment, allowing for staggered treatment designs. The control group is defined as unit-years that are "never treated" or "not yet treated".

5.2.2 Mechanisms

Finally, I explore the mechanisms driving the easement spillover effects. I calculate the acres of restored wetland easements in each sub-watershed h at the end of each year. Then, I interact the sub-watershed wetland easement acreage with a variety of different mechanisms that I hypothesize will impact how wetland easements affect yields. The mechanisms I explore include land use in the sub-watershed, field monthly precipitation levels, field soil characteristics, and field flood class. In this model, I again include field and year fixed effects to allow me to identify the coefficients of interest using within-unit variation after controlling

for common time trends.

$$Y_{it} = \omega EasementAcres_{ih} + \beta EasementAcres_{iht} * Mechanism_{it} + \Gamma X_{it} + \alpha_i + \delta_t + \epsilon_{it} \quad (4)$$

6 Results

6.1 Own-field yield effects

This section examines how wetland restoration impacts the corn and soybean yields on fields that obtain the easement. Of course, easing a field by definition means that producers are no longer allowed to crop the sections of the field under easement. Here, I identify the magnitude of the yield losses from the program.

Table 3 and 4 review the difference-in-differences results that estimate how wetland easements affect own-field yields for corn and soybeans respectively. Columns 1-3 include all of the cropped fields in Wisconsin as the control group while columns 4-6 limit the control group to fields that applied to the easement program. Applicant fields have very similar production outcomes and land characteristics to enrolled fields so the results for this sub-sample are preferable. I find that easement treatment consistently decreases yields for a field, as expected.

First, columns 1 and 4 show the average difference in mean yield between fields post-easement and untreated fields after accounting for changes in weather patterns. For corn, fields that enroll see 90 fewer bushels per acre compared to average Wisconsin croplands. Compared to their applicant counterparts, fields with easements have 68 fewer bushels per acre. For soybean crops, enrolled fields see 31 fewer bushels per acre compared to all fields in Wisconsin and 24 bushels per acre fewer compared to applicant fields.

Second, I apply the traditional difference-in-differences model by including two-way fixed effects to leverage variation within a field to identify the easement treatment effect. I evaluate how easement treatment affects yields after controlling for observable and unobservable trends at the field and year level. This provides a more plausible causal effect. I find that easement corn yields are 84 bushels lower in the difference-in-difference models with all fields and 61-66 bushels per acre lower in the model with applicants. Soybean yields are 28-29 bushels lower for fields post-easement compared to all fields and 21-24 bushels per acre lower compared to applicant fields. The results remain consistent when using the Sun & Abraham difference-in-differences model to account for the staggered treatment timing.

Further, the ranking discontinuity results are displayed graphically in 9. Tables 5 and 6 present the local average treatment effect from the regression discontinuity models. The RD results are quite similar to the difference-in-differences results. The RD picks up a local average treatment effect, which is relevant for a smaller population than the average effect of the difference-in-differences model; however, it is more plausibly causal.

The easement treatment effect for corn yields ranges from 77-95 bushels per acre. As the bandwidth around the cutoff decreases, the treatment effect decreases in magnitude as well. The easement treatment effect is 95 bushels per acre when considering all applicants, 83 bushels per acre with a bandwidth of 20, 78 bushels per acre with a bandwidth of 10, and 77 bushels per acre with a bandwidth of 5. Fields that are farther from the threshold are more productive than the fields that are nearer to the threshold that have a higher probability of being selected into the program. The optimal bandwidth for the corn model is 20 points around the cutoff according to the Imbens and Kalyanaraman (2012) selection process. Excluding the easements with rankings furthest from the cutoff ensures that the counterfactual control fields are similar to the easements on the margin. The larger bandwidth increases the observations in the sample, which allows for more variation to identify the easement effect.

Interestingly, the RD results for soybeans remain consistent across different bandwidth options. Easements on a field reduce yields by 29 bushels per acre (bandwidth of 110), 30 bushels per acre (bandwidth of 20), 31 bushels per acre (bandwidth of 10), and 30 bushels per acre (bandwidth of 5). In my preferred model with a bandwidth of 10, easement treatment decreases yields by 31 bushels per acre.

This analysis of own-field effects informs us of what yields would look like on a field if an easement had not been placed there. The preferred DID estimates using the Sun & Abrahams estimator and the applicant data are -66 bushels per acre for corn and -25 for soybeans. The optimal RD models estimate forgone yields of -83 bushels per acre of corn and -31 for soybeans. These estimates are far smaller in magnitude than the average field yields of 143 bushels per acre for corn and 42 bushels per acre for soybeans. Would a producer plant on a field with such marginal yields? My analysis does not include outside revenue for the producer in terms of insurance payments and government subsidies. The moral hazard incited by these support programs make it plausible that a producer would continue to plant on a field even if yields were low.

Next, I conduct a quick back-of-the-envelope calculation to identify a valid easement price based on the forgone yield estimates. Table 7 uses the yield estimates and data from the USDA Economic Research Service Commodity Costs and Returns to calculate alternative prices to offer producers for easements. I calculate the present value of expected agricultural profits on a per acre basis. I use the commodity price

per bushel average from 2010-2019 as well as the average operating costs in the Northern Crescent (which includes Wisconsin) to estimate profits. I then find the present value of the agricultural profits in perpetuity with an interest rate of 5%. When using the average yields of 143 for corn and 42 for soybeans, I find the present value of production to be around $5,500 for both commodities.

In a like manner, I calculate the present value of the estimated forgone yields. I use the estimates from my Sun & Abraham applicant model and my optimal RD model to calculate the present value of the forgone yields. Using the Sun & Abraham estimates, I find a present value of -$1,137 per acre of corn and $1,884 per acre of soybeans. Using the RD results, I estimate a present value of $283 per acre of corn and $3,283 per acre of soybeans. My results suggest that conservation agents are paying more for easements than is socially optimal. The average payment of an easement is $4,000 per acre. My estimates suggest that forgone profits from easements are much lower. One limitation with this approach is assuming that costs are consistent for all fields. Profits may be higher on marginal lands if producers spend less resources and labor on planting on lower-yielding lands.

6.2 Surrounding field yield effects

Additionally, I explore the spillover effects of easements using an dynamic difference-in-differences framework. I not only use the standard difference-in-differences specification, I also employ the Sun & Abraham and Callaway & Sant'Anna estimators to correct for staggered treatment timing. The Sun & Abraham estimator uses never-treated fields that are beyond the indicated buffer, as does the standard difference-in-difference model. However, the Sun & Abraham estimator ensures that fields that are treated earlier are not in the control group for units that are treated later. The Callaway & Sant'Anna estimator controls for staggered timing and also limits the sample to fields that were treated at any point in time. Fields that are treated in later periods (or not yet treated) are used as the control group for earlier-treated fields.

I begin by looking for yield spillovers on fields within 1 km of an easement. Table 8 displays the results for corn and Table 9 does so for soybeans. The periods before treatment show no evidence of pre-trends for corn yields within a 1 km buffer of restored easements across all three specifications. There is also no significant effect of easements in the first three periods post-restoration. However, periods 4, 6, 7, and 8 find significant increases in surrouding corn yields when using the standard difference-in-differences and Sun & Abraham specification. There are increases in corn yields ranging from 2-5 additional bushels per acre. Column 3 finds no evidence of spillover effects when limiting the control to not-yet treated fields.

Easement effects on surrounding soybean yields do not follow the same pattern as corn yields. It seems that neighboring soybean yields are insignificantly impacted by easements, or even slightly negatively affected. According to the standard difference-in-differences and Sun & Abraham columns, soybean yields within 1 km of easement see decreases in yields of 0.5-0.7 bushels per acre the year of restoration. Soybean yields in periods 2, 4, 5, and 6 in the 1 km buffer of easements are approximately a bushel per acre lower. Wetland easements seem to decrease surrouding soybean yields by a small amount.

Next, I examine the yield spillovers within a 3 km buffer of a restored easement in Tables 10 and 11. The standard difference-in-differences suggests that, during the first few years after restoration, easements have an insignificant effect on nearby corn yields. The exception occurs in period 0, which shows a small negative corn yield effect of -1.7 bushels per acre. After these initial years, easements seem to have a positive impact of between 2 and 5 additional bushels per acre on neighboring corn fields. The Sun & Abraham model shows similar patterns but slightly higher improved corn yields. The Callaway & Sant'Anna coefficients show an insignificant effect of easements on neighboring fields in periods 0-4. Period 5 sees an significant increase in yields by 2.7 bushels per acre. The coefficient hovers around an additional 3 bushels per acre for periods 6-8 but becomes insignificant.

For soybean fields within 3 km, the standard difference-in-differences shows that yields decrease by a minimal amount, or are not significantly impacted by easements. Periods 0, 2, 4, and 5 find small decreases in soybean yield—around half a bushel per acre. The Sun & Abraham coefficients seem attenuated toward zero in most cases and a few of the period coefficients lose their significance. The model using the Callaway & Sant'Anna estimator also finds insignificant yield effects.

Table 12 depicts the spillover effects of easements on corn fields within a 10 km buffer. Corn yields continue to follow a similar pattern of increases in yields post-restoration, but the magnitude of the spillovers becomes smaller suggesting that the effect diminishes by distance. Period 0 finds that corn yields are 2 bushels per acre lower in columns 1 and 2. Then, periods 4,6,7 and 8 finds evidence of yield increases ranging from 1.3-3.4 additional bushels per acre in the standard model. The Sun & Abraham estimator finds evidence of positive spillover effects between 1.2-4.3 bushels per acre. The Callaway and Sant'Anna coefficients suggest positive yield effects in periods 1, 4, 6 and 7 of around 2-4 bushels per acre as well. Corn fields that are within a 10 km buffer are still impacted by wetland easements.

Table 13 provides some evidence that surrounding soybean yields within a 10 km buffer also see mild decreases in yields. The soybean yields are 0.3-0.5 bushels per acre lower in period 0 and 0.5-0.7 bushels per acre lower in period 5. The effects in this model are less significant than in the model that looks at fields within 1 and

3 km of easements. Unexpectedly, the periods before treatment show that soybean yields are 0.3-1 bushel per acre higher, especially in column 2.

