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Additionality in U.S. Agricultural Conservation and Regulatory Offset Programs

Roger Claassen, John Horowitz, Eric Duquette,
and Kohei Ueda

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Abstract

Conservation payments lead to improvement in environmental quality only if farmers and ranchers who receive them adopt conservation practices that would not have been adopted without the payment. When a voluntary payment causes a change in practice(s) that lead(s) to improved environmental quality, these changes are "additional." We estimate this "*additionality*" for a number of common conservation practices that are frequently supported by existing conservation programs. We find that the level of additionality varies by practice and that additionality is high for structural and vegetative practices while the risk of nonadditionality appears to be higher for management practices. While the risk of nonadditionality cannot be completely eliminated, it can be reduced. We discuss a number of approaches to managing nonadditionality in both conservation programs and environmental offset programs.

Keywords: Additionality, conservation programs, conservation practices, conservation payments, offsets, greenhouse gas

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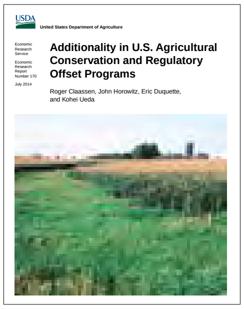

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Find the full report at *www.ers.usda.gov/publications/err-economic-research-report/err170*

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What Is the Issue?

The Federal Government spent more than $6 billion in fiscal year 2013 on voluntary conservation payment programs to encourage the adoption of a wide range of conservation practices that address multiple environmental and resource conservation goals. Conservation payments can also come from private industry, particularly in the context of an agricultural offset market established as part of a cap-and-trade system designed to reduce nutrient or greenhouse gas (GHG) emissions. Payments lead to improvement in environmental quality only if farmers and ranchers who receive them adopt conservation practices that would not have been adopted without the payment.

When a voluntary payment causes a change in practice(s) that leads to improved environmental quality, these changes are "additional." For any type of voluntary payment, there is some risk that the farmers or ranchers who receive them would have adopted the required practice(s), even without the payment. This study measures additionality for a number of common conservation practices typically supported by voluntary conservation payments and examines ways to increase additionality.

What Did the Study Find?

Additionality depends largely on the characteristics of the practices support by conservation payments. Practices that are expensive to install or provide only limited onfarm benefits are unlikely to be adopted without payments. Practices that can be profitable are much more likely to be adopted without payments, although the costs and benefits of these practices can vary widely across farms. Many farms, for example, have adopted conservation tillage without receiving conservation program payments, while other farms have not. Two broad categories of conservation practices are considered:

- **Structural and vegetative practices:** Additionality is high (roughly 80 percent) for structural and vegetative practices such as terraces and grassed waterways. These practices typically have high installation costs and offer limited onfarm benefits, at least in the short run. Most farmers and landowners are unlikely to install them without assistance.

ERS is a primary source of economic research and analysis from the U.S. Department of Agriculture, providing timely information on economic and policy issues related to agriculture, food, the environment,and rural America.

- **Conservation management practices:** Additionality results are mixed. We estimate that conservation tillage, when supported by payments, is just over 50 percent additional—considerably lower than for either category of structural practices. Our analysis of nutrient management supported by conservation program payments shows that farmers who receive payments are much more likely to have written nutrient management plans than farmers who did not receive payments. Results are less clear, however, for implementation of actual nutrient management practices. Farmers who received payments applied only 1.2 percent of nitrogen fertilizer (on average) in the fall before planting corn, while we estimated that they would have applied 12 percent of nitrogen in the fall, on average, without a payment. It is not clear, however, that corn farmers who received payments applied less nitrogen or were more likely to apply it after planting, when crop uptake is greatest.

Similar results are obtained in our analysis of nutrient management practices (reduced nitrogen application) supported through a hypothetical offset market. In our simulation, credits are earned by applying nitrogen below a “prevailing practice” baseline rate. If the offset credits sell for $15/metric ton (tonne) of carbon dioxide equivalent (CO_2-e), 30 percent of the credits would be additional. At a credit price of $35/tonne CO_2-e, additionality would increase to 50 percent or more. Nonadditionality arises because farming practices (nitrogen application rates) differ greatly across farms that appear to be similar, given the data used in our analysis.

While complete additionality cannot be ensured, it may be possible to design programs to increase it. In conservation programs, additionality could be increased by putting higher priority on practices that are less likely to be undertaken without payment support. However, if those practices are also more costly or produce less environmental benefit (when they are additional), greater additionality may not be cost effective. In a GHG offset program, additionality can be increased by limiting eligibility to regions where additionality is more likely than in other regions, but it also must be weighed against higher costs.

How Was the Study Conducted?

For existing conservation programs, additionality is estimated using propensity score matching with data from the 2009-2011 Agricultural Resource Management Survey (ARMS), which is sponsored jointly by USDA's Economic Research Service and National Agricultural Statistics Service. Once a farmer has received a conservation payment, we cannot observe what the farmer would have done without the payment. To estimate what the farmer might have done without the payment, we look at very similar or “matching” farms that have not received payments. The action taken by these matching farms, on average, is our estimate of what the farmer who received the payment would have done without the payment. The difference between the action taken, given the payment, and the action that would have been taken without the payment is a farm-specific measure of additionality. The measures we report are the average additionality across farms receiving payments. Units of measurement depend on the action taken. For nitrogen application rate changes due to payments for improved nutrient management, for example, additionality is measured in pounds (lbs) per acre of applied nitrogen. For practice adoption (e.g., conservation tillage) additionality is the probability that the adopted practice is, in fact, additional. For conservation tillage, additionality of 0.50 means that half of the conservation tillage practices supported by payments are additional.

For the offset credit analysis, we model producer response to hypothetical offset payments and estimate participation using the 2009 wheat and 2010 corn data from ARMS. Using ARMS data and nitrogen yield response functions drawn from the literature, we estimate the number of offset credits that would be provided by each farm, the proportion of the credits that would be additional, and the cost of providing those credits. We use a “prevailing practices” baseline, which is the average nitrogen application rate for farms in a small area with relatively uniform soils and climate. We analyze a number of “safety margins” (more stringent baselines or other eligibility criteria meant to reflect a conservative estimate of business-as-usual practices) to estimate the effect of these program design options on additionality.

Additionality in U.S. Agricultural Conservation and Regulatory Offset Programs

Voluntary Payments and Additionality

A large number of current and proposed State and Federal agricultural programs pay farmers and ranchers to undertake conservation practices or land use changes that can improve off-farm environmental quality (e.g., water quality, air quality, and wildlife habitat). These supported actions can include implementing a nutrient management plan, installing stream-side or field-edge buffers, adopting no-till, retiring cropland to grass or tree cover, and many other practices. In this report, we use the term "practice" to refer to any action taken to improve environmental performance, including adoption of traditional conservation practices (structural and management practices), land retirement, and changes in input use.

In fiscal year 2013, the U.S. Department of Agriculture (USDA) spent more than $6 billion through voluntary conservation programs. Many States, especially those with large farm sectors, also have conservation payment programs that are often quite similar to Federal conservation payment programs.[1] Beyond these traditional conservation programs, market-based mechanisms like pollution credit trading are increasingly seen as a way to reduce the cost of complying with regulation. Firms that are regulated (have limits on nutrient emissions, for example) could buy emission credits from unregulated sectors, including agriculture, where the cost of reducing nutrient emissions may be lower. From the farmer's perspective, these markets are a lot like government programs except that the payments come from private industry.

What are these payments accomplishing? The answer entails, in part, knowing whether the practices supported with payments would or would not have been pursued without a payment. A supported practice is *additional* if the farmer would not have used that practice if he or she had not received the payment.[2,3] Therefore, the payment produces environmental gain only if the supported practice

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[1] Not all payments are designed to support additional practices. Stewardship payments made through the Conservation Security and Conservation Stewardship Programs are based on practices already in place at the time of program enrollment and are designed to reward producers for strong conservation efforts.

[2] Ideally, additionality would be discussed and measured in terms of environmental outcomes such as improved water quality, enhanced wildlife populations, and higher levels of other environmental amenities that are valued by society. Our practice-based approach is driven by practical considerations. Measuring the environmental outcomes that result from conservation or trading programs would add considerable complexity to our analysis (see Smith and Weinberg) and has already been the focus of much research and policy development effort. Environmental benefit-cost targeting, for example, is now a feature of most USDA conservation programs, but it is a measure of the increase in environmental benefits only if the supported practices are additional (see Feather et al., for example), which has been mostly unknown. In contrast, there has been very little research on additionality in the adoption of practices in U.S. agricultural conservation programs.

[3] As we discuss later in this chapter and in the next chapter, payments may also induce farmers to adopt practices sooner than they would have without payments. Earlier adoption means that the practice is additional for the period between adoption with the payment and when adoption would have occurred without the payment.

is additional. If the supported practice would have been in use even without the payment, no environmental gain is attributed to the payment. Of course, additionality in practice use does not guarantee environmental gain. A practice that is poorly placed or unsuited to the problem it is intended to address may yield little or no environmental gain but could be considered additional if it would not have been in use without a payment.

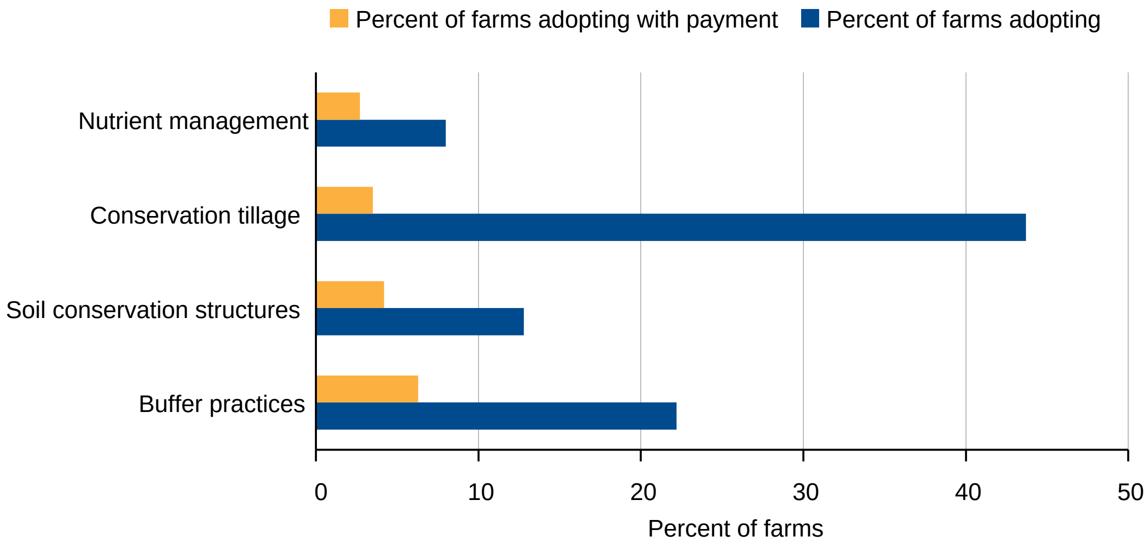
In a government conservation program, nonadditionality means that more environmental gain could have been realized under a given program budget or acreage limit. Support for nonadditional practices uses budget resources but does not contribute to improving environmental quality. In an offset credit market, nonadditionality means that regulatory limits on pollution will be breached. Nonadditional credits do not represent pollution abatement on the part of the seller, but will be used by purchasers to increase emissions to a level that would not otherwise be permitted.

Some Nonadditionality Is Inevitable

Additionality is difficult to ensure because payments are not the only reason farmers adopt conservation practices. A farmer may adopt a conservation practice without payment support because it reduces production costs or preserves the long-term productivity of his or her land. The value of these onfarm benefits, however, can vary widely across practices and, for any given practice, across farms. Some practices are widely adopted without payments (e.g., conservation tillage) while others are not (e.g., nutrient management) (fig. 1), indicating a difference in the likelihood that onfarm benefits exceed costs. For any given practice, moreover, some farmers have adopted it without receiving payments while others have not (see fig. 1)—differences that are presumably related to differences in the value the farmer assigns to onfarm benefits. These variations typically depend on many factors including soil, climate, and topography; the mix of crop and livestock enterprises; and producer management skills, risk aversion, and preferences.

Figure 1

Conservation practice adoption and payment rates for conservation practice groups



Source: USDA, Economic Research Service and USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey, 2009-11.

Furthermore, farmer expectations about onfarm benefits from a given conservation practice can change over time. Farmers who have not yet adopted a specific practice may change their assessment of it in response to successful application by neighbors, technical change that makes the practice easier to use, or a more complete understanding of onfarm benefits. Past practices on the farm, even if they are known by program administrators, are not a perfect proxy for what the farmer would do in the future in the absence of a payment. Just because a farmer has not been using a specific practice does not mean that he or she will not begin to use the practice in the coming year or in the next several years, even without receiving a payment.

Program administrators may provide payments for practices that would have been adopted without payments because they do not know farmer-specific benefits and cannot tell *whether* or *when* a specific farmer might adopt a specific practice. Farmers who believe that the practice is likely to provide sufficient onfarm benefit to fully offset costs may decide to seek a conservation payment even if it is not essential for adoption. It may not be possible to distinguish these farmers from those who will adopt the practice only if they receive a payment. Given that most conservation practices have been adopted by at least some farms without the benefit of a conservation payment, it is likely that some level of nonadditionality is inevitable for most conservation practices.

The first step in increasing additionality in conservation payment programs is to understand, as well as possible, the level of additionality in existing programs and possible future programs. Despite the lack of precise information on individual farms, it may be possible to estimate the average level of additionality across a large number of farms. It may also be possible to use these estimates and other information to improve additionality by targeting program payments more precisely. Understanding how well we can distinguish between additional and nonadditional practices is the subject of this report.

Measuring (and Managing) Additionality

A standard measure of additionality is the average effect of treatment on the treated (ATT,) a broad conceptual measure used to study many different types of policy intervention (Rosenbaum and Rubin, 1983; Caliendo and Kopeinig, 2008). While the exact definitions of “effect,” “treatment,” and “treated” depend on the specific context, “effect” always refers to an *outcome* that may have been caused by some type of “treatment” given to or provided for a “treated” individual or entity. For conservation programs, the “treatment” is the payment supporting a specific practice or practices, the “treated” refers to the farmer receiving the payment and the field or farm where the practice is to be applied, and the “effect” is the change in conservation outcomes or farming practices. In this study, we focus on changes in practice use, although changes in environmental indictors (e.g., soil erosion or nutrient runoff) or changes in environmental quality (e.g., cleaner water) could also be used as the conservation outcome. The unit of measurement for the ATT depends on the outcome being measured and may include several metrics because a single payment could affect more than one outcome. For each metric, the ATT is the *average* effect across farms that received a payment.

Given our focus on practices, the primary challenge in estimating the ATT is determining whether the conservation practice(s) in question would have been adopted without the payment. Once a payment is made and required practice(s) are in use, however, it is not possible to observe whether the farmer would have adopted the practice(s) without the payment. As already noted, previous practice use (if it is known by the program administrator) is not a perfect indicator of future practice use because practice use on any given farm is constantly evolving as market prices, technology, and farmer perceptions evolve. We take up the question of estimating what farmers who received payments would have done without them in the “Additionality in Existing Conservation Payment Programs” chapter for existing conservation programs and in the "Additionality in Offset Markets" and "Strategies To Enhance Additionality in Offset Programs" chapters for a hypothetical offset credit program.