To summarize, the evidence suggests that surrounding corn yields increase but soybean yields decrease after wetland easement restoration occurs nearby. These crops are affected differently by wetland easements. The agronomy literature seems to support these findings; there are differences in the development stages of these crops that lead to varying water tolerances. The differences in roots and pollination periods of these plants contribute to their different sensitivities to changes in water. Soybeans are generally more tolerant to flooding and drought. Corn plants tend to be more sensitive to these water extremes. These plant factors lend insights into why the crops are affected in different ways by wetland easements. Understanding the reason for these spillover yield effects could allow us to harness the potential of conservation to increase surrounding yields. In the following subsection, I further explore potential mechanisms.

6.3 Spillover effect mechanisms

To explore the pathways through which easements impact neighboring yields, I interact easement acreage in a sub-watershed by a number of different potential mechanisms. First, I explore the impact of the different Cropland Data Layer land use acres in a sub-watershed in Table 14. I find that lands with a higher proportion of crop land, fallow land, forage land, and open water lead to a heightened easement effect for corn. Areas with more open water will experience a larger hydrological effect. Soybeans are positively impacted by easements when there is a larger proportion of fallow and forage land. These lands often times resemble open fields, and may act similarly to floodplains. This could explain why they magnify the effect of wetlands easements.

Secondly, I look at the effect of wetland easements when interacted with monthly rainfall. The rainfall variables in Table 15 are in terms of 100 millimeters of precipitation in each month. [5] I find that easement effects are amplified when there is more rainfall in April, July, August, and September. Corn and soybean yields in April benefit from easements when there is more rain; this could be because easements allow for producers to plant earlier in the season and avoid incidences of prevented planting. There is also evidence that shows that more rain in July and August reduce yields in areas with more wetland easements. This could be because easements absorb water that would be beneficial to nearby crops during the growing season. The coefficient for the interaction between easement acreage and September rainfall is significantly positive. Wetland easements may collect water during the harvest season, drying out crops, and increase the yields

[5] I also run a model that looks at extreme rain events in the top 10% of rainfall magnitude and find robust results.

for both corn and soybean crops.

Subsequently, I analyze the effect of wetland easements interacted with field-specific soil characteristics. There does seem to be some evidence showing that corn fields with a higher percentage of sand content are less impacted by wetland easements in the sub-watershed. Encouragingly, fields with a higher soil water content are more positively impacted by wetland easements. The soil water content represents that amount of moisture that soils hold after excess water is drained. Soils with a higher soil moisture content (more prone to being wet) will be more largely impacted by hydrological changes from wetland easements. These soil characteristics could be useful targeting criteria for future wetland easement restorations.

Finally, I use soil survey data to evaluate the effect of easements in watersheds with different flooding frequency classes. I find that the flooding frequency impacts wetland easement effects for both corn and soybean crops. Areas in the rare frequency class experience higher corn yields from wetland easements. Intuitively, this could be because areas without the capacity to handle flooding have the highest marginal benefit from wetland easements. On the other hand, areas with very frequent flooding see a larger negative impact from wetland easements. This could suggest that adding the wetlands to frequently flooded areas traps water in systems that would be better off if able to drain.

7 Concluding Thoughts

My research identifies the forgone yields of wetland easements and quantifies the spillover effects on surrouding cropland. I conduct this analysis at the field-level with novel remote-sensing estimates of yields at a 30x30 resolution (Kang and Özdoğan 2019). Applicant parcels serve as a plausible counterfactual for what yields would have looked like for fields that obtain wetland easements. I assume that neighboring easement status is exogenous when estimating the yield spillover effects of a wetland easement for fields within a 1 km, 3 km and 10 km buffer. I leverage exogenous variation in easement treatment and timing to causally identify the yield effects of wetland easements in Wisconsin from 2010-2019.

I identify the average treatment effect of wetland easements with a difference-in-differences estimator and a local average treatment effect with a regression discontinuity framework. The average treatment effect of the forgone yields for corn ranges from 61-84 bushels per acre and the local effect is similar at 83 bushels per acre. The average treatment effect for forgone soybean yields is 21-29 bushels per acre for fields with easements and the local average treatment effect is slightly larger at 31 bushels per acre. The value of an average

yielding field is approximately $5,000 per acre, a value that mirrors the price that landowners are paid to put land towards easement. However, calculations of the estimated forgone yields are consistently lower: expectations of per acre yield value for a field in easement range from -$1,000-$3,300. My findings suggest that program cost-effectiveness and greater ecosystem benefits could be achieved using a reverse-auction strategy that bases payments on actual opportunity costs.

Further, I examine how crop yields surrouding wetland easements are affected by restoration and the factors driving this relationship. I use a dynamic difference-in-difference specification to estimate how fields within a certain distance buffer are impacted by wetland easements over time. My findings suggest that wetland easements take a few years to have a significant effect on the surrouding area. Corn fields experience increases in yields of 2-5 additional bushels per acre. Fields within a 3 km buffer experience the largest gains. On the other hand, soybean fields experience small decreases in yields or are insignificantly impacted by wetland easements. I explore the mechanisms of these spillovers by examining the impact of easement acreage in a sub-watershed interacted with land use classification, monthly rainfall, and soil classification. Easements mitigate the effect of excess precipitation during growing and harvest seasons. Areas with a higher proportion of open water, higher soil water content, and with low flood risk seem to benefit the most from wetland easement spillovers. Understanding where flood mitigation ecosystem benefits occur may be helpful when targeting future wetland conservation efforts.

Highlighting the costs and benefits of wetland easements is useful for policy makers, conservation groups, and landowners looking to maximize ecosystem benefits on conserved land. This analysis exemplifies the value of nature-based conservation in improving agricultural productivity and resilience. The years 2010-2020 constituted the wettest decade to date in Wisconsin. Extreme weather events are expected to increase in frequency and severity. Building natural systems with the capacity to impact surrounding yields is a valid pathway toward increasing agricultural resiliency. I also showcase how satellite yield data can be used to evaluate the spillover effects of land-use policy to understand how agricultural stakeholders are influenced by conservation efforts. In the future, I hope to incorporate land ownership data to this analysis to better understand who is capturing these yield spillovers and determine whether a co-benefits coordination mechanism can be designed to more efficiently spread the costs and benefits of wetland easements.

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8 Appendix

Table 1: Summary statistics for fields by group

	Applicant	Easement	Neighbor	Other
Acres	101	48	35	38
	378	150	106	352
Corn yield (b/a)	143	95	147	142
	30	62	30	29
Soybean yield (b/a)	43	24	43	41
	7.7	20.0	7.9	7.7
Both crops planted	0.63	0.42	0.51	0.42
	0.48	0.49	0.50	0.49
Acres in wetland easement	0	259	0	0
	0	423	0	0
Ranking	19	74		
	33	12		
1 km buffer	0.093	0.380	0.044	0.000
	0.29	0.49	0.20	0.00
3 km buffer	0.20	0.44	0.19	0.00
	0.4	0.5	0.4	0.0
10 km buffer	0.68	0.75	1.00	0.00
	0.47	0.43	0.00	0.00
Max land surface temp	300	301	300	299
	2.4	2.3	2.6	2.6
Hours>30°C in June	14.7	13.9	13.4	9.8
	20	20	20	16
Hours>30 °C in July	39	37	35	26
	49	48	46	38
Hours>30 °C in Aug.	15.3	14.5	13.7	9.7
	15	14	14	12
Total rainfall in June, July (mm)	251	247	249	246
	82	80	79	73
Total rainfall in August (mm)	103	104	104	106
	39	38	38	39
N	3,120	20,830	1,400,100	3,723,600

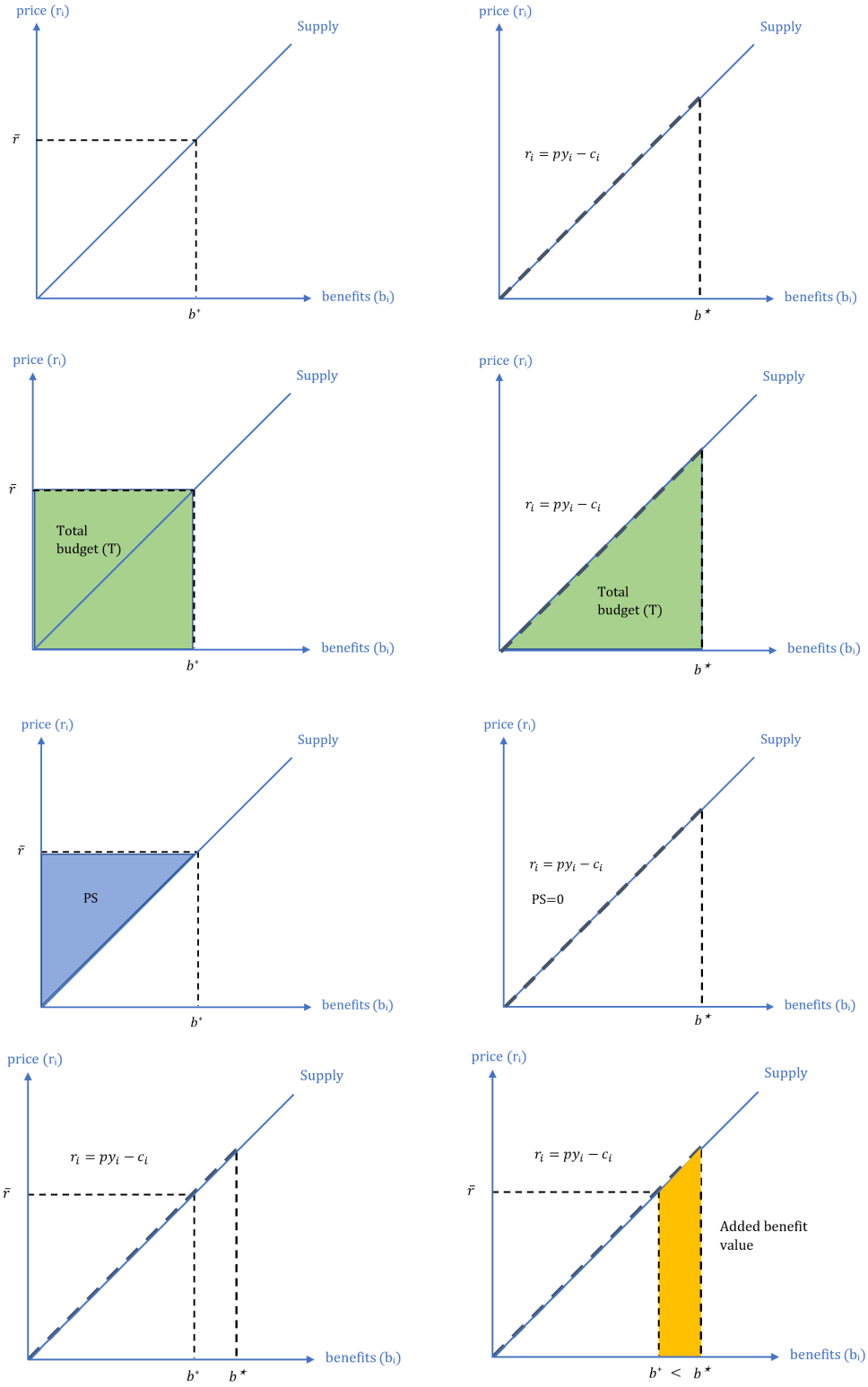
Notes: Observations are at the common land unit-year level from 2010-2019. Applicant fields are those that apply for the wetland reserve program but are not enrolled. Easement fields are those that apply for the wetland reserve program, are selected to enroll, and enroll during the sample period. Neighbors are determined by the distance to the closest easement. I focus on neighbors within a 10 km buffer. Yield estimates are from the remote-sensed machine learning algorithm by Kang and Özdoğan (2019). Yield predictions are created for Cropland Data Layer corn and soybean pixels, and then averaged over the common land unit. This table summarizes the model attributes from Landsat, MODIS, ERA5 Land Hourly, and NASA Global Precipitation Measurement.s. Common land units represented are at least 10 acres in size, and located in Wisconsin counties with any wetland easement.

Table 2: Summary statistics for mechanism variables

	N	Mean	St. Dev.	Min	Max
Sub-watershed area and land use					
Sub-watershed acres	5,147,650	23,264	10,026	23	152,171
Sub-watershed easement acres	5,147,650	65	230	0.00	2,516
Barren (%)	5,147,650	0.001	0.002	0.000	0.043
Cropland (%)	5,147,650	0.270	0.150	0.000	0.810
Developed (%)	5,147,650	0.070	0.062	0.001	0.900
Shrubland (%)	5,147,650	0.003	0.006	0.00	0.290
Grassland/Pasture (%)	5,147,650	0.130	0.099	0.00002	0.590
Fallow (%)	5,147,650	0.004	0.015	0.000	0.260
Forage (%)	5,147,650	0.092	0.063	0.000	0.360
Forest (%)	5,147,650	0.300	0.190	0.000	0.970
Open Water (%)	5,147,650	0.017	0.038	0.000	1.00
Wetland (%)	5,147,650	0.100	0.110	0.000	0.79
Monthly rainfall (mm)					
April	5,147,650	94	36	6	228
May	5,147,650	113	41	23	322
June	5,147,650	135	50	6	381
July	5,147,650	111	58	11	367
Aug.	5,147,650	106	53	11	419
Sept.	5,147,650	108	65	3	410
Oct.	5,147,650	86	37	8	229
Soil properties					
Clay content (%)	5,147,450	18.00	5.00	4.40	46.00
Sand content (%)	5,147,450	43.00	11.00	4.700	88.00
Soil organic (%)	5,147,450	3.00	2.10	0.00	82.00
Soil water content	5,147,450	21.00	2.30	12.00	50.00
Soil bulk density	5,147,450	157.00	5.30	105.00	172.00
Flood class					
None	5,023,120	0.960	0.200	0	1
Rare	5,023,120	0.003	0.055	0	1
Occasional	5,023,120	0.008	0.088	0	1
Frequent	5,023,120	0.024	0.150	0	1
Very Frequent	5,023,120	0.005	0.070	0	1

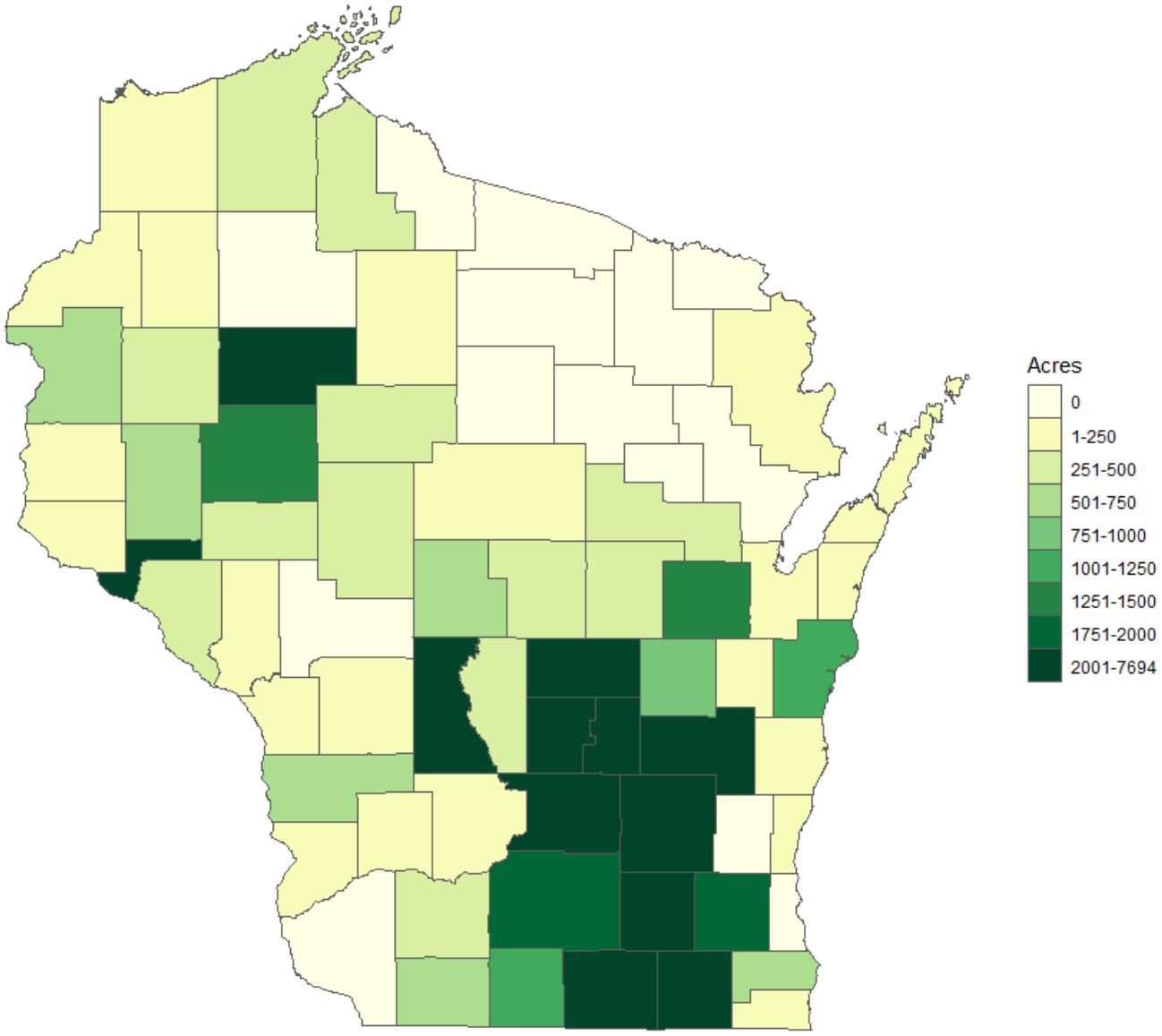
Notes: Observations are at the common land unit-year level from 2010-2019. Common land units represented are at least 10 acres in size, and located in Wisconsin counties with any wetland easement. Land use data stems from the Cropland Data Layer and depicts the proportion of land in each land use category for the sub-watershed that a field resides in. Rainfall data are from PRISM. Soil properties come from Open Land Map. Clay, sand, and soil organic content represent the content of each type of soil in measurements of kg/kg (except for soil organic content which is 5kg/kg. Soil water content at 33 kilopascals is the ratio of water to soil volume and represents the amount of moisture held in soil after excess water is drained. Soil bulk density represents the dry weight of soil divided by volume and reflects compaction. Flood frequency class is determined by the the SSURGO.

Figure 1: Conservation agent's price setting strategy



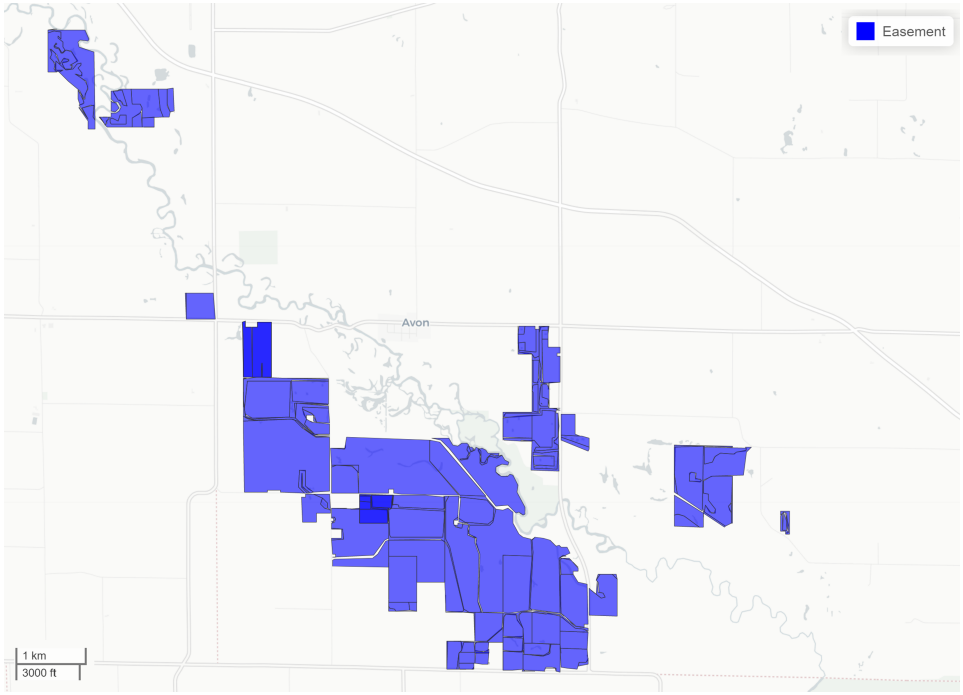
Notes: The model considers the price-making decision of the conservation agent. They can set the easement purchasing price equal to the average cropland profits in the area (left), or set the price equal to field-specific profits (right). Setting the price equal to field-specific profits allows them to increase ecosystem benefits but drives producer surplus down to zero.