Finally, estimates of additionality may provide insight that can be used to increase the level of environmental benefit realized from both traditional conservation programs and market-based programs, including offset credit trading programs. In the “Additionality in Existing Conservation Payment Programs” chapter, we discuss a number of mechanisms by which estimates of additionality could be used to improve current conservation programs. In the "Strategies To Enhance Additionality in Offset Programs" chapter, we formally analyze several program design features that have been proposed as ways to increase additionality in offset credit trading.

Three Conservation Practice and Payment Types

We consider additionality in terms of the practice supported and the type of payment provided. Individual conservation programs (e.g., USDA's Environmental Quality Incentive Program (EQIP)) can support a wide range of practices across many different types of farms and may offer different payments depending on the type of practice supported. We do not consider additionality in terms of overall programs because it depends on the level of installation/adoption costs, potential onfarm benefits, and the payments offered to producers, which can vary within and across programs. In this report, we focus on practice and payment combinations that are typical of existing conservation programs or (potential) offset credit markets. Although we use the ATT or a similar measure in each case, outcome metrics vary depending on the payments offered and practices supported.

For existing conservation programs, we consider **structural practices** and conservation payments that cover a portion of practice installation costs (sometimes referred to as cost-sharing)—a mode of financial support that dates from the 1930s—and **conservation management practices** and incentive payments that support the transition to new practices—a mode of support which came into widespread use in the 1990s. The third payment type is the sale of **pollution offset credits** in markets that are designed to reduce the overall cost of regulation by shifting abatement from high-cost firms in regulated sectors to low-cost firms in nonregulated (or less regulated) sectors, including agriculture. Although the analysis is motivated in terms of a greenhouse gas offset program, insights gleaned from our analysis could also apply to other offset programs (e.g., nutrient credit trading under emission regulations for water quality). In the balance of this chapter, for each practice/payment type, we explain the practices themselves, including a very general discussion of onfarm costs and benefits, how they are supported by conservation programs or other payments, how outcomes are measured, and the measures of additionality that will be estimated in the second, third, and fourth chapters.

Structural Practices and Conservation Payments (Cost-Sharing). A wide variety of conservation practices can be referred to as “structural.” We focus on structural practices that involve physically reshaping land and/or placing permanent vegetation in strategic locations to control the flow of water and filter nutrients and other pollutants from it. We consider two groups of these practices. The “soil conservation structures” group includes terraces, grade stabilization structures, and water and sediment basins—practices designed to control storm water runoff and move it off the field without causing soil erosion. The “buffer practices” group is made up of field-edge filter strips, riparian buffers, field borders, and grassed waterways—practices that remove nutrients and sediment from runoff water before it leaves the farm.

Structural practices often have high installation costs and tend to yield onfarm benefits that are small, intangible, or occur only in the distant future. For example, field-edge filter strips, riparian buffers, and grassed waterways, which we refer to collectively as buffer practices, are designed to capture nutrients and sediment before leaving the farm. Most of the benefits associated with buffer practices occur downstream in the form of cleaner water and are not captured by the farmer or landowner. The cost of taking land out of production and establishing vegetation can also be high, further discouraging adoption. Nonetheless, buffers may provide some onfarm benefits, such as enhanced wildlife populations for hunting or viewing. Some farmers may also receive satisfaction from practicing good stewardship (Chouinard et al., 2008). Because some farms have adopted buffer practices without cost-share payments, it is not possible to rule out self-financing of installation in the future.

For these practices, existing conservation programs provide payments that cover a portion of installation costs. EQIP, for example, typically covers 50 percent of these costs, although higher payment levels are possible for practices that are particularly effective in addressing an important resource concern. Many States also have conservation programs that can provide cost-sharing for structural practices. In most cases, cost-sharing requires recipients to maintain practices for their full lifespan, which depends on the practice but is typically 10-15 years for the practices we consider.

For practices in the “buffer” group, instead of relying on EQIP, a producer could receive payments from the CRP, which covers a portion of practice installation costs (commensurate with EQIP cost-sharing) and an annual rental payment that covers lost income on land used for the buffer practice for the life of the contract (10-15 years). Our data show that a large majority of producers receiving payments for buffer practices are (or were) enrolled in the CRP.

For structural practices, our measure of outcome is whether the practice is in use on the farm. Although financial assistance may have been provided some years ago, properly maintained practices can be effective for decades (well beyond the estimated lifespan or CRP contract length). For farms that received conservation payments for structural practice adoption (at any time in the past) our measure of additionality is the proportion of these farms where the practice would not be in use if financial assistance had not been received.

Management Practices and Incentive Payments. Management practices involve changes in the methods used to plant or fertilize crops, manage livestock grazing, use irrigation water, etc. Common management practices include conservation tillage, nutrient management, and rotational grazing. Because these practices often reduce input use, they can reduce a farmer’s production costs. For example, conservation tillage may reduce fuel and labor costs and requires less investment in tillage implements and large tractors needed to pull them. On the other hand, conservation tillage may also require a planter or seed drill that can cut through the residue that remains on the soil surface and may require greater reliance on chemical weed control. Nutrient management may allow farmers to reduce fertilizer costs but could increase the cost of applying fertilizer (adding a fertilizer application after planting, for example) and may expose farmers to yield risk if fertilizer cannot be applied when needed (because of wet weather, for example). Management practices can also affect yields and other outputs from the farm. Reducing tillage may delay planting (and reduce yields) where springtime weather is wet and cool, but may also preserve soil moisture (and increase yields) where rainfall is limited and drought risk is high. Given the wide range of conditions faced by farmers, any given management practice may be profitable for some farms but not for others.

We consider two groups of management practices. Conservation tillage includes mulch till (30 percent or greater residue cover at planting), ridge-till, strip-till, and no-till practices. Nutrient management includes comprehensive nutrient management and manure management (which typically involves land application of manure). Nutrient management is, in fact, a collection of practices that form a nutrient management plan and are implemented as a group. For example, nutrient management in crop production will always involve selection of nutrient application rates and may also involve the method of application, timing of application, soil testing, plant tissue testing, and other actions that help match available nutrients to crop needs.

For these practices, conservation programs typically offer payments that support the transition to new practice(s). In EQIP, for example, farmers can receive a per-acre payment for a period of 3 years to help smooth transition to new practice(s). To receive payments, farmers must agree to use the practice(s) for 3 years on at least a part of their farm. Once the payments end, however, farmers are free to decide whether to continue using the practice or drop it. For farmers who would not have adopted the practice in the absence of the payment, these 3 years provide some additional environmental benefit. The ultimate goal of transition incentive payments, however, is to encourage farmers to adopt conservation management practices for the long run.[4] When a short-term payment leverages a long-term change in practices, the environmental benefits can be much larger than if the practice is dropped when the payments end. The underlying assumption is that management practices can be profitable over the long term for farms that are not yet using them, although there may be transition costs (e.g., to purchase or modify machinery) that can be covered (at least partially) by payments. Payments that leverage long-term adoption may also have a “demonstration” effect. That is, other farmers may also adopt conservation management practices once they are successfully (and profitably) applied on a neighbor’s farm.

We only measure additionality that flows from long-term changes in practice adoption. Our data (see the “Additionality in Existing Conservation Payment Programs” chapter for details) do not provide information on practices that are no longer in use on the farm and, therefore, do not provide information on payments that might have been associated with those practices. And, of course, we are unable to track any demonstration effect that may be associated with a transition incentive payment. In the “Additionality in Existing Conservation Payment Programs” chapter, we provide more detail on how these data limitations may affect our estimates of additionality.

For conservation tillage, our measure of outcome is whether conservation tillage is in use on the farm, not only when the payments were made but also after the payments have stopped. Our measure of additionality for farms that receive incentive payments is the proportion of these farms who continue to use conservation tillage (even if the payments have expired) and would not have adopted conservation tillage without a payment.

For nutrient management, we use several measures of additionality. The first is the proportion of farms that have written nutrient management plans but would not have written plans in the absence

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[4] Roberts and Lubowski address a similar question in the CRP. They argue that CRP benefits often extend beyond the end of CRP contracts because landowners do not necessarily return land to crop production. While it would be interesting to do a similar study for working land programs, we are not aware of data, at least at this time, that could support this type of analysis.

of the incentive payment. While it is important to understand whether producers are likely to develop a written plan in the absence of funding, it is the application of those plans that can produce improvements in environmental quality. To capture the effect of nutrient management payments on actual nutrient management practices, we also look at several practices likely to be included in nutrient management plans for corn farms, where nitrogen application and the potential for nitrogen runoff is a particularly important issue. Specifically, we consider three measures of additionality on corn farms that received nutrient management payments:

- Difference between nitrogen application rates with and without the nutrient management payment (lbs per acre);

- Difference in the proportion of total nitrogen fertilizer applied in the fall with and without the nutrient management payment; and,

- Difference in the proportion of nitrogen fertilizer applied after planting with and without the nutrient management payment.

Finally, we measure additionality at a specific point in time. We do not account for the possibility that farmers who receive payments for a given conservation practice may have eventually adopted the practice even without a payment. A farmer who received a payment for adopting conservation tillage in the 1980s, for example, may have been very unlikely to adopt the practice at that time without a payment. An estimate of additionality, made at that time, would have indicated that the supported practice was very likely additional. In more recent years, when the data used in the "Additionality in Existing Conservation Payment Programs" chapter were collected, the likelihood of adoption in the absence of a payment is considerably higher, leading us to conclude that the practice is somewhat less likely to have been additional. Ideally, a measure of additionality would recognize that an important role of incentive payments is to encourage a more rapid rise in the proportion of producers who use the practice. These payments may convince some farmers to try conservation management practices sooner than they would have without a payment, even though they would have eventually adopted the practice, even without the payment. The experience of these producers, if successful, may also convince others to try the practice without payment support. While we acknowledge the existence of these effects, our data do not support analysis of these outcomes.

Greenhouse Gas Offset Credit Program. Conservation payments can also come from private sources, largely through Government-sanctioned offset markets (sometimes referred to as credit trading). In an offset market, regulated entities seek to reduce the cost of pollution abatement by purchasing offsets from farmers or ranchers who can reduce emissions at a lower cost. In a nutrient trading market designed to protect water quality, for example, a regulated company could buy credits from farmers who agree to adopt specific practices that reduce nutrient runoff. These credits allow the purchaser to generate greater nutrient emissions than would otherwise be allowed. Additionality is essential—offsets must represent emission reduction that would not have been realized in the absence of the credit sale. If offsets do not represent additional reductions in nutrient emissions, total emissions will be higher than they would have been under the regulation without the offset program because purchasers will increase emissions by the amount of the credits they purchase while credit sellers fail to reduce emissions by the same amount.

Our empirical analysis is based on a simulated (hypothetical) program of agricultural GHG offsets that would complement cap-and-trade regulations designed to limit U.S. GHG emissions. While a nationwide cap-and-trade system is unlikely to be implemented soon, this offset approach could also be used in conjunction with water quality regulations. Even though the number of actual water quality trading programs is small and the number of trades to date is modest, interest in trading-based conservation incentives is high and may grow as States begin implementing rules designed to achieve water quality improvements in specific water bodies.

The simulated offset program would address only a single greenhouse gas emission (nitrous oxide) and a single agricultural management activity (nitrogen application rates). Using Intergovernmental Panel on Climate Change (IPCC) standards, we estimate that some portion of all nitrogen applied as fertilizer will be lost to the atmosphere in the form of nitrous oxide, an extremely potent greenhouse gas.[5] A reduction in the rate of nitrogen application is assumed to reduce nitrous oxide emissions which are expressed as a carbon dioxide equivalent (CO_2-e).

In setting up the offset rules, the Government must specify who is eligible and how many credits they can earn for a given practice. These rules take the form of a baseline: each farmer is assigned a baseline nitrogen rate. A farmer who signs up to apply nitrogen fertilizer at rates lower than his assigned baseline can sell credits (in units of CO_2-e) to regulated entities. In our analysis, these baselines are based on the average nitrogen application rate over a group of similar farms; this is called a "prevailing practice" baseline. Under this approach, however, farms already using below-average nitrogen application rates would be able to sell some credits without actually reducing nitrogen application. These credits are not additional because they do not represent reductions in fertilizer application and subsequent GHG emissions. Farmers who would normally use nitrogen at rates above the baseline would have to commit to applying nitrogen at a rate below the designated baseline to receive credits; any offsets they sell would represent actual reductions in nitrogen use and would be additional. In all cases, the payment received by the farmer is equal to the number of credits sold (this is his baseline minus his agreed-upon nitrogen application rate), multiplied by the price per credit that he can get in the credit market.

Additionality is the actual reductions in nitrogen application (or, equivalently, the reduction in greenhouse gas emissions measured in CO_2-e) relative to the farm's observed nitrogen application rate.[6] An ATT-type measure (which we also report) is the proportion of credits that represent actual reductions in GHG emissions (through reduction in nitrogen application). Table 1 is a summary of practice, payment, and outcome metrics for selected conservation practices and programs.

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[5] CO_2-e emissions per unit of applied nitrogen (N) are calculated as follows: N emissions equal to 0.01 multiplied by N application; N emission is converted to N_2O emission by multiplying N emissions by 1.57; and N_2O emissions are converted to CO_2-e by multiplying N_2O emission by 310. So, each pound of nitrogen applied is assumed to result in CO_2-e emissions of 4.87 lbs. See appendix 2 for more details. In reality, the relationship between nitrogen fertilizer application and nitrogen emissions is more complicated and depends on soil moisture, precipitation after application, temperature, soil permeability, and other factors.

[6] We have this information for farms included in the 2009 and 2010 ARMS surveys. These data are used to estimate producer GHG offset market participation (see the third chapter for details). We note that credit buyers and the government would not necessarily have this information. We discuss issues surrounding the collection and potential accuracy of this information in the fourth chapter.

Table 1

Summary of practice, payments, and outcome metrics for selected conservation practices and programs

Practice group	Payment type	Action required for payment	Outcome measure(s)	Measure of additionality
Additionality in structural practices supported by existing programs				
Soil conservation structures[1]	Share of actual cost	Practice installation	Practice use on field	Proportion of cost-shared practices that would not be in use without the cost-sharing
Buffer practices[2]	Share of actual cost; annual rental payment on land (CRP only)	Practice installation	Practice use on field	Proportion of cost-shared practices that would not be in use without the payment(s)
Additionality in management practices support by existing programs				
Conservation tillage[3]	Per-acre payments for 3 years	Use conservation tillage for 3 years (when payments are received)	Conservation tillage in use on field (after payments end)	Proportion of conservation tillage, supported with incentive payments (at some time, even in the past) that are still in use but would not be in use if the payment had not been made.
Nutrient management (NM)[4]	Per-acre payments for 3 years	Possess NM plan and apply it for 3 years (when payments are received)	Existence of written plan (after payments end)	Proportion of written NM plans, supported with incentive payments (at some time, even in the past) that are still in use but would not be in use if the payment had not been made.
			Nitrogen (N) application rate in corn (even after payments end)	Difference between nitrogen application rate for corn (lbs. per acre) with and without payment
			Proportion of N applied in fall for corn (even after payments end)	Difference in proportion of N applied in fall for corn with and without payment
			Proportion of N applied after planting for corn (even after payments end)	Difference in proportion of N applied after planting for corn with and without payment
Additionality in reducing nitrogen application through a simulated greenhouse gas offset program[5]				
GHG offset credits	Payment per credit, rate determined by market	N application rate below “reference” rate for area	GHG emission credits generated by reducing nitrogen application	Credits generated based on the difference in nitrogen application with and without the GHG offset credit program.