Figure 2: Map of county-level variation in easement acreage



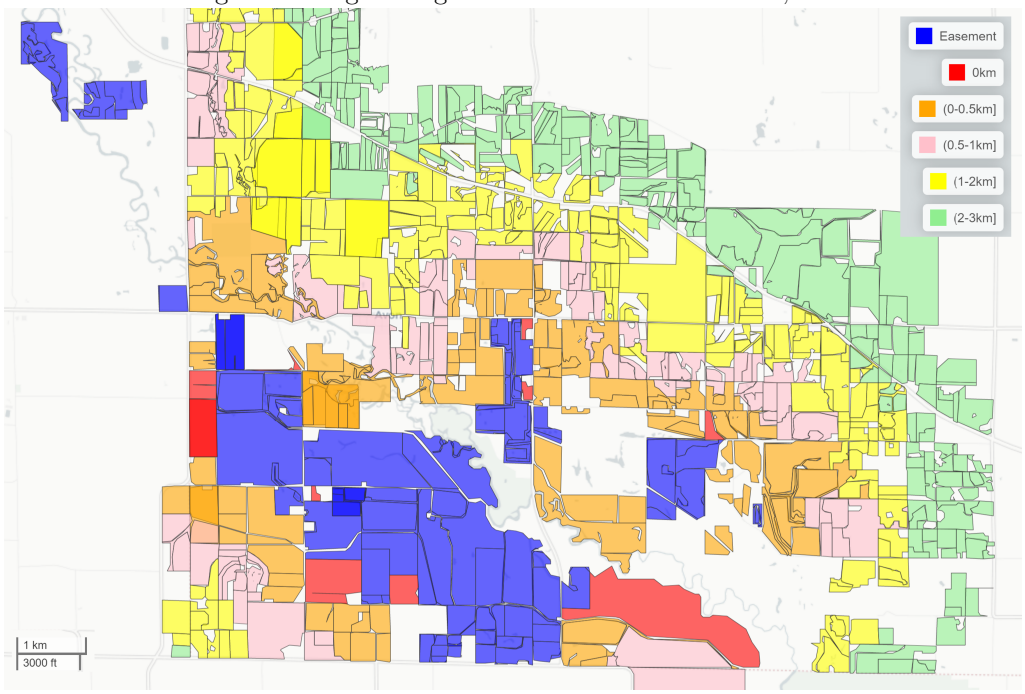
Notes: The total number of acres in the wetland reserve program and agricultural conservation easement program are shown for Wisconsin in 2019. The counties that have zero acres in wetland easement are heavily forested, and excluded from these analyses. Wetland easements are concentrated in the southeastern part of the state, where corn and soybean production is high and a large number of wetlands were historically located.

Figure 3: Example of fields with wetland easements in Avon, WI



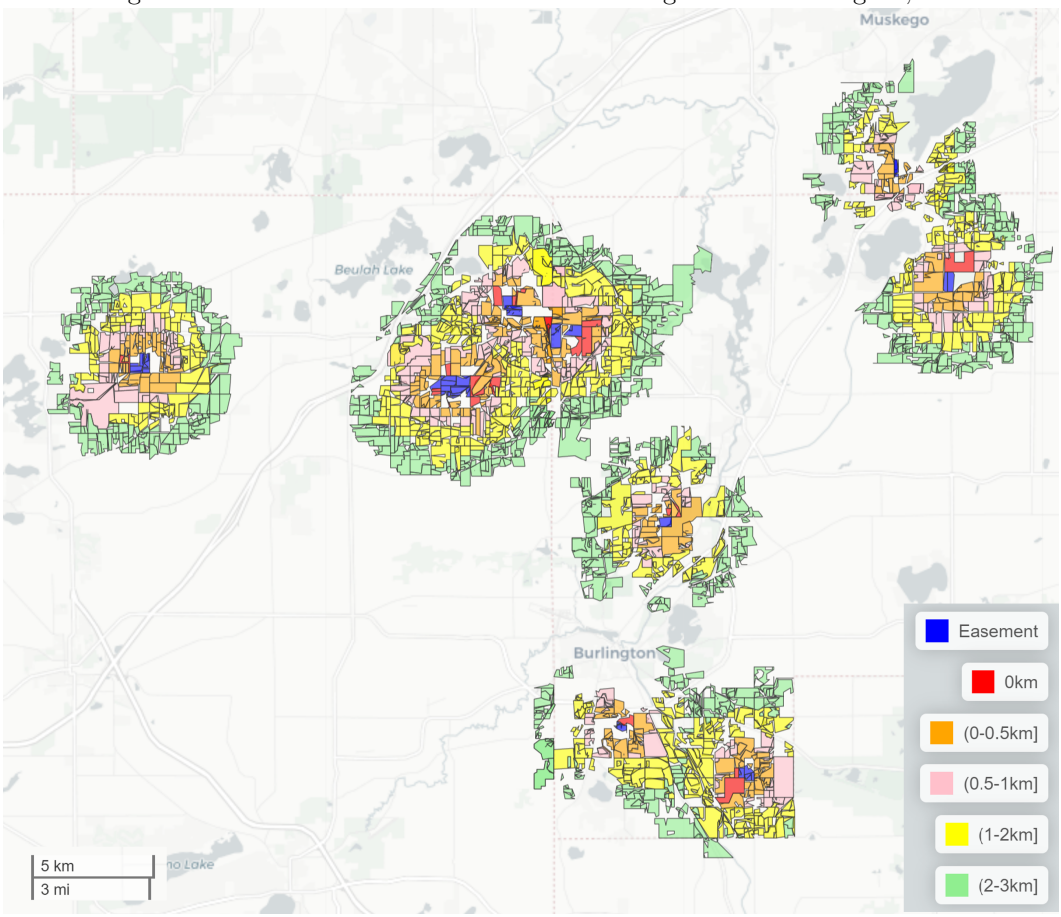
Notes: Each purple polygon here depicts a common land unit with a proportion of its field under wetland easement. These wetland easements are in the Sugar River floodplains, and located next to the Avon Bottoms Wildlife area. The NRCS has protected over 3,000 acres here to provide habitat for local wildlife and act as flood buffers.

Figure 4: Neighboring fields for easements in Avon, WI



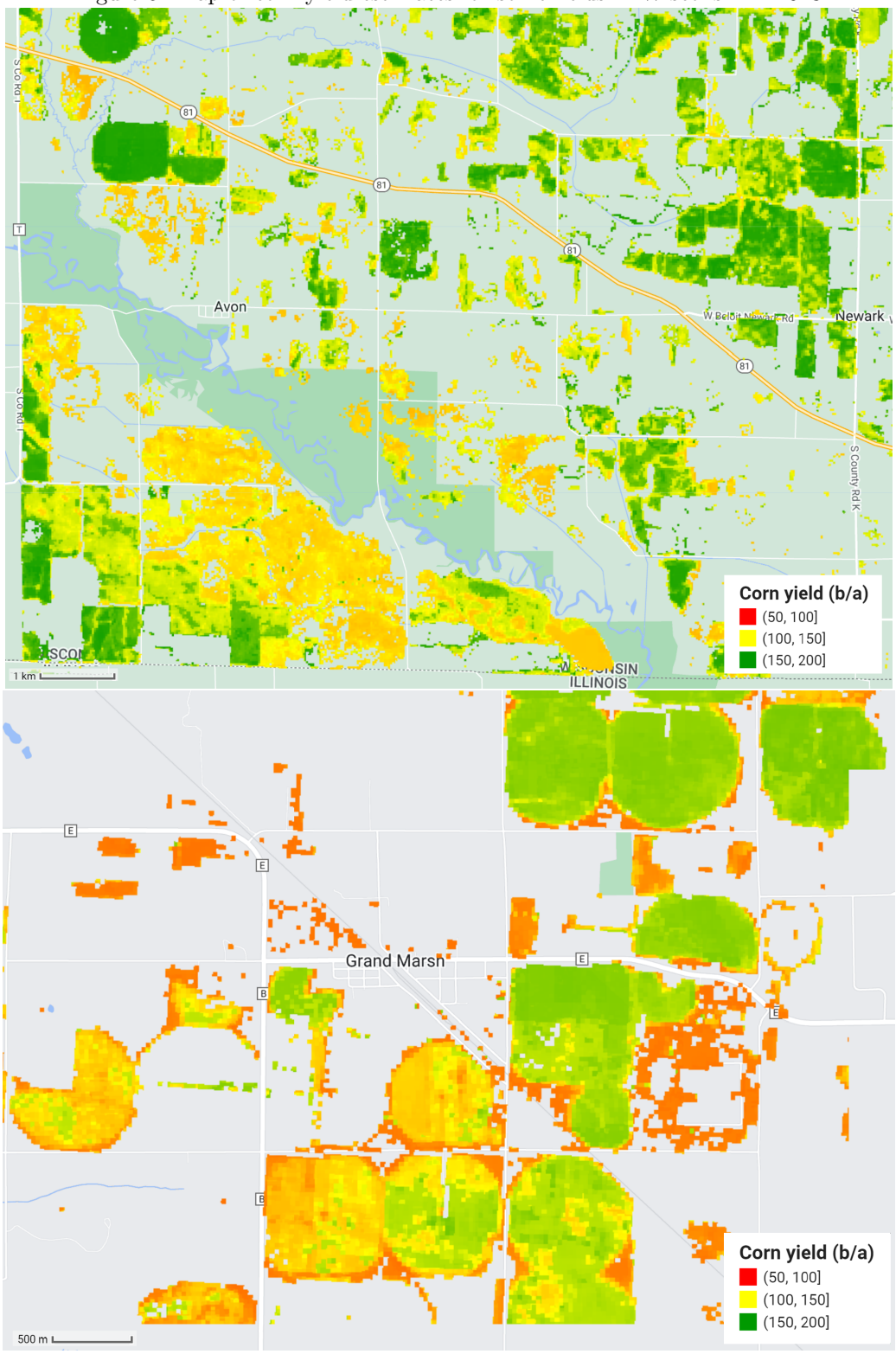
Notes: The common land units that are within a 3 kilometer buffer of the wetland easements in the Avon Bottoms are highlighted. These polygons are croplands that experience spillover effects.

Figure 5: Clusters of wetland easements and neighbors in Burlington, WI



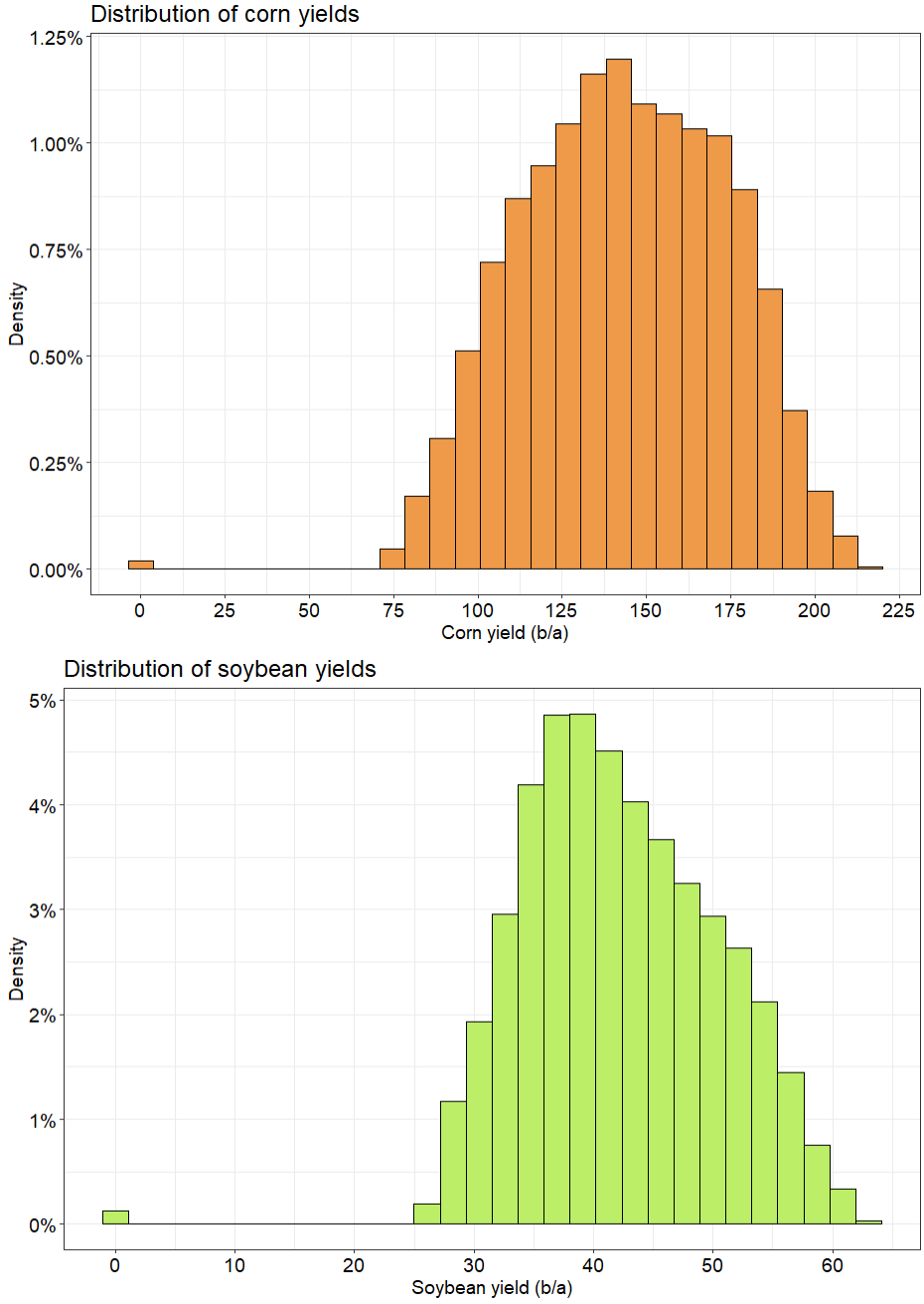
Notes: Each purple polygon depicts a common land unit with a proportion of its field under wetland easement. The common land units that are within a 3 kilometer buffer of the wetland easements are highlighted. Burlington is a city between Racine and Walworth County in the southeastern corner of Wisconsin. The wetland easements are a few kilometers from each other and oftentimes neighbor local lakes and riverbeds.

Figure 6: Map of corn yield estimates for some fields in Wisconsin in 2013



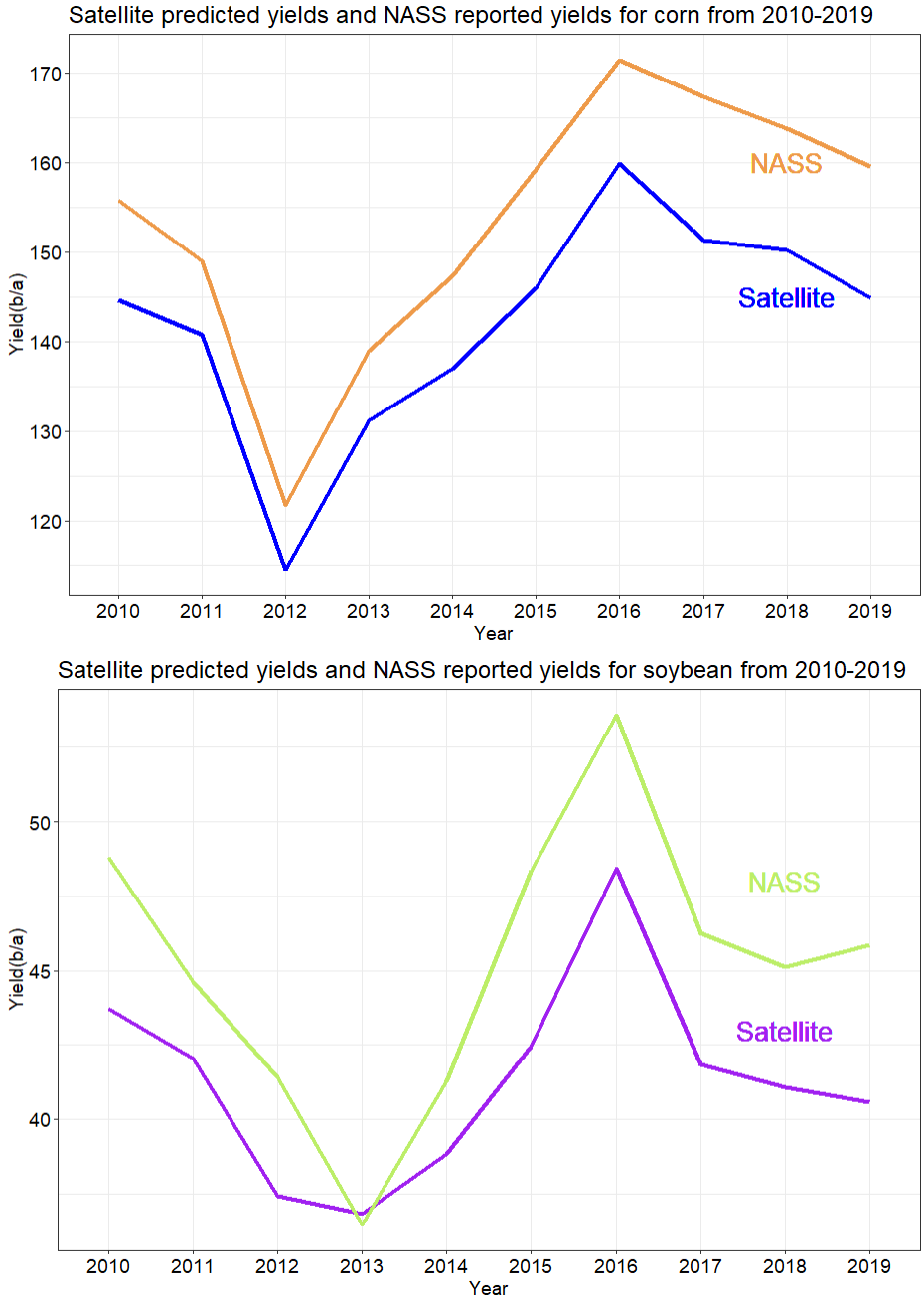
Notes: Yield estimates are from the remote-sensed machine learning algorithm by Kang and Özdoğan (2019). Corn yields are predicted for Cropland Data Layer corn pixels. These are then averaged by the common land unit. This map shows estimates for 2013 in the county of Avon and Adams. Fields closer to the river seem to be consistently lower yielding. Notice that the second map shows crop systems with center pivot systems.