[1] Terraces, grade stabilization, and water and sediment basins.
[2] Filter strips, riparian buffers, field borders, grassed waterways.
[3] Mulch till, ridge till, no-till.
[4] Comprehensive nutrient management, manure management.
[5] See text for description of simulated credit eligibility rules.
GHG = greenhouse gas; CRP = USDA Conservation Reserve Program.

Source: USDA, Economic Research Service and USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey, 2009-11.

Additionality in Existing Conservation Payment Programs

Additionality is critical to the success of U.S. agricultural conservation policy. Voluntary payments are the single most important means by which U.S. farmers and ranchers are encouraged to conserve resources and improve environmental quality. Although the possibility of nonadditionality has been recognized for a number of years, only a handful of studies have attempted to measure additionality in the adoption of practices supported by existing conservation payments.

Measuring additionality can be difficult. Once a payment is made to a specific farmer, for a specific practice, it is no longer possible to observe whether the farmer would have adopted the practice without the payment. Developing an estimate of this missing counterfactual is the critical task in measuring additionality. Using a technique known as propensity score matching (PSM), we attempt to estimate what farmers who received conservation payments (payment farms) would have done without the payment by looking at practice use for a group of very similar, or “matched,” farms that did not receive payments (nonpayment farms).

The theory behind propensity score matching can be understood by analogy to a controlled experiment. In controlled experiments, individuals are assigned randomly to “treatment” and “nontreatment” groups to minimize the possibility of systematic differences between groups, thereby ensuring that differences in outcome, on average, reveal the effect of the treatment. In policy evaluation studies, however, researchers are seldom able to randomly assign the treatment which, in our case, means a conservation payment. A simple comparison of farms that received conservation payments to those that did not may be misleading. Suppose some farmers are more likely than others to seek and receive payments for a given practice and that these same farmers are more likely than others to adopt the practice without a payment (although, of course, this cannot be observed once the payment is made). In this situation, using the average adoption rate among all nonpayment farms as an estimate of what payment farms would have done without the payment will overstate additionality because the payment farms would be more likely than nonpayment farms to adopt the practice even without a payment. This scenario is realistic because conservation program payments usually cover only a portion of conservation practice adoption cost and, therefore, attract farmers who believe they will realize benefits from conservation practice adoption. Matching methods such as PSM can provide a better estimate of additionality if farms that are similar on a range of characteristics are also likely, on average, to make similar decisions about production and practice adoption (see Caliendo and Kopeinig for a review of matching methods).

The validity of PSM rests largely on the assumption that all important differences in the likelihood of receiving “treatment” (a conservation payment) can be accounted for using observed characteristics. If that is true, the matched nonpayment farms form a comparison group that has the same characteristics as a randomly selected control group, and the average difference in outcomes between the payment farms and matched nonpayment farms can be attributed to the payment. If unobserved factors are important, however, PSM will not completely remove potential biases. Although this assumption cannot be formally tested, its plausibility rests on the extent to which available data are rich enough to determine whether farms are observationally equivalent with respect to the likelihood of receiving a conservation practice adoption payment.

Propensity score matching models have been used to estimate additionality in several agri-environmental contexts. Mezzatesta et al. use a propensity score matching model to estimate additionality for a select group of conservation practices in 25 Ohio counties. They find additionality in practice adoption in excess of 80 percent for hayfield planting, cover crops, and field-edge filter strips but less than 25 percent for conservation tillage. Liu and Lynch use propensity score matching to show that State and local Purchase of Development Right (PDR) programs have reduced the rate of farmland loss in six Mid-Atlantic States by 40-55 percent. Chabe-Ferret and Subervie use difference-in-difference matching to estimate additionality for French implementation of an EU agro-environmental subsidy program that supported cover crops, grass buffers, reduced application of fertilizer and pesticides, increased crop diversity, and transition to organic farming. They found that the payments resulted in only small increases in crop diversity and use of cover crops. For grassed buffers, the authors conclude that payments were justified because of large benefits, despite low levels of additionality. Additionality was estimated to be high for transition to organic production.

Data on Practices and Payments

Data on practice adoption and payments are from the crop-specific, field-level portion of ARMS for 2009 (wheat), 2010 (corn), and 2011 (barley and sorghum). For each practice listed in the left-hand column of table 2, respondents were asked which practices were in use on the surveyed field, whether a payment was received in conjunction with the practice, and what program the payment came from. Options included EQIP, CSP, and CRP continuous signup, and other Federal, State, and local programs. (The same acronym is used for the Conservation Security Program, 2004-08, and the Conservation Stewardship Program, 2009 to present.)

Practices were grouped by function to reduce the number of propensity score models to be estimated and increase the number of observations used for each (table 2, second column). For example, field-edge filter strips, grassed waterways, field borders, and riparian buffers were grouped together as buffer practices because they filter nutrients and sediment from runoff before it leaves the field or farm. Other groups include conservation tillage practices (e.g., mulch-till, no-till), soil conservation structures (e.g., terraces, grade stabilization structures), and nutrient management. For the practice groups, producers were classified as adopters if they had adopted at least one practice in the group and were considered payment farms if they had received a payment in conjunction with at least one practice in the group.

The frequency of adoption and payment for specific practices is shown in figure 2. In the conservation tillage group, the percentage of farmers adopting no-till and other conservation tillage is fairly similar. The other three groups tend to be dominated by single practices. Soil conservation structures are mostly terraces, and buffer practices are mostly grassed waterways. So, our estimates of additionality for these groups are likely to reflect the dominant practices. Comprehensive nutrient management accounts for about 70 percent of the nutrient management group.

For each practice group, table 2 also shows which ARMS surveys provided the data and the conservation payment programs that support the adoption practices in each practice group. The data vary across practice groups for a number of reasons:

- Different surveys are used for different practice groups because survey questions varied across survey years. For example, the conservation tillage model does not include wheat because questions about conservation tillage payments were not asked on the 2009 survey.

- Farms that reported CRP payments are considered only for buffer practices because CRP does not fund soil conservation structures, tillage practices, or nutrient management.

Table 2

Conservation practice groups, program payments, surveys, and adoption and payment rates

Practice group	Practices	Programs[1,2]	ARMS[3]	Farms adopting	Receiving payments for adoption
				Percent	
Buffer practices	Field-edge filter strips, grassed waterways, field borders, riparian buffers	EQIP, CRP, other	Wheat, 2009	13.7	5.3
			Corn, 2010	25.3	6.8
			Overall	**22.2**	**6.3**
Soil conservation structures	Terraces, grade stabilization structures, and water and sediment basins	EQIP, other	Wheat, 2009	20.1	7.3
			Corn, 2010	9.9	3.0
			Overall	**12.8**	**4.2**
Conservation tillage	No-till, strip till, mulch till, ridge till	EQIP, other	Corn, 2010	43.2	3.5
			Barley, 2011	55.5	8.2
			Sorghum, 2011	52.9	0.7
			Overall	**43.7**	**3.5**
Nutrient and manure management[4]	Comprehensive nutrient management, manure management	EQIP, other	Wheat, 2009	4.0	1.5
			Corn, 2010	9.6	3.2
			Barley, 2011	20.7	9.4
			Sorghum, 2011	1.9	0.2
			Overall	**8.0**	**2.7**

ARMS = Agricultural Resource Management Survey; CRP = USDA Conservation Reserve Program; EQIP = USDA Environmental Quality Incentives Program.

[1] CRP payments are considered only with the buffer practice group because CRP does not support practices in the other practice groups.

[2] Farms that received Conservation Security Program (CSP; 2004-2008) or Conservation Stewardship Program (CSP; 2009-present) payments are excluded entirely because a portion of these payments support stewardship (ongoing conservation efforts) rather than additional conservation. Moreover, enhancement payments—a large part of CSP—supported small changes to existing practices and, therefore, are not well matched to ARMS questions, which are based on full adoption of standard conservation practices.

[3] Data on practice adoption and payments are from ARMS. Different surveys are used with different practice groups depending on the practice and program participation questions in any given year.

[4] Excludes farms that are likely subject to regulation based on confined animal feeding operation. Nutrient management payments to these farms would not be additional, nor should they be matched to other farms that do not face regulation.

Source: USDA, Economic Research Service and USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey, 2009-11.

- Farms that reported CSP payments are excluded entirely. A portion of CSP payments were based on ongoing conservation effort (or stewardship) rather than additional conservation. Moreover, practice “enhancements” funded under the 2004-2008 version of the CSP sometimes differed from standard practices that are funded by other programs and are the subject of ARMS questions.[7]

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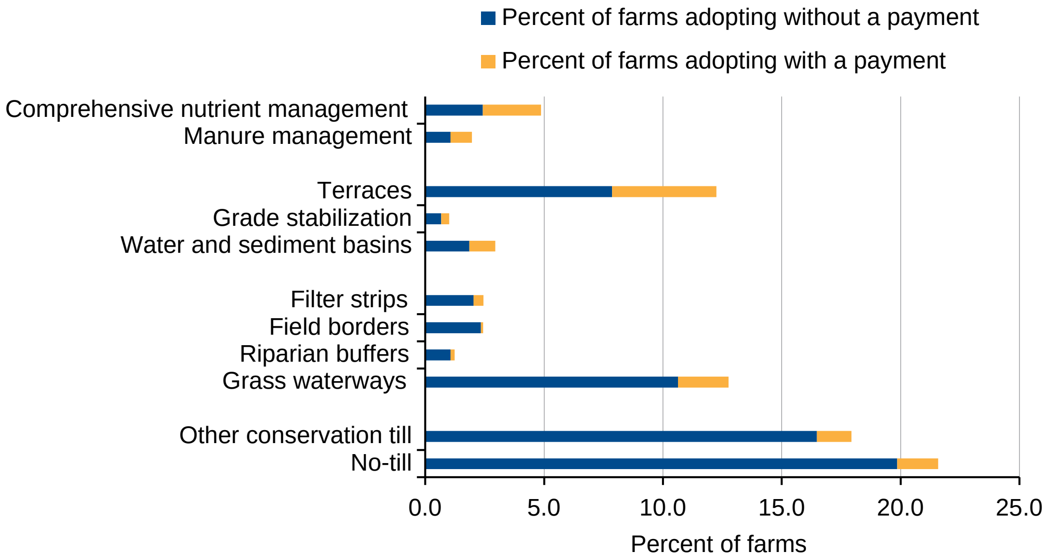
[7] Enhancements were often improvements to existing practices. For example, producers could add components to nutrient management plans, agreeing to inject manure or to test plant tissues before adding nitrogen after planting.

Figure 2

Conservation practice adoption and payment rates for widely used conservation practices



Source: USDA, Economic Research Service and USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey, 2009-11.

- Farms likely to be regulated as confined animal feeding operations (CAFOs) under State laws were excluded from the nutrient management analysis because all CAFO regulations require producers to devise and use some type of nutrient or manure management plan. Nutrient management payments are nonadditional for these farms as the practice would have been adopted without the payment.[8]

While our data provide a great deal of information on practice adoption and payments, they do not capture every possible response to payments. That is particularly true of transition incentive payments offered to farmers who agree to adopt conservation management practices, including conservation tillage and nutrient management. As noted in chapter 1, payments are provided for a period of 3 years to encourage adoption of conservation management practices that could also be profitable after the initial transition period. Ideally, payments would prompt a permanent change and, therefore, could be effective for many years beyond the period of the actual payments. Some situations, however, are not captured by our data but may affect the overall level of additionality actually achieved by transition incentives:

- Some farmers who received transition incentive payments in the past may have dropped the supported practice once the payments ended. Additionality is underestimated on these farms because these farms did use the practice(s) in question, albeit for a short time, and would not have used it (them) without the payment.

- Some farmers who received transition incentive payments would have eventually adopted the practice in question, although the payments caused them to adopt the practice earlier than they

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[8] Data on State-level programs were obtained through a review of documents available from the State and a series of interviews with USDA's Natural Resources Conservation Service (NRCS) officials who work with farmers to meet the requirements of State regulation.

otherwise might have. Our measure of additionality implicitly assumes that nonpayment farms would have already adopted a given practice if they were going to adopt it at all (without a payment). If some of the nonpayment farms do adopt at some future time without a payment, our measure may be overstating additionality.

- Farmers who adopt early because of payments may also create a demonstration effect. If they show that a conservation practice can be profitable, other farmers may also decide to adopt without a payment. To the extent that there is a demonstration effect, we may be understating additionality.
- Additionality may vary across regions because some practices are better adapted (more likely to be profitable) in some regions than in others. Unfortunately, our data do not contain enough observations to allow us to make regional estimates.

Estimating the ATT for Structural and Management Practices

We use PSM to estimate the ATT measures for conservation structural and conservation management practices introduced in chapter 1. The first step is to estimate the propensity scores. A farm's propensity score is the probability of receiving a conservation payment for a specific practice group. We use statistical models, one for each practice group shown in table 2, to link the receipt of a payment (0-1) to the characteristics of the practice, field, farm, farmer, and program (table 3). To ensure high-quality matches, the data must account for all factors affecting conservation practice adoption and the likelihood that farms would be selected by the program agency to receive payments. Our specifications are based on a review of the extensive literature on the possible motivating factors for conservation practice adoption (e.g., Caswell et al.; Ervin and Ervin; Featherstone and Goodwin; Fuglie and Kascak; Lichtenberg; Soule et al.; Traoré et al.; Wu and Babcock). These studies show a range of factors that affect adoption, including practice characteristics (e.g., cost, yield effects), field characteristics (e.g., productivity, erodibility), farmer characteristics (e.g., age, education), farm characteristics (e.g., farm size, primary products, tenancy), and availability and size of conservation payments.

Conservation policy itself poses a major challenge for matching because it involves a complex mix of Federal, State, and local programs. For many USDA conservation programs, priorities are set by USDA staff at the State or even local level, tailoring programs to meet local resource conservation and environmental needs. In EQIP, for example, State-level staff are largely responsible for determining which resource concerns are addressed and which practices are supported, but environmental priorities and supported practices can also vary across counties within a State. Many States also have their own conservation payment programs that typically use USDA practice definitions and standards and offer similar levels of financial assistance. This variation in program priorities also needs to be captured in the propensity score models. To proxy for variation in environmental priorities, we include practice-specific estimates of EQIP and CRP spending at the county level. We also include State-level fixed effects to pick up any additional differences in policy and priorities across States.

Next, we matched payment and nonpayment farms. Rather than defining a small group of matched farms to serve as a comparison group for each payment farm, our statistical approach assigns a set of weights to each nonpayment farm (one for each payment farm) that are proportional to the difference in propensity scores between the nonpayment farm and each payment farm. While all of the nonpayment farms are included in the comparison group, nonpayment farms that have propensity

Table 3

Data for propensity score models

Variable	Description	Nutrient management	Conservation tillage	Buffer practices	Soil conservation structures
		Averages for practice-specific datasets			
Field					
Productivity	NCCPI (unit interval)	0.490	0.550	0.517	0.599
Erodibility	Highly erodible field (0/1)	0.129	0.127	0.113	0.117
Wetland	Wetland in field (0/1)	0.035	0.025	0.034	0.022
Farm					
Size	Log of total farm acreage	6.840	6.594	6.789	6.745
Manure	Manure applied to field (0/1)	0.181	0.255	0.186	0.108
Farmer					
Occupation	Primarily farming (0/1)	0.909	0.917	0.906	0.886
Age	Years	55.871	55.392	55.893	56.182
Education	College degrees (0/1)	0.225	0.199	0.214	0.227
Land tenure	Owns field (0/1)	0.513	0.526	0.519	0.477
Programs					
EQIP payments	$/cropland acre in county	0.068	0.035	0.02	0.063
	“ in adjacent counties	0.058	0.034	0.016	0.056
CRP payments	“ in county	n/a	n/a	0.219	n/a
	“ in adjacent counties	n/a	n/a	0.212	n/a
Other					
Population density	1,000 people per acre (by county)	0.088	0.108	0.089	0.095
Local adoption rate	Unit interval	0.09	0.327	0.224	0.138
Number of observations		2,608	1,157	2,176	1,180
Number treated		73	37	110	55
Number treated (corn only)		26	n/a	n/a	n/a

NCCPI = National Commodity Crop Productivity Indicator (see Dobos et al.); CRP = USDA Conservation Reserve Program; EQIP = USDA Environmental Quality Incentives Program.
n/a = not applicable.

Source: USDA, Economic Research Service and USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey, 2009-11.

scores that are far from the payment farm are assigned very small weights. So, our estimate of what the payment farm would have done without a payment will largely reflect nonpayment farms that are very similar to payment farms, as measured by the propensity score.

With the weights assigned, we estimated the counterfactual outcomes. That is, what would have happened had the payment not been received for each farm that did, in fact, receive a payment for a given practice group. We then calculated farm-level measures and averaged them to arrive at our group-specific estimates of ATT.

Additionality Is High for Some (But Not All) Practices

Results for soil conservation structures, buffer practices, conservation tillage, and written nutrient management plans are given in table 4. For each of these practice groups, the unit of measure is practice use. For payment farms, practice use is given so the rate of use is 1 (see "With Payment" column). For nonpayment farms, the column "Estimated Without Payment" is our estimate of the average probability that payment farms would have adopted the practice without the payment. Our estimate of additionality (the ATT; see last column in table 4) is the difference between the rate of adoption with the payment and our estimate of what the rate of adoption would have been without the payment.

We find high levels of additionality for buffer practices (0.80 or 80 percent) and soil conservation structures (0.82). From table 4, we note that the rate of adoption with payment is 1 ("With Payments" column), while the rate of adoption that would have been realized without the payment is estimated to be 0.18 ("Estimated Without Payment" column), and our estimate of additionality (the ATT) is the difference (1 - 0.18 = 0.82). Our findings are generally consistent with those of Mezzatesta et al., who find high levels of additionality (above 80 percent) for hayfield planting (which involves taking land out of crop production), cover crops, and filter strips, practices that also have high upfront costs or provide little onfarm benefit, at least in the short term. For these practice groups, we note that the adoption rate for all nonpayment farms is much smaller than the estimate for payment farms without payments, which are based on the matching procedure, indicating that matching makes a difference in our estimates of ATT. This difference indicates that payment farms are systematically different from nonpayment farmers (i.e., they would make different decisions, on average, regarding conservation practice adoption even without payments). This difference may be due to any of the factors included in the models used to estimate propensity scores (see table 3).

For conservation tillage, we estimate additionality of 0.56 (56 percent), considerably lower than for either category of structural practices, but much higher than the estimate of Mezzatesta et al., who find that less than 25 percent of conservation tillage adopted with payment support is additional. The

Table 4

Additionality in adoption of common conservation practices

Practice	Unit	Payment farms		All non-payment farms[2]	Additionality in adoption (standard error)
		With payment	Estimated without payment[1]		
Soil conservation structures	Practice use (rate)	1	0.22	0.09	0.82 (0.046)
Buffer practices	Practice use (rate)	1	0.20	0.15	0.80 (0.030)
Conservation tillage	Practice use (rate)	1	0.44	0.42	0.56 (0.070)
Nutrient management	Practice use (rate)	1	0.12	0.05	0.88 (0.051)

[1] Estimated as the average rate of adoption for nonpayment farms using the weights defined through the Propensity Score Matching (PSM) procedure.

[2] Estimated adoption rate for all nonpayment farms, not using the weights defined through the PSM procedure.

Source: USDA, Economic Research Service and USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey, 2009-11.

difference in estimates may indicate that conservation tillage is better adapted in the portion of Ohio studied by Mezzatesta et al. (55 percent overall adoption rate) than in the 26 States included in our study (40-percent overall adoption rate).

Finally, our estimate of additionality for nutrient management plans (0.88) is also quite high. The estimate is based on survey questions that ask producers whether they have written plans for nutrient and/or manure management and whether they have received payments in conjunction with these plans. This indicates that farmers are unlikely to write down their nutrient management practices without receiving a payment but does not provide any indication of how nutrient management plans actually affect nutrient application.

In terms of actual nutrient management practices, we consider nitrogen application rates, fall nitrogen application, and postplanting application in corn. In table 5, the “With Payment" column is the average observed rate of nitrogen application, proportion of nitrogen applied in fall, or the proportion of nitrogen applied after planting for farms that received nutrient management payments. The column “Estimated Without Payment” is our estimate of these three measures that have occurred on payment farms without the payment. We estimate that corn producers who received nutrient management payments are much less likely to apply nitrogen fertilizer in the fall than they would have been without the payment. In the absence of the payments, we estimate that these farms would have applied 12.9 percent of nitrogen fertilizer in the fall, but actually applied only 1.2 percent of total nitrogen in the fall. So, nutrient management payments appear to effectively eliminate fall application of nitrogen. For application rates and postplanting application, the results are not definitive. For nitrogen application rates, we show that payment farms applied an average of 94.6 lbs of nitrogen per acre, while we estimate that they would have applied 115.6 lbs per acre without the nutrient management payment. Our point estimate of ATT (farms that received nutrient management payments apply 21 lbs per acre less nitrogen, on average, than farms that did not receive payments) is not precise (the estimated standard error is large), and it is not significantly different from zero in a statistical sense. For postplanting application, we estimate that payment farms apply 38.1 percent of nitrogen after planting, while we estimate that they would have applied only 24.8 percent after

Table 5

Additionality for nutrient management practices in corn

Practice	Unit	Payment farms: With payment	Payment farms: Estimated without payment[1]	All non-payment farms[2]	Additionality in rate/timing (standard error)
Nitrogen (N) application rate	Pounds per acre	94.6	115.6	115.6	-21.0 (24.8)
Fall nitrogen application	Percent N applied in fall	1.2	12.9	14.4	-11.6* (5.90)
Postplant nitrogen application	Percent N applied after planting	38.1	24.8	23.4	13.3 (14.0)

[1] Estimated as the nitrogen application rate, percent of N applied in fall, or after planting for nonpayment farms that are similar to or “matched” with payment farms.

[2] Nitrogen application rate, percent of N applied in fall or after planting for all nonpayment farms, regardless of similarity to payment farms.

*= significant with $p<0.05$.

Source: USDA, Economic Research Service and USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey, 2009-11.

planting in the absence of a payment. Likewise, the difference of 13.3 percent is not a precise estimate (the estimated standard error is large) and is not statistically different from zero.

Overall, the estimates conform to expectations in the sense that additionality is higher for practices that provide only limited benefit to producers, at least in the short run, and are expensive to install and difficult to reverse. Our results suggest that current conservation payment programs are reasonably effective in securing additional benefits from the adoption of structural practices. That is true largely because of the underlying economics of adoption: For most farms, the onfarm benefits for these practices (at least as perceived by the farmer) are usually not large enough to offset the cost of practice installation.

Of course, additionality can never be guaranteed. In the long run, soil conservation structures can protect the underlying productivity of the land, and buffers can provide landscape amenities including wildlife habitat and hunting opportunities. Many farmers have, in fact, installed soil conservation structures and buffer practices without financial assistance, presumably because they believe that the expected benefits of adoption exceed costs. This may be particularly true of farmers and landowners who conserve soil or protect environmental quality because of strong bequest motives or conservation ethics. On highly erodible land, some farms may have installed soil conservation structures as part of a conservation compliance plan. We note, however, that a majority of compliance plans include only management practices (e.g., conservation cropping, conservation tillage, and crop residue management) (Claassen et al., 2004).

The situation is different for management practices like conservation tillage and nutrient management. Under favorable conditions, conservation tillage can reduce the cost of labor, fuel, and machinery without reducing crop yields, although the transition to conservation tillage may require upgrading some equipment (e.g., a planter or grain drill that can handle heavier residue) and may involve learning new techniques for weed and pest control. Because conservation tillage can be profitable—only 10 percent of ARMS survey respondents who reported using conservation tillage also reported receiving a payment in conjunction with adoption—lower additionality in conservation tillage is not surprising.

For nutrient management, our results are somewhat mixed. We find that payments do make a difference in whether producers have written nutrient management plans (88 percent would not be in place without the payments). In terms of actual nutrient management practices, payments also appear to be effective in reducing fall nitrogen application in corn. It is not clear, however, whether the plans are making a difference in overall nitrogen application rates or in encouraging corn farmers to apply a larger proportion of total nitrogen after planting.

Our results may have been slightly different if a sufficiently large number of observations had been available to estimate the ATT for individual practices. Doing the analysis on a practice-by-practice basis, rather than grouping them together, would have increased the number of farms in the pool of nonpayment farms available for matching to any given payment farm. With our grouped data approach, for example, a farm that received a payment for installing a grassed waterway and another farm that received a payment for a filter strip would both be buffer practice payment farms. When considering the additionality of a buffer practice that happened to be a grassed waterway, the farm that was paid to install the filter strip would not be available for matching. If the analysis were done on individual practices, however, the farm receiving the filter strip payment would be in the pool of farms available for matching. With extra farms in the matching pool, our estimate of the additionality could change. The size and direction of the change would depend on the number of farms added to the matching pool and whether these added farms were systematically more or less likely to include a grassed waterway than other nonpayment farms that were already available for matching.

Improving Additionality in Conservation Programs

While there has been very little research on additionality in U.S. programs, estimates of additionality could be used to improve existing programs in a number of ways. While complete additionality is not a realistic goal, policymakers and program administrators may be able to increase its incidence in conservation efforts on the ground. Because many conservation programs, including Federal programs, are managed largely at the State or local level, it is not possible to comment directly on specific design features of existing programs. We can, however, offer some ideas on improving additionality, some of which may already be used in some programs in some locations.

Information on additionality could be incorporated into existing conservation programs by adjusting conservation program benefit-cost indices to reflect the likelihood of additionality for certain practices. Benefit-cost indices are used to rank applications for acceptance in all major USDA conservation programs, and have been shown to be effective in increasing the level of environmental benefit that can be realized from a fixed budget (or under an acreage cap), assuming supported practices are additional (see Feather et al., for example).

A wide variety of indices are currently in use. They can be used to prioritize across resource concerns (e.g., wildlife habitat versus water quality), locations (e.g., for water quality, fields that are adjacent to streams may be prioritized over fields that are not), and practices (when more than one practice could be used to accomplish a given objective). Farmers who propose practices that are less expensive—per unit of environmental gain—would be ranked more highly and are more likely to receive a conservation payment than farmers who propose more expensive practices.

Existing indices, however, implicitly assume full additionality. Given that full additionality is not likely to be realized and appears to vary across practices, maximizing environmental gain from a fixed budget requires that the benefit-cost indices consider *additional* environmental gain. Practice-specific estimates of additionality could be used to adjust the expected benefits calculation within these indices to reflect expected additionality, particularly if additionality is estimated at a relatively small geographic scale.

To explain further, we turn to a specific example, in which we abstract from the heterogeneity across farms and fields that is characteristic of agriculture. Suppose that conservation tillage (CT) can reduce soil erosion by 5 tons per acre per year and total transition incentive payments are $25 per acre. Given these assumptions, a budget of $10,000 could support CT payments on 400 acres, yielding total soil erosion reduction of 2,000 tons/year at a (one-time) cost of $5/ton. If only half of the CT practices supported with payments are additional, however, *additional* soil erosion reduction is only 1,000 tons/year and the effective cost of *additional* erosion reduction is $10/ton (because the entire $10,000 budget has been spent).

More expensive practices that are also more likely to be additional may be competitive with CT once additionality is factored in. Consider a structural practice that would reduce erosion by 10 tons per acre and could receive roughly $70 per acre in financial assistance but has expected additionality of 80 percent. A budget of $10,000 would fund this practice on 143 acres, yielding total soil erosion reduction of 1,430 tons/year at a cost per ton of $7 per ton. If only 80 percent of the practices supported with payments are additional, however, *additional* soil erosion reduction is only

1,145 tons/year and the effective cost of *additional* erosion reduction is $8.75/ton—a little less than for CT. If the cost-share on the structural practice is higher, say $120 rather than $70, the cost of additional erosion reduction would rise to $12/ton and CT would be the more cost-effective option, even though we expect lower additionality for CT when compared to structures. In the real world, of course, these comparisons would be more complex because of variation in soils, topography, and climate. Which practice is more cost-effective can differ across locations depending on climate, soil, and topography.

Another way to increase additionality is to ask producers to reach a specific level of environmental performance to be eligible for conservation payments. To control sediment and nutrient runoff to surface water, for example, producers could be required to adopt a practice that is already widely used in their area (e.g., conservation tillage), if they have not already done so, to be eligible to receive payments based on other, less frequently used practices that are likely to offer additional environmental gain (e.g., buffer practices). Where conservation tillage is well adapted and already broadly used, it may even be reasonable to require conservation tillage without increasing the contract payment.[9] The greater the requirements for receiving conservation payments, the less likely it is that the farmer will pursue the full suite of practices on his own, making the practices more likely to be additional. Requiring multiple practices, however, could also discourage participation on the part of some producers who may be willing, for example, to change their nitrogen application regime but are unwilling to adopt no-till. These unintended consequences could reduce the overall gain in environmental quality sought by requiring program participants to adopt a suite of practices.

Finally, we note that conservation payments can also encourage farmers to expand crop production onto environmentally sensitive land. Lichtenberg and Ramirez (2011) argue that the Maryland State program of conservation cost-sharing has encouraged farmers to crop highly erodible land that would not have been cropped without the conservation cost-sharing to help defray the cost of keeping the soil in place—a process known as “slippage.” In the case of slippage, supported practices are additional because they would not have been in place without the payment, but the environmental effect of payment may be to increase (rather than decrease) soil erosion.

Improving Additionality Estimates

Ours are among the first estimates of additionality in practices supported by U.S. conservation payment programs. Because there has been very little work in this area, however, our research raises a number of questions for future work. In particular, integration of survey data (e.g., ARMS) with conservation program contract data, conservation planning data, and spatially explicit data on soils and topography could help improve estimates.