Figure 7: Corn and soybean yield distribution from satellite predictions 2010-2019



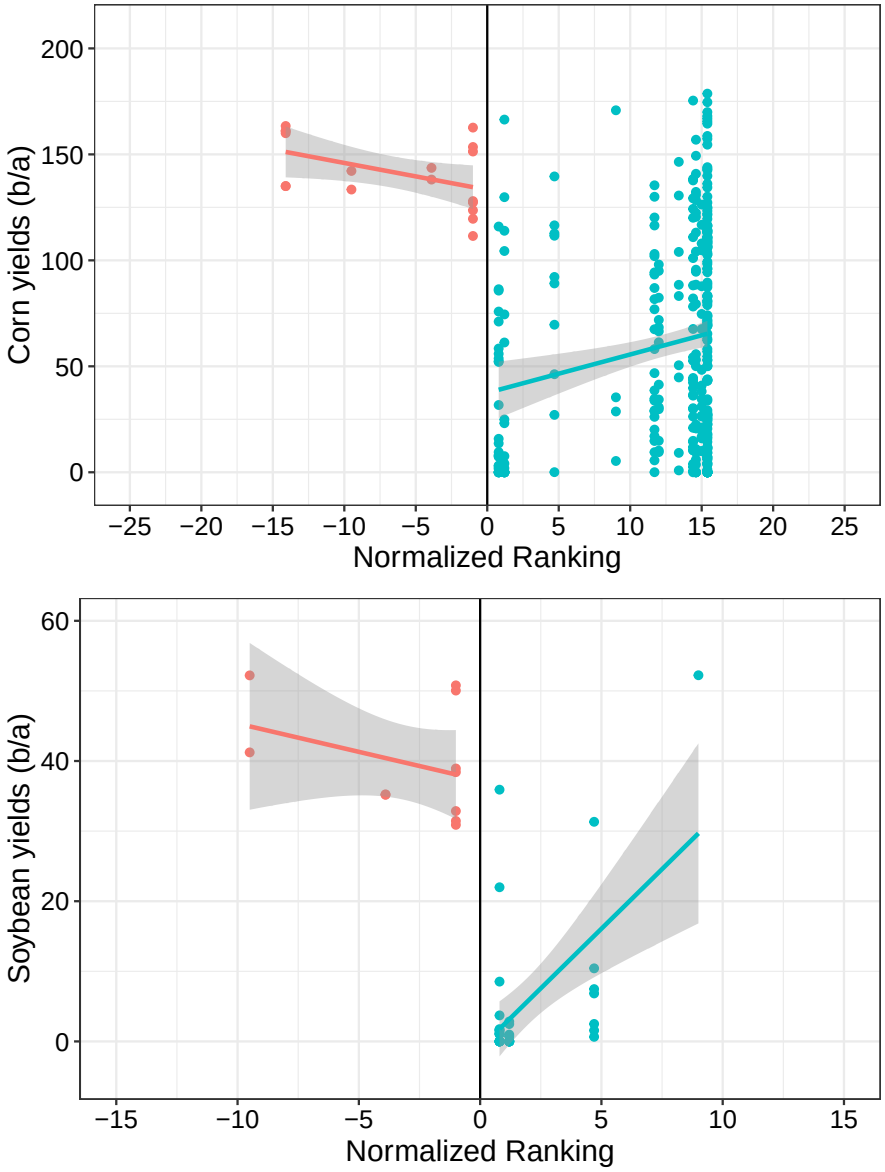
Notes: Yield estimates are from the remote-sensed machine learning algorithm by Kang and Özdoğan (2019). The distribution of yields represented is for all croplands in the sample from 2010-2019. I estimate that the yields for croplands with easement are 0 bushels per acre in the retired areas that were previously planted. If a field is completely placed in easement, then the yield in that year and in the following years is 0 for both corn and soybean. One of the model limitations is predicting yields at the tail ends of the distribution.

Figure 8: NASS vs. satellite yield comparison from 2010-2019



Notes: Yield estimates are from the remote-sensed machine learning algorithm by Kang and Özdoğan (2019). The yields represented are for all croplands in the sample from 2010-2019. Yields drastically decline in 2012 due to a large-scale drought. The model yields follow the same trends as the county-level NASS yield patterns, but are approximately 5-10 bushels per acre lower.

Figure 9: Regression discontinuity figure for corn and soybean yields



Notes: Regression discontinuity results are from the sample of applicants and easements that applied in the year 2013 and 2015. The ranking cutoff in 2013 is 70 while in 2015 it is 60; I normalize the cutoff to 0. I compare the yields of the applicant and enrolled fields after the easement contract closes and producers can no longer crop on the contracted part of the field. I assume that the closing date for applicant fields is two years after the application date. Fields that are right of the cutoff have a proportion of their field in wetland easement. The yields may be non-zero since the remaining parts of the field may stay in agricultural production. The optimal bandwidth is derived using the data-driven Imbens and Kalyanaraman (2012) method and is 20 for the corn model.

Table 3: Wetland easement effect on own corn yields (DID)

	corn b/a					
	(1)	(2)	(3)	(4)	(5)	(6)
Restored wetland (0/1)	-90.22***	-83.55***	-83.94***	-67.65***	-60.91***	-66.12***
	(2.746)	(2.764)	(2.733)	(4.002)	(3.463)	(3.655)
Dependent variable mean	143.3	143.3	143.3	101.9	101.9	101.9
Adjusted R^2	0.115	0.635	0.636	0.346	0.652	0.674
Observations	3,842,253	3,842,253	3,842,253	10,225	10,225	10,225
Applicant Sub-Sample				✓	✓	✓
Controls	✓	✓	✓	✓	✓	✓
Field fixed effects		✓	✓		✓	✓
Year fixed effects		✓	✓		✓	✓
Sun & Abraham			✓			✓

Notes: An observation is considered treated when at least 50% of a common land unit has an active wetland easement in the years following contract closing. The difference-in-differences model includes field and year fixed effects. The included control variables are the precipitation levels, max temperature, and extreme degree days from June, July and August. The applicant sub-sample limits the control fields to those that have ever applied to the wetland easement program. The Sun & Abraham specification corrects for staggered treatment timing. Clustered (sub-watershed) standard-errors in parentheses.

Table 4: Wetland easement effect on own soybean yields (DID)

	soybean b/a					
	(1)	(2)	(3)	(4)	(5)	(6)
Restored wetland (0/1)	-30.71***	-28.17***	-29.37***	-23.73***	-21.49***	-24.49***
	(0.7364)	(1.139)	(0.7654)	(1.206)	(1.293)	(1.029)
Dependent variable mean	41.9	41.9	41.9	28.3	28.3	28.3
Adjusted R^2	0.105	0.632	0.633	0.424	0.708	0.734
Observations	2,475,292	2,475,292	2,475,292	6,945	6,945	6,945
Applicant Sub-Sample				✓	✓	✓
Controls	✓	✓	✓	✓	✓	✓
Field fixed effects		✓	✓		✓	✓
Year fixed effects		✓	✓		✓	✓
Sun & Abraham			✓			✓

Notes: An observation is considered treated when at least 50% of a common land unit has an active wetland easement in the years following contract closing. The difference-in-differences model includes field and year fixed effects. The included control variables are the precipitation levels, max temperature, and extreme degree days from June, July and August. The applicant sub-sample limits the control fields to those that have ever applied to the wetland easement program. The Sun & Abraham specification corrects for staggered treatment timing. Clustered (sub-watershed) standard-errors in parentheses.

Table 5: Wetland easement effect on own corn yields (RD)

	corn b/a			
	(1)	(2)	(3)	(4)
Restored wetland (Ranking ≥ 0)	-94.91***	-82.55***	-77.76***	-76.84***
	(9.551)	(14.45)	(13.66)	(8.613)
Bandwidth	110	20	10	5
Optimal bandwidth		✓		
Dependent variable mean	78.780	64.102	59.197	56.726
Observations	448	360	71	65
Adjusted R^2	0.48763	0.31593	0.46048	0.49734

Notes: An observation is considered treated when a common land unit has an active wetland easement in the years following contract closing. The RD model includes the running variable (the ranking), treatment status, and an interaction term. Control variables include a yearly time trend, the precipitation levels, max temperature, and extreme degree days from June, July and August. Clustered (sub-watershed) standard-errors in parentheses.

Table 6: Wetland easement effect on own soybean yields (RD)

	soybean b/a			
	(1)	(2)	(3)	(4)
Restored wetland (Ranking≥ 0)	-28.54***	-29.61***	-31.08***	-29.80***
	(3.401)	(3.330)	(4.349)	(1.151)
Bandwidth	110	20	10	5
Optimal bandwidth			✓	
Dependent variable mean	19.149	13.902	13.817	11.393
Observations	287	227	46	43
Adjusted R^2	0.53519	0.33753	0.73596	0.75033

Notes: An observation is considered treated when a common land unit has an active wetland easement in the years following contract closing. The RD model includes the running variable (the ranking), treatment status, and an interaction. Control variables include a yearly time trend, the precipitation levels, max temperature, and extreme degree days from June, July and August. Clustered (sub-watershed) standard-errors in parentheses.

Table 7: Present value of forgone yields

	Average		DID		RD	
Commodity	Corn	Soybeans	Corn	Soybeans	Corn	Soybeans
Price per bushel	4.32	10.61	4.32	10.61	4.32	10.61
Yield (b/a)	143.47	42.63	66.12	24.49	82.55	31.08
Revenue	619.79	452.30	285.64	259.84	356.62	329.76
Operating cost	342.48	165.62	342.48	165.62	342.48	165.62
Profit	277.31	286.68	-56.84	94.22	14.14	164.14
Present value	$5,546.21	$5,733.69	-$1,136.83	$1,884.38	$282.72	$3,282.78

Notes: The price, revenue, and operating costs are based on averages in the Northern Crescent region from the 2022 USDA ERS Commodity Report. I assume that these are consistent across croplands with and without easements in my sample. The DID column uses estimates from the Sun and Abraham difference-in-differences model using applicants as the control group. The RD yield estimates are from the optimal model according to the the Imbens2012 bandwidth. I calculate the profit per field by multiplying the expected price by the yield. I then subtract the operating costs from the revenue to find profit per acre. I find the present value of the profit assuming a 5% interest rate. This captures the expected agricultural profits of a cropland, and we can compare the present value to the easement purchasing cost.