Our estimate of additionality for conservation tillage, which is based on data drawn from multiple States, is considerably higher than the estimate reported by Mezzatesta et al., which applies only to a portion of Ohio, where conservation tillage appears to be well adapted. These results may reflect the fact that conservation tillage is better adapted in some areas than in others, implying that nonadditionality could be most effectively managed at a State or local level.

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[9] An ad hoc version of this may already be used in some locations. NRCS staff in some States report encouraging farmers to add practices to their proposals—sometimes without cost-sharing or incentive payments—to improve their offer index score and increase their chance of being selected for participation. To the extent that farmers follow this advice, the extra practices may increase additionality.

One question raised by the conservation tillage data is why some farmers adopt conservation practices without payments when payments are available. This is not an isolated or occasional event. A majority of the practices adopted within each of our practice groups have been adopted without the benefit of payments (table 2). This is also found by other studies of additionality in conservation practice adoption (e.g., Mezzatesta et al.) and slippage in conservation programs (Ramirez and Lichtenberg, 2011).

While we have no definitive answer to this question, we suspect that (1) variation across States and counties in the availability of practice-specific payments, (2) competition for conservation program payments, (3) transaction costs incurred by farmers, and (4) practice specifications (which are sometimes viewed as too demanding) all play some role. Farmers who are convinced that conservation tillage (or any other management practice) will be profitable may decide not to apply for a conservation program, particularly where acceptance is not guaranteed or payments are small. Some farmer may adopt conservation practices because they want to be good stewards. Chouinard et al. show that some farmers would be willing to relinquish some current return to practice good stewardship.

Because conservation program budgets are limited, program managers must set priorities and may be forced to reject or defer some applications for lack of funding.[10] Figure 3 shows the average rate of EQIP payments for conservation tillage during 1997-2010. In many areas, payments for conservation tillage are simply not available (e.g., most of South Dakota). In other areas, the per-acre payment is modest (e.g., most of North Dakota). Payments are also quite variable for nutrient management and other practices.

Another question for further research is to understand the extent to which farmers “un-adopt” management practices when transition incentive payments end. Farmers who receive incentive payments for management practices like conservation tillage or nutrient management are not obligated to continue using the supported practice after incentive payments end. We do not know how many farms may have un-adopted practices in the past. In the ARMS data, these farms show up as nonpayment farms (given that the practice is not in use on the field, respondents are not asked to indicate whether they received a payment at any time in the past). Understanding the extent of un-adoption may be important because these payments yield less environmental gain than they would if the practices were continued. Payments may be critical to practice adoption during the 3-year period when payments are made and may generate benefits that are additional for that period, but environmental gain is temporary.

Conservation structures, such as terraces, grassed waterways, and filter strips, are less likely to be un-adopted because they have a long useful life, are difficult to remove, and producers who receive financial assistance are obligated to maintain the practices for their full useful life. So, it is reasonable to assume that these practices are still in use on farms that received financial assistance on installation costs.

Finally, a number of other data limitations could have affected our results. While our data are rich and account for a wide range of factors that may affect the benefits and costs of practice adoption, more information could improve the accuracy of matching and the reliability of additionality

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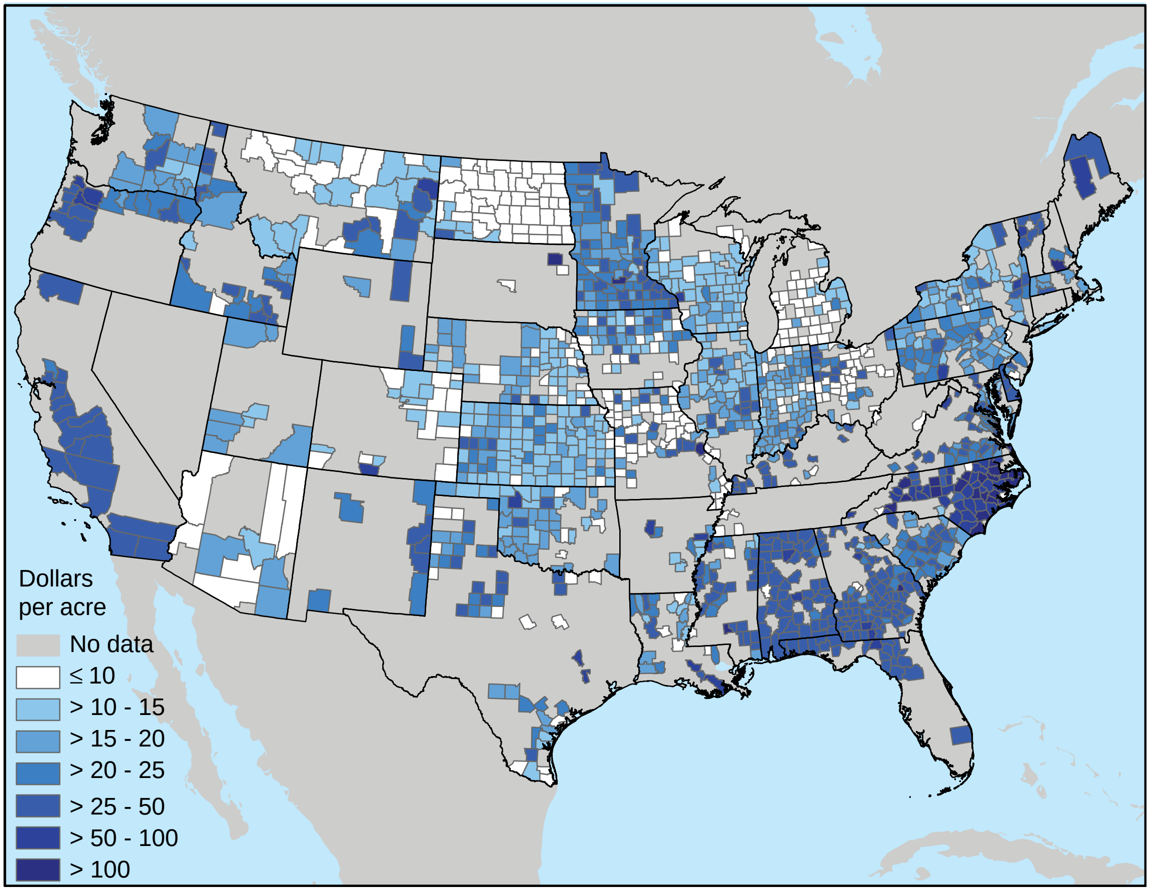
[10] During 2011-13, NRCS data show EQIP contract acceptance rates of 49, 46, and 46 percent, respectively. These rates are based on applications that were considered for funding in a given fiscal year. Applications that were ruled ineligible or cancelled by the producer (prior to consideration for funding) are excluded.

Figure 3

Average payment rates for conservation tillage in the Environmental Quality Incentives Program (EQIP)



Source: USDA, Economic Research Service.

estimates. Field characteristics, for example, are often a critical determinant in the adoption of soil conservation structures and buffer practices. We control for field characteristics by including variables on highly erodible status, the productivity of the soil, and presences of wetlands (including riparian wetlands). Soil conservation structures are more likely to be cost-shared on highly erodible land because the erosion hazard is greater than on non-highly erodible land. Nonetheless, both highly erodible and non-highly erodible lands encompass soils that vary widely in terms of erosion potential. Within non-highly erodible soils, for example, erosion potential ranges from very low, where soil conservation structures would not be used, to land that is very close to being highly erodible where soil conservation structures are often used. Likewise, buffers are more likely to occur in fields that border some type of water body. While data on nearby wetlands may serve as a proxy for nearby water (wetlands are often located in the transition from land to water), more information on proximity to water may help identify fields where buffer practices are likely to be supported with conservation payments. Accurately identifying the location of ARMS fields is feasible and would facilitate links to spatially referenced data on land quality and landscape position.

The complexity of the conservation payment program environment may also be a barrier to good estimates. Many conservation programs are managed largely at the State and local levels, so program priorities can vary widely across or even within States. To proxy for conservation program priorities, we use EQIP and CRP payments per cropland acre calculated at the county level and averaged over time for each of our practice groups. This procedure is designed only to provide a general indicator of the (State and local) program manager's assessment of the conservation needs in a given area and the willingness to address it. We assume that the managers of other Federal and State conservation programs essentially agree with the assessment implicit in EQIP funding. More specific information on Federal, State, and local program priorities, including ranking criteria and payment rates, would be helpful in assessing program priorities. Data on these programs are not currently collected into a single database. While most State and local programs rely on the USDA-NRCS conservation practice standards to determine which actions constitute practices that could be supported, information on these programs is also difficult to obtain.

Finally, more information on complex practices like nutrient management could lead to better estimates of additionality. While we find only very weak evidence that nutrient management payments to corn farmers are encouraging them to reduce nitrogen application or apply it after planting in corn production, these results may be due to small sample sizes and/or a lack of information on farm-specific nutrient management plans. In general, we expect that nutrient management plans will limit fertilizer application rates, move application closer in time to crop uptake, and encourage fertilizer to be applied in ways that resist runoff during heavy rain. We do not know, however, which specific nutrient management practices are included in the nutrient management plans adopted by the farms in our dataset. While it is unlikely that any nutrient plan would allow fall application of nitrogen before corn, it is less clear what level of overall application will be allowed or whether nutrient management plans require postplanting nitrogen application. For example, our analysis of postplanting nitrogen application implicitly assumes that every nutrient management plan requires that some nitrogen be applied after planting, which may not be correct. Without knowledge of plan specifics, we cannot be absolutely sure that our estimates of additionality are actually measuring the effect of payments on the adoption of specific nutrient management practices.

Additionality in Offset Markets

Additionality also applies to offset markets because offset payments, which are described below, can potentially be awarded for practices that are not additional. Under an offset market, farmers receive payments for voluntarily adopting eligible practices. Because offset sales would be voluntary and the set of practices that provide services such as reduced greenhouse gas emissions or improved water quality are similar to those subsidized by current conservation programs, offsets and conservation programs may look similar to farmers. Because offset payments come from private sources, rather than the Government, however, the payment amount would reflect the supply of and demand for offset credits. The cap-and-trade/offset system is therefore referred to as a *market-based* approach.

Offset markets are designed to supplement a cap-and-trade type policy. In most cases they cannot operate effectively without the overarching limit on industrial-source emissions established by a cap-and-trade system. Under cap-and-trade, the Government requires some polluters, called "covered sources," to hold permits (often referred to as "allowances") for every ton of pollution they emit. Allowances can be traded among covered sources. Examples of possible covered sources include wastewater treatment plants (water quality cap-and-trade systems) or electric power plants (proposed greenhouse gas cap-and-trade systems). When an offset policy is added to cap-and-trade, covered sources can buy offsets from noncovered sources. Agriculture is not likely to be covered by cap-and-trade regulations, so it may be a source of offsets. With offsets in hand, a covered source can emit pollution at levels that exceed the number of allowances held. Overall, covered sector emissions will be higher than the initial aggregate cap, and noncovered sources will emit less than they would otherwise, to the extent that the offset-credited practices are additional.[11]

Offsets use the power of markets to spread the cost of emissions reduction efficiently across multiple sectors of the economy, rather than relying on Government programs to allocate emissions reductions between agriculture and industrial sources. The prices of both offsets and traded allowances must be essentially identical because both can be submitted by covered sources to meet their emissions reduction obligation. Farmers who can potentially supply offsets can make money if the cost of adopting the necessary farming practices is below the market-based price of the offsets they sell. The cost of emission control in the covered sector is an upper bound on the market price of offsets because firms will not purchase offsets if they can meet emission requirements more cheaply through onsite emission controls.

The rules for the offsets—what kinds of farming practices or land uses can receive credits and the number of credits that would be awarded for any particular practice or land use—must be established by Government. Just like in conservation programs, however, the program administrator who is setting the rules for offset eligibility cannot fully distinguish between practices that the farmer would have carried out anyway and those practices that are being undertaken solely because of the offset opportunity.[12] Thus, offset credits could end up being awarded for practices that are not additional. This risk can be minimized but it cannot be eliminated entirely.

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[11] The decision of which polluters should be covered sources (that is, required to hold permits) is a policy decision. Under both water quality trading rules and the climate offset trading rules set out by the Waxman-Markey bill (which was approved by the U.S. House of Representatives but not the U.S. Senate in 2010 and did not become law), agriculture would not be a covered source.

[12] Offset buyers would purchase offsets from farms that were willing to follow the offset rules at prevailing market prices but would not be responsible for distinguishing between additional and nonadditional practices.

To earn credits, the landowner would undertake an eligible practice, following all relevant guidelines. Farmers can then sell any offset credits they are awarded to covered sources. Therefore, we will refer to a farmer's *generating credits* and *selling credits* as synonymous. Since agriculture is not likely to be covered by greenhouse gas cap-and-trade regulation, farms do not need to submit credits for their own emissions and they would never need to buy credits.[13] Farms would be liable to follow through on any agreement to adopt a particular practice but they are presumed not to be liable if, for example, the estimate of greenhouse gas reductions that are assigned to that practice turn out to be wrong.

Designing and Modeling a Greenhouse Gas Offset Market

The United States does not have a nationwide greenhouse gas cap-and-trade program. Instead, this analysis is based on a hypothetical offset program using guidance from the 2010 Waxman-Markey bill, existing water quality trading rules, and offset provisions in regional and international cap-and-trade markets. Waxman-Markey provides detailed guidance about the likely components of a national offset program and shows the concerns that legislators had about offset integrity. The bill contained an extensive list of possible eligible practices.

This analysis focuses on application rates of commercial nitrogen fertilizer to grain crops. Nitrogen fertilizer rates provide an informative example because the economics of nitrogen application are fairly well understood relative to other potential offset activities; the relationship between nitrogen application and the resulting nitrous oxide emissions, a greenhouse gas, is relatively straightforward; and nitrous oxide emissions from nitrogen fertilizer are one of the largest categories of agricultural greenhouse gases.[14] In this analysis, offsets are modeled using a baseline approach. Under this approach, the program administrator would assign a baseline nitrogen rate to each field that is potentially eligible to participate in the offset market. The farmer would then be eligible to receive sellable credits if he or she applied nitrogen at a rate below this baseline, with the number of credits equal to the accompanying reduction in greenhouse gases (see appendix 2 for details). Because of this specification of the baseline feature, farmers who would normally have applied at rates below their assigned baseline would receive credits for this amount, even though it does not constitute a reduction and therefore is nonadditional. Farmers who would normally apply fertilizer at rates above the baseline would have to reduce application rates to the baseline before being eligible to generate offset credits. (The credits generated by farmers who would have applied at rates above their assigned baseline but choose to fertilize at below-baseline rates would be additional.) Note that farmers who apply at rates above their baseline are not penalized, they just cannot earn offset credits.

The economic analysis has three parts: (i) a model of nitrogen fertilizer application by the farmer given that he or she has decided to supply offsets, (ii) a procedure to assign each farm's baseline nitrogen rate, and (iii) a model of the farmer's decision to supply offsets, given the previous two components. These components are aggregated to estimate the total volume of additional nitrogen reductions and of credited offsets that would have been offered by farmers if the offset policy had been in place in 2009 (for wheat) or 2010 (for corn), assuming that the policy would not have

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[13] Farms could be required to buy credits if they previously had sold credits and then wanted to change farming practices in ways that were outside their original contract.

[14] In the water pollution context, farming practices that reduced runoff of nitrogen could also be considered for an offset payment program, although the connection between application rates and eventual runoff is subject to a greater array of complicating factors.

affected input or output prices and conditional on observed wheat and corn acreages. These crops are analyzed for separate years because of data availability.

Step (i) Model of nitrogen fertilizer application conditional on the farmer deciding to sell an offset. The first step is to model the profit-maximizing nitrogen rates for each farm in our data if they were paid \$15/tonne CO_2-e, which is equivalent to \$0.033 per pound of nitrogen rate reduction; this price is in the range of allowance prices that have been predicted for nationwide carbon markets. This is not to say that we assume full participation. As we discuss below, whether the farm will participate depends on the farm's assigned baseline relative to its cost of reducing nitrogen application low enough to be eligible for an offset credit.

If the farmer decides to participate, he or she will reduce nitrogen rates up to the point that any revenue loss, due to lower yields, is less than or equal to the offset payment plus fertilizer cost savings. If nitrogen costs \$0.40 per pound (\$800 per ton),[15] the producer would reduce nitrogen application so long as the expected loss in crop revenue (yield times price) for the last pound of nitrogen reduction is less than \$0.433 (the cost of the nitrogen plus the opportunity cost of forgoing the offset credit). As the farmer reduces his or her nitrogen rate, the crop revenue he or she loses for each successive pound of nitrogen reduction will rise until any further reduction in the nitrogen rate would imply a revenue loss of more than \$0.433. The nitrogen rate at this point is the profit maximizing rate, if the farmer decides to participate in the market.

We estimate yield loss due to nitrogen rate reduction using yield response functions drawn from the literature (see appendix 2 for details).[16] Wheat yields are modeled separately but using the same general approach as that used for corn. Each yield model's parameters further recognize that farms differ in their soils, climate, other growing conditions, and overall yield variability. In the case of wheat, the selected model implies that all farmers who face the same offset price (\$15/tonne CO_2-e, which is equivalent to \$0.033/lb. of reduction in nitrogen application) would reduce fertilizer use by the same absolute amount (8.46 lbs nitrogen/acre), or roughly 13 percent on average. This approach recognizes that differences in soils, climate, and other productivity variables will affect the profit-maximizing rate of nitrogen application, but it implies that these factors would not affect the reduction in the nitrogen application rate in response to the offset credits.

In the case of corn, the selected model implies that all farmers who face the same offset price would reduce nitrogen application by the same relative amount (12-percent reduction in nitrogen application). This approach recognizes that differences in soils and climate will affect the profit-maximizing nitrogen rate and assumes that a farm that applied above-average amounts of nitrogen in 2010 with no offset market present would have applied lower amounts if the offset market had been present, but it implies that that farm would have maintained the same above-average proportion. In absolute terms, the average reduction in the nitrogen application rate for corn would be roughly 14 lbs nitrogen/acre, if the farmer decides to participate in the offset market.

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[15] This price reflects the March 2009 price for anhydrous ammonia (see http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx). In March 2009, anhydrous ammonia (82-percent nitrogen) sold for \$688 per ton, yielding a net price of \$842 per ton of nitrogen.

[16] Under this yield response function, a reduction in fertilizer application also results in a yield reduction. If some farmers are overapplying fertilizer, however, a reduction in fertilizer application may have little or no effect on yield. Given that fertilizer is costly, however, it is reasonable to assume that farmers who purchase fertilizer believe that the marginal unit of fertilizer at the observed rate of application is beneficial, even if overapplication is occurring. So, farms may require payments to reduce nitrogen application even if there is no cost to doing so.

Step (ii) Assigning baseline nitrogen rates: Each field's designated baseline nitrogen rate is based on prevailing practice (average nitrogen application rate) among farms in the same geographic region and with the same soil and climate conditions. Farms located in regions where farmers tend to apply high levels of nitrogen are assigned higher baselines. Farms located in regions where farmers tend to apply low levels of nitrogen are assigned lower baselines. The technical appendix explains the statistical procedure used to estimate these average rates. The appendix further explains how market conditions, such as wheat prices or nitrogen fertilizer prices, might affect these rates and shows how baselines could be adapted year by year to reflect those changing market conditions.

This "prevailing practices" approach to assigning each farm's baseline has several advantages.[17] Both farmers (offset sellers) and offset buyers could readily see the applicable baseline, making it easy for them to interact in the market and make potential offers. Farm records and other detailed, individual-specific information would not be needed to establish offset credit eligibility.[18] This feature helps keep transaction costs low, minimizing the potential for these costs to be a barrier to offset trading. Because baselines are derived from elements that are outside the farmer's control, moreover, farmers cannot alter production or conservation practices to increase the emissions baseline they are assigned, a response that would increase the number of nonadditional offset credits in the market.

An alternative to the prevailing-practices approach would be to construct a field's baseline based on what the farm did in the years just prior to an offset trade. This is known as a "past-practices approach." Under a past-practices approach, a farm may be able to influence the baseline it would be assigned in any given year by applying higher nitrogen rates the year before, a form of potential moral hazard. A past-practices approach may also make offset trades and offset administration more cumbersome since baselines would rely on individual farm records. Policy administrators would also have to set up procedures to ensure that farmers' reports of what they did in previous years were accurate. Each of these issues would add to the transaction costs associated with the offset market. How large these effects are and their consequences for offset market performance are not well known. A past-practices approach could also lead to lower levels of nonadditionality that could justify higher transaction cost and higher risk of moral hazard.[19]

Prevailing nitrogen rates were constructed for this analysis using ARMS data. The field-level portion of ARMS focused on wheat farms in 2009 (which includes winter wheat planted in fall 2008) and corn farms in 2010. The prevailing-practices baseline approach we analyze is similar to many proposed offset protocols and analyses (Climate Check, 2008; Millar et al., 2010; EPRI, 2011). It is more precise than baselines that use State-recommended fertilizer rates or, in the case of water quality trading, the total maximum daily load (TMDL).

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[17] We reiterate that this baseline is an administrative parameter that only applies to the offsets program. It has no effect on farms that choose not to sell offsets.

[18] This report's analysis uses soil and productivity data from publicly available soil maps, not field-specific measures.

[19] One proposal (EPRI, 2011) was to construct the baseline as the farm's business-as-usual rate based on historical, verifiable farmer fertilizer records, where available, and when such records were not available, the baseline would be derived from county-level yield data and State-recommended fertilizer rates. This formulation approach introduces a second form of potential moral hazard in which farms would choose the second option whenever it was more beneficial to them. The county average yield/recommended fertilizer rate shares with our baseline the beneficial property of being outside the control of the participating farmer, but this report's prevailing-practices approach yields more precise farm-level estimates of nitrogen use than the county average yield/recommended fertilizer rate method.

For each of the ARMS fields included in this analysis, we construct the average per-acre rate of nitrogen application, including commercial and composted manure but not un-composted manure.[20] These data are used in the analysis both to capture business-as-usual practices and to create averages for farms in the same geographic region and with the same soil and climate conditions that serve as the baseline for each field in the area (see appendix 2 for details).

Step (iii) Farmer decision to supply offsets. The calculations assume that farmers seek to maximize profits and will decide whether and how to participate in the offset program on that basis. Farms with business-as-usual nitrogen rates (the rate that would have been used in the absence of the credit sale) at or below their assigned baseline will participate since they can do so at essentially zero cost. These credits, of course, are nonadditional because the producer did not actually reduce nitrogen application. Our analysis shows that all farms initially at or below their baseline also find it profitable to reduce nitrogen application, thereby reducing nitrous oxide emissions and earning credits that are additional.

Farms with business-as-usual nitrogen rates that are above their baseline may or may not participate. These farmers would have to apply nitrogen at below the baseline rate to be eligible for offset credits. While they incur the cost of revenue losses and realize reduced fertilizer cost, they do not receive the offset credit and associated payments on reductions needed to satisfy the baseline.

Farms with business-as-usual nitrogen rates well above the baseline may find that the offset payment does not cover the cost of reducing nitrogen. Under the model used here, wheat farms with business-as-usual nitrogen rates that are more than 8.46 lbs nitrogen per acre above their baseline will definitely not participate because 8.46 lbs is the amount of nitrogen reduction that makes the farmer the most money with the offset market in place. If a reduction of 8.46 lbs would not make the farmer eligible (because he or she would still not be below the baseline) then the farmer will not participate.

Other farms that have business-as-usual nitrogen rates above their baseline (but not so far above) may or may not find it profitable to produce and sell offsets, even if a portion of their nitrogen rate reduction does not produce offset credits. The value of the offset credits, even if received for only a part of the nitrogen rate reduction, when added to fertilizer cost savings could be enough to offset lost revenue due to lower yields. For a more detailed discussion about which of these farms might participate, see appendix 2.

Offset Market Performance

We assess the performance of this hypothetical offset market as if it were operating in 2009 (wheat), or 2010 (corn) with no change in crop acreage, previous crops grown, crop prices, or input prices relative to observed 2009 or 2010 market conditions. We calculated five performance measures:

- *Participation* is the proportion of acres from which offsets are sold.
- *Credited offsets* are the difference between the assigned baseline and the predicted nitrogen application for all farms that choose to supply offsets. Credited offsets include both additional reductions and nonadditional “paper” reductions awarded to farms with business as usual nitrogen rates below the baseline.

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[20] This is not to assume that nitrogen is applied evenly over the entire field, only that the offset baseline and rules would be based on this field-level average rather than some smaller sub-field unit.

- *Additional greenhouse gas emission reduction* is the difference between emissions from the farm's business-as-usual nitrogen rate and emissions from its predicted nitrogen rate; it is the amount of greenhouse gas reductions that occur as a result of farmers reducing their nitrogen rates as a result of the program.

- *Net increase in greenhouse gas emissions* is the difference between total offset credits and additional offset credits. Nonadditional offset credits do not result in reduced nitrogen emissions on the farms that sell them. Nonetheless, they will be used by purchasers to increase GHG emissions above the level that would otherwise be permitted, resulting in an overall increase in GHG emissions. The net increase is less than the volume of nonadditional credits because some participating farms with business-as-usual nitrogen rates above their baseline will not receive offset credits for the full amount of their nitrogen rate reduction.[21]

- *Emission abatement costs* are the lost profits from production and are measured as revenue loss due to crop yield reduction less fertilizer cost savings. Because costs are such an important aspect of the additionality issue, it is worth reiterating that costs are incurred only for additional reductions; nonadditional credits are costless for the farmer to produce.

Additionality Is Low for Wheat Farms in the Market Envisioned Here

Given a payment of \$15/tonne of CO_2-e, wheat farmers would sell 2.89 million tonnes of CO_2-e in offset credits (1,318 million lbs of nitrogen reduction) on 23.4 million acres (57 percent of wheat acreage) and would receive total payments of \$43.3 million. The additional reduction in GHG emission, however, is estimated to be only 0.97 million tonnes of CO_2-e (the equivalent of reducing applied nitrogen by 440 million lbs), or roughly 34 percent of credited offsets (table 6). This proportion is analogous to the ATT that was reported in the previous chapter.

A large proportion of offset credits are not additional given the assumptions of this analysis because nitrogen application rates are highly variable among farms, even in a given year and even among farms that otherwise appear quite similar in terms of growing conditions. It has long been known that farms that are situated right next to each other, and therefore typically facing similar growing conditions and market conditions, often choose very different management regimes, including different fertilizer rates. Because of this variability, many farms end up being assigned baselines that are above their business-as-usual nitrogen rate, resulting in nonadditional credits generated at no cost to the farmer. The results in table 6 show the consequences of that unpredictability: substantial levels of predicted nonadditionality in our simulated offset market.

The production and participation models provide several other insights into offset market performance. First, most farms that provide nonadditional credits also provide additional reductions. The reason is that farms with business-as-usual nitrogen rates below their baseline can earn profits by reducing nitrogen use further. That is, the value of the offset credits produced by reducing nitrogen application plus fertilizer cost savings are worth more than the wheat production forgone by reducing nitrogen application rates, based on the wheat production model's assumptions.

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[21] These farms participate because they still receive sufficient revenue from their offset sales to make it worth their while to supply offsets.

Table 6

Additionality in offset credits: Wheat

Mean baseline (range)[1]	63.9 lbs nitrogen (N)/acre (16.8 - 121.4)
Proportion of wheat acres selling offsets	0.57
Total offset credits	2.89 million tonnes CO_2-e (1.3 billion lbs N)
Total payment for offset credits	$43.3 million
Costs to farm sector of greenhouse gas (GHG) reduction (reduced N use)	$7.3 million
Net revenue farm sector: Offset revenue minus cost	$36 million
Additional GHG reduction	0.97 million tonnes CO_2-e (440 million lbs N)
Ratio of additional reductions to total offsets	0.34
Estimated abatement cost savings	$7.3 million
Net increase in GHG emissions	1.91 million tonnes CO_2-e (865 million lbs N)

Tonne = metric ton; CO_2-e = carbon dioxide equivalent.

[1] Baseline rate is for nonirrigated wheat field and varies by observable characteristics of the field, including soil type, climate, and other factors.

Source: USDA, Economic Research Service and USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey, 2009-11.

The flip side to this implication is that some farms will reduce nitrogen use by more than the number of offset credits they receive. Consider a farm that would normally have been applying nitrogen at a rate just above its assigned baseline. This farm can reduce its nitrogen by a small amount—an additional reduction in GHG emissions—and then qualify for offset credits for any further reductions. The farm earns no credits for that first small reduction because it is above the baseline, but the farm still finds it profitable to participate in the offset market because it earns enough revenue from the remainder of its reductions, which do fall below the baseline, to make participation profitable. Because some additional reductions are not credited, the total volume of offsets is slightly smaller than the sum of additional reductions plus credits that are issued for nonadditional "reductions."