Table 8: Dynamic effects of easements on corn yields within 1 km

	corn b/a			
	(1)	(2)	(3)	(4)
= -4	0.6332	-0.2374	0.0630	2.632
	(1.107)	(2.245)	(0.5281)	(1.899)
= -3	1.401	1.018	-0.2330	2.144
	(1.067)	(1.207)	(0.5414)	(1.409)
= -2	-0.9883	-1.495	-0.4410	-0.7781
	(1.215)	(1.290)	(0.5080)	(1.352)
= 0	-1.105	-0.9050	-2.280***	-1.390
	(1.193)	(1.167)	(0.5941)	(1.213)
= 1	1.575	1.495	1.080*	0.3084
	(1.131)	(1.254)	(0.5864)	(1.360)
= 2	-1.124	-0.6017	1.328**	-0.7586
	(1.306)	(1.580)	(0.6056)	(1.378)
= 3	-0.3539	-0.6071	0.1753	-3.626**
	(1.261)	(1.865)	(0.6244)	(1.567)
= 4	2.041*	1.855	1.093**	-1.186
	(1.053)	(1.963)	(0.5373)	(1.768)
= 5	1.090	1.576	1.060*	-2.233
	(1.448)	(2.389)	(0.6104)	(2.148)
= 6	2.260	3.786	3.220***	-0.2688
	(1.425)	(2.731)	(0.6073)	(2.157)
= 7	2.347*	4.760	3.534***	-0.1558
	(1.416)	(3.115)	(0.6970)	(2.620)
= 8	5.464***	7.134*	2.832**	-1.186
	(2.078)	(3.985)	(1.184)	(3.018)
Dependent variable mean	143.42	145.81	143.42	145.81
Observations	3,834,809	50,608	3,834,809	50,606
Adjusted R^2	0.63363	0.65943	0.63436	0.66153
Control group	never treated	not yet treated	never treated	not yet treated
Field fixed effects	✓	✓	✓	✓
Year fixed effects	✓	✓	✓	✓
Sun & Abraham			✓	✓

Notes: Treated units are common land units that are within 1 km of a restored wetland easement. Control units are those outside of this boundary (never treated) or those that are inside the boundary that are treated later on in time (not yet treated). Yield changes are compared to the pre-treatment period one year before restoration. The Sun and Abraham approach uses the same framework but removes the bad controls. Clustered (sub-watershed) standard-errors in parentheses. Signif. Codes: ***: 0.01, **: 0.05, *: 0.1

Table 9: Dynamic effects of easements on soybean yields within 1 km

	soybean b/a			
	(1)	(2)	(3)	(4)
= -4	0.0997	-0.0457	0.3105**	0.4058
	(0.3095)	(0.5275)	(0.1382)	(0.4160)
= -3	0.3027	0.3123	0.2217	1.020***
	(0.3236)	(0.3523)	(0.1586)	(0.3299)
= -2	-0.5199	-0.6678**	0.2440*	-0.5487*
	(0.3331)	(0.3267)	(0.1458)	(0.3295)
= 0	-0.7525**	-0.7129**	-0.3942***	-0.6060*
	(0.3721)	(0.3525)	(0.1515)	(0.3413)
= 1	-0.1337	-0.1963	0.1391	-0.0387
	(0.3093)	(0.3183)	(0.1458)	(0.3550)
= 2	-0.8133**	-0.7329*	0.0236	-0.5964
	(0.3424)	(0.4108)	(0.1467)	(0.3634)
= 3	-0.1280	-0.3357	-0.2098	-0.5414
	(0.3624)	(0.4906)	(0.1498)	(0.3977)
= 4	-0.7060**	-0.6398	-0.2672*	-1.081**
	(0.3076)	(0.4981)	(0.1428)	(0.4557)
= 5	-1.121**	-0.7236	-0.6167***	-1.343**
	(0.4691)	(0.6340)	(0.1608)	(0.6369)
= 6	-0.9117**	-0.3039	0.1450	-0.9061
	(0.4509)	(0.6863)	(0.1939)	(0.6434)
= 7	-0.2561	0.0531	0.3603**	-0.8467
	(0.4212)	(0.7470)	(0.1817)	(0.7383)
= 8	0.7714	0.4613	0.4654	-0.9940
	(0.6519)	(1.009)	(0.2973)	(0.8336)
Dependent variable mean	41.903	42.981	41.903	42.981
Observations	2,470,384	35,572	2,470,384	35,571
Adjusted R^2	0.62856	0.60452	0.62919	0.60858
Control group	never treated	not yet treated	never treated	not yet treated
Field fixed effects	✓	✓	✓	✓
Year fixed effects	✓	✓	✓	✓
Sun & Abraham			✓	✓

Notes: Treated units are common land units that are within 1 km of a restored wetland easement. Control units are those outside of this boundary (never treated) or those that are inside the boundary that are treated later on in time (not yet treated). Yield changes are compared to the pre-treatment period one year before restoration. The Sun and Abraham approach uses the same framework but removes the bad controls. Clustered (sub-watershed) standard-errors in parentheses. Signif. Codes: ***: 0.01, **: 0.05, *: 0.1

Table 10: Dynamic effects of wetland easements on corn yields within 3 km

	corn b/a			
	(1)	(2)	(3)	(4)
= -4	0.7658	-0.6298	0.0473	1.965
	(0.8681)	(1.365)	(0.5172)	(1.238)
= -3	0.7131	-0.0117	-0.1920	1.441
	(0.7970)	(0.7810)	(0.5454)	(0.9937)
= -2	-0.4443	-0.9422	-0.4465	-0.1240
	(0.9120)	(0.8931)	(0.5065)	(1.022)
= 0	-1.733*	-1.381	-2.336***	-1.938**
	(0.9212)	(0.8989)	(0.6076)	(0.9148)
= 1	0.5347	0.7456	1.080*	-0.4110
	(0.9128)	(1.008)	(0.5889)	(1.089)
= 2	-0.5222	0.2580	1.432**	-0.2020
	(0.9876)	(1.132)	(0.5973)	(1.076)
= 3	0.1443	0.4845	0.1471	-1.922
	(0.9925)	(1.368)	(0.6292)	(1.242)
= 4	1.204	1.605	1.114**	-0.7053
	(0.8420)	(1.313)	(0.5366)	(1.326)
= 5	1.030	2.377	1.050*	-0.9843
	(1.061)	(1.606)	(0.6133)	(1.545)
= 6	2.170**	4.740***	3.197***	0.7684
	(0.9763)	(1.760)	(0.6063)	(1.606)
= 7	2.907**	6.042***	3.569***	1.446
	(1.144)	(2.098)	(0.6891)	(1.928)
= 8	5.345***	8.186***	2.540**	1.063
	(1.601)	(2.693)	(1.174)	(2.566)
# Fields	475,180	26,246	475,180	26,246
Dependent variable mean	143.42	146.14	143.42	146.14
Observations	3,834,809	222,717	3,834,809	222,715
Adjusted R^2	0.63371	0.67060	0.63460	0.67238
Control group	never treated	not yet treated	never treated	not yet treated
Field fixed effects	✓	✓	✓	✓
Year fixed effects (10)	✓	✓	✓	✓
Sun & Abraham			✓	✓

Notes: Treated units are common land units that are within 3 km of a restored wetland easement. Control units are those outside of this boundary (never treated) or those that are inside the boundary that are treated later on in time (not yet treated). Yield changes are compared to the pre-treatment period one year before restoration. The Sun and Abraham approach uses the same framework but removes the bad controls. Clustered (sub-watershed) standard-errors in parentheses. Signif. Codes: ***: 0.01, **: 0.05, *: 0.1

Table 11: Dynamic effects of wetland easements on soybean yields within 3 km

	soybean b/a			
	(1)	(2)	(3)	(4)
= -4	0.2704	0.1915	0.3105**	0.4509
	(0.2570)	(0.3542)	(0.1382)	(0.3057)
= -3	0.3726	0.3842	0.2217	0.5977**
	(0.2459)	(0.2564)	(0.1586)	(0.2549)
= -2	-0.0108	-0.0957	0.2440*	-0.0065
	(0.2511)	(0.2334)	(0.1458)	(0.2280)
= 0	-0.5005*	-0.4747*	-0.3942***	-0.4675*
	(0.2625)	(0.2568)	(0.1515)	(0.2494)
= 1	-0.0798	-0.1427	0.1391	-0.1531
	(0.2651)	(0.2733)	(0.1458)	(0.2690)
= 2	-0.4831*	-0.4552	0.0236	-0.4679
	(0.2596)	(0.3139)	(0.1467)	(0.2952)
= 3	-0.1383	-0.3355	-0.2098	-0.4826
	(0.2873)	(0.3884)	(0.1498)	(0.3464)
= 4	-0.6054**	-0.6210	-0.2672*	-0.8123**
	(0.2376)	(0.3823)	(0.1428)	(0.3550)
= 5	-0.9218***	-0.6662	-0.6167***	-0.9589**
	(0.3269)	(0.4600)	(0.1608)	(0.4197)
= 6	-0.6850**	-0.2984	0.1450	-0.5962
	(0.3341)	(0.5225)	(0.1939)	(0.4745)
= 7	-0.2158	-0.0790	0.3603**	-0.4613
	(0.3224)	(0.5920)	(0.1817)	(0.5405)
= 8	0.7865*	0.5776	0.4654	0.1487
	(0.4659)	(0.7649)	(0.2973)	(0.6255)
# Fields	437,152	24,829	437,152	24,829
Dependent variable mean	41.903	43.061	41.903	43.061
Observations	2,470,384	155,378	2,470,384	155,378
Adjusted R^2	0.62865	0.62730	0.62919	0.62817
Control group	never treated	not yet treated	never treated	not yet treated
Field fixed effects	✓	✓	✓	✓
Year fixed effects (10)	✓	✓	✓	✓
Sun & Abraham			✓	✓

Notes: Treated units are common land units that are within 3 km of a restored wetland easement. Control units are those outside of this boundary (never treated) or those that are inside the boundary that are treated later on in time (not yet treated). Yield changes are compared to the pre-treatment period one year before restoration. The Sun and Abraham approach uses the same framework but removes the bad controls. Clustered (sub-watershed) standard-errors in parentheses. Signif. Codes: ***: 0.01, **: 0.05, *: 0.1

Table 12: Dynamic effects of wetland easements on corn yields within 10 km

	corn b/a			
	(1)	(2)	(3)	(4)
= -4	0.2567	-1.652*	-0.1116	0.5974
	(0.6071)	(0.8535)	(0.5132)	(0.8039)
= -3	-0.0271	-0.8308	0.2212	0.7631
	(0.6052)	(0.5742)	(0.5683)	(0.6900)
= -2	-0.3429	-0.9226*	-0.5300	-0.1875
	(0.5681)	(0.5460)	(0.5137)	(0.6183)
= 0	-1.976***	-1.592**	-2.865***	-1.997***
	(0.6847)	(0.7147)	(0.7134)	(0.6819)
= 1	0.9552	1.318*	1.044*	0.4890
	(0.6831)	(0.7553)	(0.6070)	(0.7833)
= 2	0.7046	1.563*	1.874***	1.266*
	(0.6808)	(0.8081)	(0.6052)	(0.7637)
= 3	0.1310	0.9453	0.0151	-0.9602
	(0.7256)	(0.9605)	(0.7090)	(0.9460)
= 4	1.275**	2.332***	1.011*	0.3650
	(0.5732)	(0.8827)	(0.5801)	(0.9092)
= 5	0.9763	3.025***	0.7446	-0.5681
	(0.7060)	(1.110)	(0.6997)	(1.047)
= 6	2.984***	6.010***	3.146***	2.477**
	(0.6565)	(1.168)	(0.6715)	(1.091)
= 7	3.334***	6.849***	3.946***	3.376***
	(0.7634)	(1.409)	(0.7060)	(1.237)
= 8	3.864***	7.528***	1.629	1.271
	(1.198)	(1.879)	(1.391)	(2.131)
# Fields	475,180	134,209	475,180	134,209
Dependent variable mean	143.42	146.83	143.42	146.83
Observations	3,834,809	1,122,817	3,834,809	1,122,815
Adjusted R^2	0.63406	0.66978	0.63618	0.67299
Control group	never treated	not yet treated	never treated	not yet treated
Field fixed effects	✓	✓	✓	✓
Year fixed effects (10)	✓	✓	✓	✓
Sun & Abraham			✓	✓