A second implication of the model is that the proportion of credits that represent additional nitrogen reductions rises as the offset price rises (fig. 4). As the offset price rises, farms supply higher volumes of additional reductions, while the volume of nonadditional credits is fixed when the baseline is established. This higher supply comes from an increase in both the number of participants and the volume of nitrogen reduction conditional on participation. If the offset credit price reached $35/tonne CO_2-e ($0.08/lb. N), for example, the total number of offsets offered would be 4.13 million tonnes CO_2-e and the additional offsets would be 2.52 million tonnes CO_2-e, roughly 60 percent of total credits.[22] At very low prices, however, additional reductions would be a small

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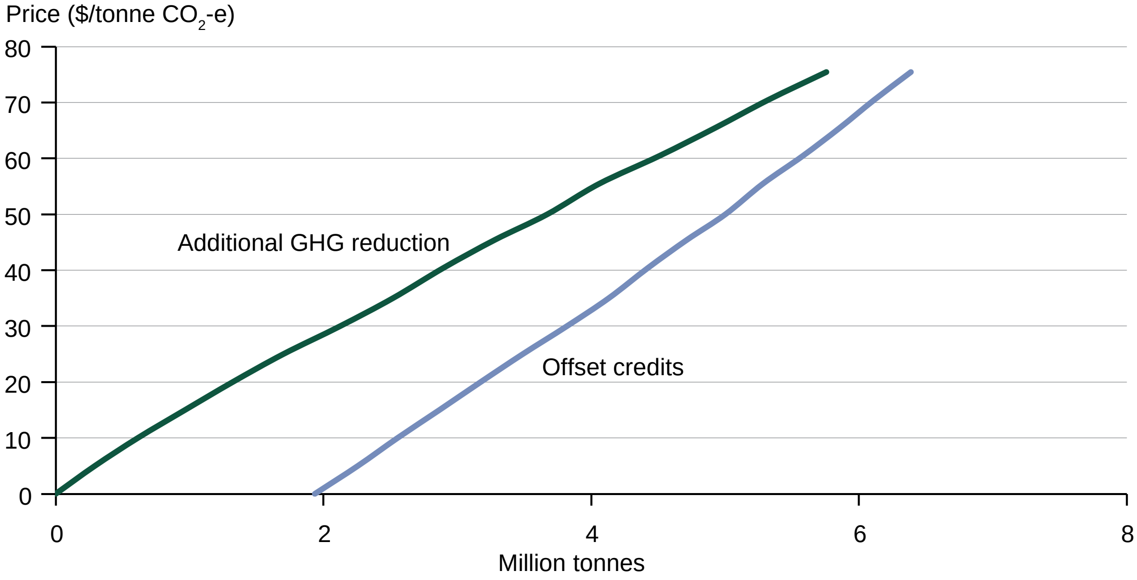
[22] In its May 2013 report, the Interagency Working Group on Social Cost of Carbon of the U.S. Government estimates the social cost of carbon emissions for 2020 at $12, $43, and $65 per tonne for discount rates of 2.5 percent, 3 percent, and 5 percent, respectively. If these estimates are accurate, they could justify regulation that would impose costs greater than $15 per tonne.

Figure 4

Supply of additional reductions and offset credits for wheat



Tonne = metric ton; CO_2-e = carbon dioxide equivalent; GHG = greenhouse gas.
Source: USDA, Economic Research Service.

proportion of the market. Note that at a price very close to zero, no additional reductions would be supplied, but a quantity of nonadditional credits (roughly 1.91 million tonnes CO_2-e) would be eligible, assuming very low transaction costs.

The cost to farmers of supplying 0.97 million tonnes CO_2-e in offset credits (generated by reducing applied nitrogen by 440 million lbs) is estimated to be $7.3 million (nonadditional credits are costless to farmers). Costs are estimated by noting that the offset supply curve is close to linear (see figures 4 and 5), which implies that the average cost of reductions is roughly half of the offset price or roughly $7.50/tonne CO_2-e. This fraction implies that offset providers could indeed make profits from the offset market, assuming the offset market was competitive. Because the offset supply curve is so close to linear and because our calculations are designed primarily to understand how the offset market functions, we use this one-half cost ratio for the bulk of our remaining calculations.

Potential for abatement cost savings is estimated by assuming that the price of offset credits will be equal to the marginal cost of abatement in the covered sector, assuming sufficient competition among these firms.[23] If the credit price is $15/tonne CO_2-e, the cost savings due to the purchase of additional credits by regulated firms could be as high as $15/tonne CO_2-e multiplied by 0.97 million tonnes CO_2-e or $14.6 million. Given that the marginal cost of agricultural abatement is about one-half the credit price (and, therefore, one-half the marginal cost abatement in the covered sector) the cost of abatement in the covered sector would be roughly $7.3 million, and the net reduction in

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[23] Marginal abatement cost is an upper bound on offset credit prices. Firms will abate rather than purchase credits if they cannot be purchased for less than their own abatement cost. Credit prices could be lower, depending on the supply of credits and the demand for them. Our estimates of cost savings are also upper bounds.

cost would be \$7.3 million. If the marginal cost of abatement—and the price of an offset credit—is higher (lower), the potential cost savings would be larger (smaller).

The effect of nonadditional credits on overall benefits to society is more difficult to assess, at least in monetary terms. Credits equaling 1.91 million tonnes CO_2-e are nonadditional (equal to the 2.89 million tonnes in CO_2-e in total offset credits less the 0.97 million tonnes in additional CO_2-e). The offset program would mean that GHG emissions exceed regulated levels by 1.91 million tonnes CO_2-e because emissions by offset credit purchasers would be higher than they would be without offsets while credit sellers do not reduce emissions by enough to fully offset higher emissions from regulated sources. The increase in emissions would increase environmental damage but would also reduce the cost of abatement for covered firms.

Finally, there are several qualifications to the interpretation of the table 6 results. Estimates are based on a sample of 41.1 million wheat acres, which is essentially the 2009 nonirrigated wheat acreage in the 17 States covered by the field-level ARMS survey for 2009[24] minus a few observations that were dropped for reasons explained in the technical appendix. The estimates are also constructed under the assumption that offsets were made available for all crops (with appropriate crop-specific nitrogen baselines), not just wheat, so that offset market opportunities did not themselves affect the mix of crops chosen by farmers. The estimates do not reflect the effect of an economy-wide cap-and-trade system on wheat prices or fertilizer prices.

Majority of Offsets Are Not Additional on Corn Farms, as Modeled

Given a payment of \$15/tonne CO_2-e, corn farmers would sell 7.03 million tonnes CO_2-e in offset credits based on 3.177 million lbs of nitrogen reduction credit generated on 33.3 million acres (50 percent of corn acreage), receiving a total of \$105.5 million (table 7). Additional reduction in GHG emission, however, is estimated to be only 1.99 million tonnes CO_2-e (the equivalent of reducing applied nitrogen by 900 million lbs), or roughly 28 percent of credited offsets. Again, this proportion is analogous to an ATT as explained in the previous chapter. Additionality in this scenario is low in corn for the same reason it is low in wheat: nitrogen application rates are highly variable across farms that are otherwise similar, and therefore a prevailing practices baseline will entail many farms having nitrogen rates already below their administrative baseline.

As with wheat, the proportion of credits that represent additional nitrogen reductions rises as the offset price rises (fig. 5). If the offset credit price reached \$35/tonne CO_2-e (\$0.08/lb. N), for example, the total number of offsets offered would be 10.29 million tonnes CO_2-e and the additional offsets would be 5.08 million tonnes CO_2-e, roughly 49 percent of total credits. At very low prices, however, additional reductions would be a small proportion of the market. At a price very close to zero, no additional reductions would be supplied, but a quantity of nonadditional credits (roughly 5.15 million tonnes CO_2-e) would be eligible, assuming very low transaction costs.

Building on the wheat analysis, the average cost of additional reductions is about half the price of an offset, or \$7.50/tonne CO_2-e. The total cost to farmers for reducing GHG emissions (based

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[24] ARMS field-level (phase 2) surveys are designed to survey farms in States that collectively account for 90-95 percent of production for the crop being surveyed. States in the 2009 wheat survey included California, Colorado, Idaho, Illinois, Kansas, Michigan, Minnesota, Missouri, Montana, Nebraska, North Dakota, Ohio, Oklahoma, Oregon, South Dakota, Texas, and Washington.

Table 7

Additionality in offset credits: Corn

Mean baseline (range)[1]	120.1 lbs nitrogen (N)/acre (16.0 – 196.5)
Proportion of acres selling offsets	0.50
Total offset credits	7.03 million tonnes CO_2-e (3.2 billion lbs N)
Total payment for offset credits	$105.5 million
Costs to farm sector of greenhouse gas (GHG) reduction (reduced N use)	$14.8 million
Net revenue farm sector: Offset revenue minus cost	$90.7 million
Additional GHG reduction	1.99 million tonnes CO_2-e (900 million lbs N)
Ratio of additional reductions to total offsets	0.28
Estimated abatement cost savings	$14.9 million
Net increase in greenhouse gas emissions	5.04 million tonnes CO_2-e (2.3 billion lbs N)

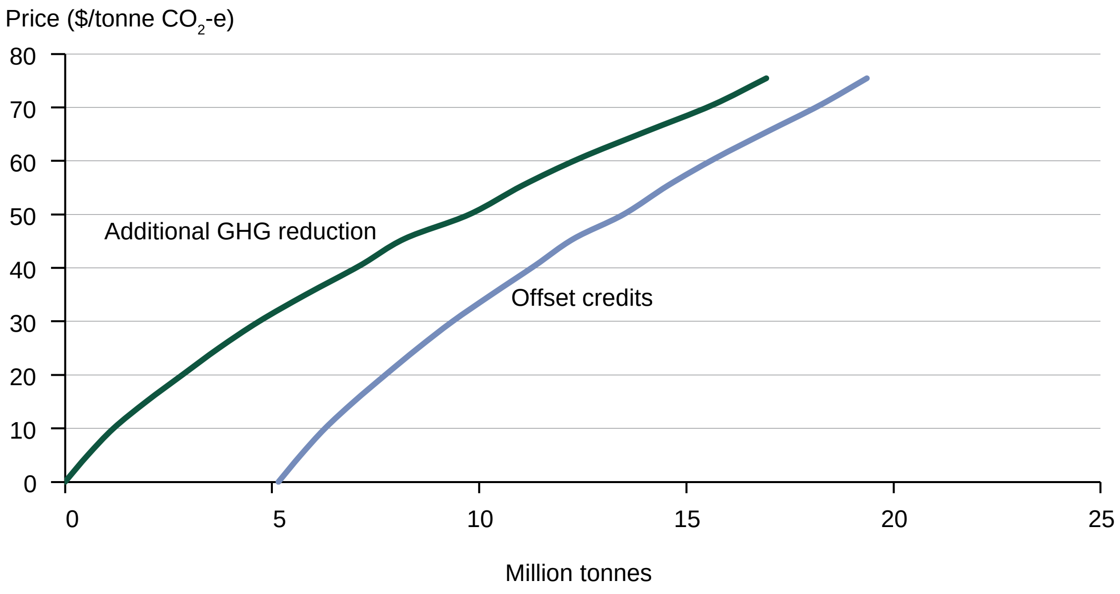
Tonne = metric ton; CO_2-e = carbon dioxide equivalent.

[1] Baseline rate is for nonorganic, nonirrigated cprn field and varies by observable characteristics of the field, including soil type, climate, and other factors.

Source: USDA, Economic Research Service and USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey, 2009-11.

Figure 5

Supply of additional reductions and offset credits for corn



Tonne = metric ton; CO_2-e = carbon dioxide equivalent; GHG = greenhouse gas.
Source: USDA, Economic Research Service.

on reduced nitrogen application by 900 million lbs) is estimated to be \$14.9 million. The cost of abatement for firms in the covered sector (who buy offset credits) is estimated to be \$29.85 million (1.99 million tonnes CO_2-e times marginal abatement cost of \$15/tonne CO_2-e). So abatement cost savings for additional reductions would be roughly \$14.9 million.

Estimates are based on a sample of 66.6 million corn acres, which is the 2010 nonirrigated, nonorganic corn acreage in the 18 States in the ARMS corn production practices survey,[25] minus a few observations that were dropped because the nitrogen rate seemed implausible. Again, future estimates should be adjusted to a per-acre basis and multiplied by the corn acreage in that year. Our estimates would not account for any differences in the quality distribution of corn acres across years. We leave that issue for future research.

In the next chapter, we consider ways to adjust the baseline to increase additionality. The effectiveness of a “safety margin” approach to reducing the number of nonadditional credits is analyzed. A safety margin involves tightening the baseline so that fewer “paper” offset credits are created for farmers who already apply nitrogen at below average rates. We also discuss, but do not analyze, a range of other policy strategies that could be used to increase additionality.

Limitations of the Analysis

This analysis has several limitations to consider in understanding how the results can be applied. The hypothetical offset program analyzed here utilizes a single practice for a single crop in a single year. Based on the analysis, readers may draw the conclusion that nitrogen rates are a poor candidate for offsets but that perhaps some other greenhouse-gas-reducing practices would fare better. An evaluation of additionality under each of these other practices requires estimates of how expensive the candidate practice would be and, more importantly, requires that this cost not be the same for all farms, as different farms choose different farming practices. Unfortunately, the farm-specific costs of adopting other important practices, such as no-till, are difficult to estimate given existing data and methods. Building the capacity needed to develop farm-specific cost estimates for other practices is an important topic for future research.

Rather than a practice-by-practice approach, as implied by this analysis, farms could be assigned an emissions baseline (a performance baseline, not a practice baseline) and receive offsets for any combination of practices that led to lower emissions. While this approach could significantly increase additionality, research in this direction has been hindered because analysis of emissions (performance) baselines and offset supply requires substantially more data, including a more complex cost model *and* emissions data based on a full picture of farm operations. Modeling the emissions that would arise under the full range of possible practice combinations that the farm could consider would be complicated. Calculating emissions for a wide range of practices on the full range of farms would require substantial computational effort.

This report’s hypothetical offset programs apply only to a single crop for a single year. Research has not, for example, considered that one year’s nitrogen application might affect residual soil nitrogen for the next year’s crop and therefore affect next year’s application rate or even the crop that is

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[25] States in the 2010 ARMS corn survey included Colorado, Georgia, Indiana, Illinois, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, New York, North Carolina, North Dakota, Ohio, Pennsylvania, South Dakota, Texas, and Wisconsin.

grown. Research has also not considered how other practices might change as the farmer reduces his nitrogen use; some of the accompanying changes might have further greenhouse gas implications.

These issues could be addressed by having offset rules that could be applied to each possible crop, to each possible practice, and to multiple years. A nitrogen-reduction offset would presumably be issued for multiple crops; that is, a nitrogen rate baseline for each farm for corn, wheat, legumes, sugar beets, and all of the other crops that the farm might grow. Indeed, if the baseline were issued only for corn, there is the risk that a farm that would not have otherwise planted corn would choose to plant corn in order to qualify for offset payments and, because corn is one of the heaviest nitrogen users, would end up applying more nitrogen than if the farm had planted its planned alternative crop. An offset that was available for all crops would avoid this problem. While the remedy for the crop-by-crop or practice-by-practice approach is conceptually straightforward, the administrative requirements would be considerable.

Strategies To Enhance Additionality in Offset Credits

The previous chapter's results show that there is substantial risk of nonadditionality in a greenhouse gas offset market that relies on a prevailing practice baseline. This chapter considers six policy strategies for increasing additionality: (i) safety margins, (ii) an offset subsidy, (iii) a past practice baseline (based on farm records), (iv) expanded practice requirements for offsets, and (v) stepwise offset credits. We analyze safety margins using the model developed in chapter 3. Other strategies are discussed but not formally analyzed.

Analysis of Safety Margins

A safety margin is a quantity (pounds of N per acre) that is subtracted from the prevailing practice rate. The resulting lower baseline would be used to determine the farm's starting point for offset credits. With safety margins, there would be fewer farms with business-as-usual nitrogen rates below the baseline and fewer nonadditional credits. Of course, the lower baselines will also discourage participation among farmers with relatively high nitrogen application rates who might have participated under the "prevailing practices" baseline and provided additional GHG reductions in excess of the number of credits sold. A safety-margin fits readily in the competitive market framework of the "Additionality in Offset Markets" chapter because it keeps transaction costs low.