Notes: Treated units are common land units that are within 10 km of a restored wetland easement. Control units are those outside of this boundary (never treated) or those that are inside the boundary that are treated later on in time (not yet treated). Yield changes are compared to the pre-treatment period one year before restoration. The Sun and Abraham approach uses the same framework but removes the bad controls. Clustered (sub-watershed) standard-errors in parentheses. Signif. Codes: ***: 0.01, **: 0.05, *: 0.1

Table 13: Dynamic effects of wetland easements on soybean yields within 10 km

	soybean b/a			
	(1)	(2)	(3)	(4)
= -4	0.3266**	0.1464	0.2978**	0.1764
	(0.1647)	(0.2081)	(0.1422)	(0.2114)
= -3	0.1958	0.1885	0.6978***	0.7875***
	(0.1779)	(0.1778)	(0.1614)	(0.1910)
= -2	0.2441	0.2031	0.2395*	0.3263**
	(0.1655)	(0.1517)	(0.1387)	(0.1545)
= 0	-0.4082**	-0.3677**	-0.3805**	-0.3632**
	(0.1772)	(0.1806)	(0.1783)	(0.1768)
= 1	0.0692	0.0406	0.2327	0.1576
	(0.1709)	(0.1765)	(0.1482)	(0.2012)
= 2	-0.1492	-0.0926	0.1728	0.0689
	(0.1743)	(0.1971)	(0.1393)	(0.1853)
= 3	-0.1310	-0.1739	-0.2329	-0.2066
	(0.1785)	(0.2298)	(0.1569)	(0.2167)
= 4	-0.3000*	-0.2065	-0.3323**	-0.3135
	(0.1564)	(0.2280)	(0.1464)	(0.2136)
= 5	-0.6877***	-0.3419	-0.8040***	-0.7210***
	(0.1929)	(0.2730)	(0.1720)	(0.2493)
= 6	-0.0433	0.3519	0.0981	0.0388
	(0.2278)	(0.3166)	(0.2064)	(0.3172)
= 7	0.1852	0.4496	0.4255**	0.1767
	(0.2094)	(0.3489)	(0.1746)	(0.3429)
= 8	0.7189**	0.8085*	-0.0662	-0.4339
	(0.3123)	(0.4602)	(0.3406)	(0.5286)
# Fields	437,152	126,040	437,152	126,040
Dependent variable mean	41.903	43.166	41.903	43.166
Observations	2,470,384	767,193	2,470,384	767,191
Adjusted R^2	0.62893	0.63543	0.63157	0.63853
Control group	never treated	not yet treated	never treated	not yet treated
Field fixed effects	✓	✓	✓	✓
Year fixed effects (10)	✓	✓	✓	✓
Sun & Abraham			✓	✓

Notes: Treated units are common land units that are within 10 km of a restored wetland easement. Control units are those outside of this boundary (never treated) or those that are inside the boundary that are treated later on in time (not yet treated). Yield changes are compared to the pre-treatment period one year before restoration. The Sun and Abraham approach uses the same framework but removes the bad controls. Clustered (sub-watershed) standard-errors in parentheses. Signif. Codes: ***: 0.01, **: 0.05, *: 0.1

Table 14: Wetland easements and land use interaction effect on corn and soybean yields

	corn b/a (1)	soybean b/a (2)
Easement Acres	-0.0342***	-0.0027
	(0.0122)	(0.0031)
Easement Acres × Barren	1.323	0.2307
	(0.8356)	(0.1994)
Easement Acres × Cropland	0.0316*	-0.0040
	(0.0188)	(0.0055)
Easement Acres × Developed	0.0567	-0.0065
	(0.0698)	(0.0156)
Easement Acres × Shrubland	0.0500	0.0224
	(0.0436)	(0.0141)
Easement Acres × Grassland/Pasture	0.0063	0.0031
	(0.0134)	(0.0029)
Easement Acres × Fallow	0.0908***	0.0136**
	(0.0237)	(0.0054)
Easement Acres × Forage	0.1863***	0.0440***
	(0.0356)	(0.0099)
Easement Acres × Forest	0.0245	0.0020
	(0.0173)	(0.0040)
Easement Acres × Open Water	0.1711**	0.0059
	(0.0792)	(0.0229)
Easement Acres × Wetland	0.0100	0.0008
	(0.0129)	(0.0034)
Dependent variable mean	143.42	41.903
Observations	3,834,809	2,470,384
Adjusted R^2	0.63886	0.63458
Year fixed effects	✓	✓
Field fixed effects	✓	✓
Controls	✓	✓

Notes: Treatment is calculated as the acres of restored wetland easement in a subwatershed in a year. The observation unit continues to be at the field-level. Fields with any easement are excluded from the analyses. Land cover is the proportion of the subwatershed in each Cropland Data Layer class. The interaction terms highlight how the wetland restoration yield effects vary by surrouding land use types. Clustered (sub-watershed) standard-errors in parentheses. Signif. Codes: ***: 0.01, **: 0.05, *: 0.1

Table 15: Wetland easements and rainfall (100 mm) interaction effect on corn and soybean yields

	corn b/a (1)	soybean b/a (2)
Restored wetland (acres)	-0.0064*	-0.0016**
	(0.0033)	(0.0007)
Restored wetland × April Rain	0.0033***	0.0011***
	(0.0011)	(0.0004)
Restored wetland × May Rain	-0.0014	-7.66×10^{-5}
	(0.0011)	(0.0003)
Restored wetland × June Rain	0.0013	0.0002
	(0.0009)	(0.0003)
Restored wetland × July Rain	-0.0016	-0.0007***
	(0.0012)	(0.0003)
Restored wetland × Aug. Rain	-0.0026***	-0.0008***
	(0.0007)	(0.0002)
Restored wetland × Sept. Rain	0.0062***	0.0015***
	(0.0011)	(0.0003)
Restored wetland × Oct. Rain	0.0005	-0.0002
	(0.0010)	(0.0003)
Dependent variable mean	143.42	41.903
Observations	3,834,809	2,470,384
Adjusted R^2	0.63320	0.61850
Year fixed effects	✓	✓
Field fixed effects	✓	✓
Controls	✓	✓

Notes: Treatment is calculated as the acres of restored wetland easement in a subwatershed in a year. The observation unit continues to be at the field-level. Fields with any easement are excluded from the analyses. Precipitation data is collected from PRISM and represents the mean rainfall in a month for each field. The interaction terms highlight how the wetland restoration yield effects vary by precipitation levels. Clustered (subwatershed) standard-errors in parentheses. Signif. Codes: ***: 0.01, **: 0.05, *: 0.1

Table 16: Wetland easements and soil characteristic interaction effects on corn and soybean yields

	corn b/a (1)	soybean b/a (2)
Restored wetland (acres)	0.0069	0.0051
	(0.0262)	(0.0066)
Restored wetland × Clay %	-0.0004	-0.0002
	(0.0004)	(0.0001)
Restored wetland × Sand %	-0.0003*	-5.02×10^{-5}
	(0.0002)	(3.26×10^{-5})
Restored wetland × Soil Organic %	-0.0007	-0.0001
	(0.0005)	(0.0001)
Restored wetland × Soil Water Content	0.0008**	9.1×10^{-5}
	(0.0004)	(8.91×10^{-5})
Restored wetland × Soil Bulk Density	6.83×10^{-6}	-5.61×10^{-6}
	(0.0002)	(3.96×10^{-5})
Dependent variable mean	143.42	41.903
Observations	3,834,809	2,470,384
Adjusted R^2	0.63320	0.62437
Year fixed effects	✓	✓
Field fixed effects	✓	✓
Controls	✓	✓

Notes: Treatment is calculated as the acres of restored wetland easement in a sub-watershed in a year. The observation unit continues to be at the field-level. Fields with any easement are excluded from the analyses. Soil covariates are at the field-level and taken from Open Land Map. Clay, sand, and soil organic content represent the proportion of the soil in each of these categories. Soil water content is the mass of water in the soil. Soil bulk density is the dry weight of soil divided by its volume, and it captures the ability of water to flow. Clustered (sub-watershed) standard-errors in parentheses. Signif. Codes: ***: 0.01, **: 0.05, *: 0.1

Table 17: Wetland easements and flood frequency class interaction effects on corn and soybean yields

	corn b/a	soybean b/a
	(1)	(2)
Restored wetland (acres)	-7.46×10^{-5}	-0.0005
	(0.0056)	(0.0013)
Restored wetland × None	0.0015	0.0002
	(0.0058)	(0.0013)
Restored wetland × Rare	0.0371***	0.0005
	(0.0063)	(0.0016)
Restored wetland × Occasional	0.0068	-0.0048***
	(0.0059)	(0.0013)
Restored wetland × Very frequent	-0.0498***	-0.0061***
	(0.0081)	(0.0019)
Dependent variable mean	143.28	41.865
Observations	3,745,113	2,411,213
Adjusted R^2	0.63166	0.62399
Year fixed effects	✓	✓
Field fixed effects	✓	✓
Controls	✓	✓

Notes: Treatment is calculated as the acres of restored wetland easement in a subwatershed in a year. The observation unit continues to be at the field-level. Fields with any easement are excluded from the analyses. Flood frequency parameters are from the USDA Web Soil Survey. Flooding frequency measures the susceptibility of soils to flood at the SSURGO map unit level. Clustered (sub-watershed) standard-errors in parentheses. Signif. Codes: ***: 0.01, **: 0.05, *: 0.1