The safety margins considered here tighten baselines selectively to ensure that larger baseline adjustments occur in areas that have the largest variability in nitrogen rates and, therefore, the greatest potential for creating nonadditional credits. A related approach is to disallow offsets from some types of farms or farms in some regions where the risk of nonadditionality is large relative to other regions. This second strategy might be more accurately called an eligibility criterion, but it is similar in operation to a safety margin and we consider it with the safety margin approach. We consider several scenarios below. The analysis for corn in the "Additionality in Offset Markets" chapter is the no-safety-margin case and will now be referred to as scenario 1.

Scenario 2 – Offset eligibility restricted to areas with higher likelihood of additionality. This scenario modifies scenario 1 by allowing offsets only in regions[26] where the variability of nitrogen application rates is less than a given cutoff level. For example, in column 2 of table 8 (scenario 2a), only farms located in regions with a coefficient of variation[27] below 0.75 would be eligible to sell offsets (other columns represent lower cutoff levels; 0.5 for scenario 2b and 0.3 for scenario 2c). Lower cutoffs translate into more stringent offset sale requirements. Fewer regions will be eligible for offset sales, and the volume of offsets offered by the corn sector would be correspondingly reduced. We expect that when the imposed cutoff is lower, the additionality of the remaining eligible offsets would increase, although we also expect that the total number of offset credits offered for sale will decline. Although this approach may be effective for GHG offsets, because GHGs are global pollutants, excluding regions may not be possible in other pollution offset markets where the location of abatement is important.

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[26] Regions are defined by groups of major land resource areas (MLRA). MLRAs are areas of relatively uniform climate, topography, soils, and crops. See USDA-NRCS, 2006. For the purpose of this study, MLRAs were grouped together as shown in appendix table 2-2.

[27] A measure of relative variation which is equal to the standard deviation of fertilizer application rates divided by the average application rate.

Table 8

Results for eligibility cutoffs and safety margins

Scenario	1	2a	2b	2c	3a	3b
Coefficient of variation for eligibility cutoff[1]	None	0.75	0.50	0.30	0.50	0.50
Safety margin (percent reduction in baseline)[2]	0	0	0	0	10	20
Proportion of acres excluded from eligibility	0.00	0.02	0.25	0.85	0.25	0.25
Mean baseline, lbs nitrogen per acre	106.89	109.38	121.57	141.33	109.38	97.28
Ratio of additional reductions to total offsets	0.28	0.29	0.33	0.47	0.28	0.23
Proportion of acres selling offsets	0.50	0.49	0.38	0.09	0.25	0.17
Total offset credits, million tonnes CO_2-e	7.03	6.81	5.07	0.99	2.70	1.80
Total payment for offset credits, million $	105.40	102.80	76.50	15.00	40.79	27.18
Costs to farm sector of GHG reduction, million $	14.80	14.75	12.48	3.58	5.66	3.10
Net farm to sector: Offset revenue minus cost, million $	90.70	88.05	64.02	11.42	15.88	10.89
Additional GHG reduction, million tonnes CO_2-e	1.98	1.96	1.66	0.47	0.75	0.41
Estimated abatement cost savings, million $	14.80	14.75	12.48	3.58	5.66	3.10
Net increase in GHG emissions, million tonnes CO_2-e	5.01	4.86	3.42	0.52	1.91	1.39

GHG = greenhouse gas; tonne = metric ton; CO_2-e = carbon dioxide equivalent; MLRA = major land resource area.

[1] Offsets are offered only in regions with a coefficient of variation below the specified level. The coefficient of variation is defined as the ratio of the standard deviation to the mean nitrogen per acre within MLRA group j (see appendix table 2-2) CV_j-$\sigma_j/\bar{N}_j$.

[2] The baseline is the safety margin $(1-(\frac{\gamma}{100}))\,\hat{N}_i$ where γ is the percentage reduction and $\hat{N}_i$ is the prevailing practice baseline.

Source: USDA, Economic Research Service and USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey, 2009-11.

Results are shown in columns 2, 3, and 4 (marked as scenarios 2a, 2b, and 2c) of table 8. As the eligibility criteria become stricter the proportion of offset credits that are additional increases, although the total number of offset credits provided, the proportion of corn acres eligible for offset credits, and the participation rate also decline. For the strictest eligibility criterion we analyze, nearly half of all offsets are additional. At that point, 15 percent of corn acres are eligible for offset credits and 9 percent of acres actually produce credits.

Scenario 3 – Proportional safety margins. In scenario 3, the scenario 1 (prevailing practices) baselines are reduced by a given proportion. For example, if the prevailing nitrogen rate was 60 lbs per acre, the new baseline would be 10 percent below that, or 54 lbs per acre. A proportional safety margin is analyzed because it is an intuitive way to introduce safety margins. We impose an eligibility criterion of < 0.5 as in scenario 2b.

Table 8 (columns 5 and 6, marked as scenarios 3a and 3b) shows that the proportional safety margin does not improve additionality; in fact it worsens it. The ratio of additional offsets to total offsets declines from 0.33 when the prevailing practices baseline is used with an eligibility cutoff of $CV < 0.5$ and no safety margin (scenario 2b, column 3) to 0.23 when the baseline is reduced by 20 percent (scenario 3b, column 6). A reduction in the baseline will reduce participation even as it reduces the number of nonadditional credits. With a lower (more stringent) baseline, the farmers that are most likely to forgo offset credit sales are those who have nitrogen application rates above the baseline and provide additional reductions in nitrogen rate in excess of their credited reductions. So, even as a proportional safety margin reduces the number of nonadditional offset credits in the market, it reduces the number of additional credits even more.

Other Strategies for Improving Additionality

An ***offset subsidy*** is a payment (in addition to the credit purchase price) made by the Government to offset credit sellers for each offset credit sold, increasing the effective price of offsets to farmers. If the subsidy rate were 10 percent, for example, then someone who sold 100 credits at $15 would receive $1,650 rather than $1,500 (of which $150 would be from the Government), assuming that the offset price is unchanged.[28] The subsidy stimulates the production of additional offset credits (by reducing fertilizer application) without affecting the number of nonadditional credits (which depends only on the baseline and business-as-usual nitrogen rates).[29] The subsidy payment introduces a Government cost, however, for payments and related administration.

An offset subsidy imposes a cost on taxpayers that is absent from other market-based policies. In evaluating the overall effects of the subsidy, this cost must be weighed against the value of improved additionality.

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[28] Offsets are often predicted to reduce the market price for allowances but they can be beneficial even if the offset market is relatively small or covered-sector marginal abatement costs are close to constant because they reduce total (or inframarginal) abatement costs.

[29] Sellers of nonadditional credits would also be eligible for the subsidies. If transaction costs are zero, the sale of nonadditional offsets would not be affected. Even in a well-designed market, however, transaction costs may be very low but will not be zero. Some farms that have a small number of qualifying nonadditional credits might not bring those credits to market when the offset price is $15 per tonne of CO_2-e but might bring them to market when the subsidy is added. Thus, an offset subsidy might lead to a slight increase in nonadditional credits. This increase would need to be weighed against the benefits from a greater supply of additional reductions.

Baselines based on past practice on individual farms (an alternative to the prevailing practice approach) would be field-specific and based on practices used in the years prior to an offset trade, to the extent that past practice can be determined. A past practice baseline could be specified based on farm records, farmer testimony, and possibly remote sensing. This information, if unbiased, could be expected to provide a more accurate picture of the farm's business-as-usual practices and thereby enable baselines that reduced the risk of nonadditionality. The farm records approach, however, raises three sorts of problems:

- *Moral hazard*. Under the farm records approach, farms could influence the baseline they were awarded in any given year by applying higher nitrogen rates than they otherwise would, a form of moral hazard.[30] The potential magnitude of this problem is unknown. The problem could also be moderated by tying baselines to fertilizer application in years prior to the beginning of the offset program. If farmers are uncertain about their ability to sell offsets or the price they will receive, they may also be reluctant to take costly actions to increase their ability to generate offset credits in the future.

- *Transaction costs.* The farm records approach would also make offset trades and offset administration more cumbersome because farmers may not be willing to share records with offset buyers unless there was a high likelihood of a sale (making the market thinner). Farmer effort may be needed to bring the records up to the policy's standards, again reducing participation that would otherwise be valuable. Of course, in some cases, relevant farm records would simply not be available. If farms could opt out of the farm records baseline and instead be assigned a prevailing-practices baseline, a remedy that is sometimes proposed, then many of the advantages of the farm records baseline would be lost.

- *Remaining nonadditionality.* Farm records, even when readily available and even when not affected by moral hazard, would still be only a rough guide to the farm's business-as-usual practices because past practices are not a perfect predictor of future practices. Thus, some of the nonadditionality issues covered in this report would remain.

This discussion is only a description of possible economic issues and has not estimated the size of these effects. The disadvantages of moral hazard or transaction costs would need to be weighed against the combination of additionality and nonadditionality arising under a prevailing-practice baseline.

Strategies are available to policymakers to reduce the problems that would arise under a farm records approach. A greater availability of remotely sensed data could avoid the need for actual farm records and thus could greatly reduce the transaction costs of relying on farm-level practices. Assigning a baseline based on the farm's practices in some fixed past year or a combination of years rather than the single year before enrollment would reduce moral hazard because it would be more costly (or impossible, in the case of a fixed past year) for the farmer to influence his or her baseline. Combining these two features—a fixed base year and remotely sensed data—may eventually be practicable. A fixed based year, however, would increase the adverse selection problem because the farther back in time that base year was, the less reliable farming practices would be as predictors of future practices. But it is likely that even with these prediction errors, more accurate baselines could be constructed and additionality increased.

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[30] The effect is comparable to a rural landowner cutting down a forest in order to be paid to replant it, or plowing up a no-till field in order to be paid to use no-till.

Under ***expanded practice requirements***, farmers who want to sell offsets or receive conservation payments would have to adopt a broader set of practices, not just the single practice change analyzed above. Under this approach, farmers in an offset program who wanted to earn credits for reduced nitrogen application might be required either to (i) carry out multiple greenhouse-gas-reducing practices in conjunction with reducing nitrogen below the baseline or (ii) sell a minimum number of offset credits. By increasing the requirements for an offset credit, these policies make it less likely that the farmer would have undertaken the practices without the offset payment. As the scope of actions required for participation increases, the likelihood that all of the required actions have already been taken on any given farm is reduced and the risk of nonadditionality declines.

Water quality trading rules provide an example of the first approach. In many jurisdictions, farmers who want to be eligible to make water quality trades must adopt an array of best management practices (BMPs), a term that refers to practices designed to reduce nutrient runoff from agriculture, rather than a single practice that would be desirable on its own.[31] An example of the second approach is to require a farmer to earn a minimum number of credits. With a baseline of 60 lbs of nitrogen per acre, for example, the farmers might be required to reduce their nitrogen rate to below 55 lbs per acre in order to receive credits. In this case, for any nitrogen application rate of 55 lbs or below, farmers would receive credits for the full difference between their rate and 60 lbs.

The economics of this strategy are complex. Nonadditionality is reduced, but the expanded set of practices is now more costly. There is some risk that some farmers who would participate in the single-practice offset program would not participate when more is required. So, the overall effect on additional credits is not readily apparent.

Stepwise offset credits are essentially a sliding scale for offset credit awards. To understand this approach, consider a sample farm that would have had a baseline of 60 lbs of nitrogen per acre. Under a stepwise or sliding scale approach, this farm could start earning credits at higher applications rates, say 75 lbs per acre but would earn a lower number of credits for the first few pounds of reductions, then more credits for greater reductions. For example, the farm could be allowed to earn one-quarter credit for each pound below 75 until 60 lbs, then one-half credit for each pound below 60 until 50 lbs, and then one and one-quarter credits for each pound below 50 lbs. This approach could enhance additionality by increasing credits as nitrogen rates decline, making it more likely that credits will be based on additional reductions in nitrogen application.

The stepwise crediting approach has the advantage of allowing even farms with very high business-as-usual rates to earn at least some credits. Suppose this farm's business-as-usual rate was 75 lbs/acre and that the farm would find it prohibitively costly, in terms of lost yield, to apply below 60 lbs/acre. Under the prevailing practice baseline approach, this farm would not participate in the offset market and, in particular, would have no incentive to reduce its nitrogen application below 75 pounds. Under the stepwise approach, this farm may have at least some incentive to reduce nitrogen application, by earning one-quarter credit per pound reduced below 75 lbs per acre.

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[31] Water quality trading discussions sometimes refer to these additional practices as something the farm must adopt "before" being allowed to earn trading credits, but no time dimension is actually involved. In most circumstances, the expanded set of practices must be adopted simultaneously with the practice of interest.

Conclusion

Additionality is, and will continue to be, an issue for U.S. conservation payment programs and the design of environmental offset markets. To the extent that policymakers seek to maximize environmental gain per dollar of conservation program expenditure, payments for nonadditional practices will undercut that goal. Environmental benefits derived from nonadditional practices—even if the environmental gain is considerable—cannot be attributed to conservation payments. In offset programs or other environmental markets that seek to reduce the cost of regulation, nonadditional practices mean that regulated emissions caps will not be fully realized.

For existing conservation programs, high levels of additionality are observed for structural practices, which tend to be expensive to install and often yield modest onfarm benefits, at least in the short run. For soil conservation structures (terraces, grade stabilization, and water and sediment basins) and buffer practices (filter strips, riparian buffers, grassed waterways, and field borders) we estimated that 82 and 80 percent of farms applying these practices, respectively, would not have done so without a conservation payment to help defray costs. On many farms, the cost of installing these practices is likely to exceed the extra profit or other benefits that the farmer expects to receive, even though there can be significant benefits to society through environmental gain and maintenance of long-term soil productivity.

For conservation management practices, the evidence on additionality in existing programs is mixed. Our estimate of additionality in conservation tillage is low relative to our estimates for structural practices (56 percent), although it is higher than a previous estimate. For nutrient management, we estimate that farmers who receive payments are much more likely to have written nutrient management plans. For an estimated 88 percent of farms that have written nutrient or manure management plans, conservation payments prompted plan development. Of course, the existence of a plan does not ensure its implementation. This report finds that farmers who received payments are much less likely to apply nitrogen in the fall before planting corn. Corn farmers who did receive payments applied 1.2 percent of nitrogen fertilizer in the fall, on average, while matched farmers that did not receive payments applied almost 13 percent of nitrogen in the fall. This is an important result because fall-applied nitrogen is particularly vulnerable to runoff and leaching. On the other hand, this study does not provide evidence that producers who received payments for nutrient management apply less nitrogen fertilizer than farmers who do not receive payments. Although corn farmers who received nutrient management payments appear to have applied less nitrogen fertilizer than corn farmers who did not receive payments, our estimates are not statistically precise and do not constitute strong evidence that nutrient management payments are having an effect on nitrogen application rates. Similarly, nutrient management payments appear to increase the likelihood of applying nitrogen after planting, but estimates are not statistically precise. If nutrient management payments do result in lower nitrogen application rates or higher rates of postplant application (when plant needs are greatest), nitrogen loss to the environment through runoff and leaching could be reduced by nutrient management payments.

To the extent that conservation and offset programs seek to encourage cost-effective environmental gain, additionality is best considered in the context of environmental benefits and costs. In the budget- or acreage-limited programs that are typical of U.S. conservation policy, a cost-effective response to the risk of nonadditionality associated with any specific conservation practice depends on the level of expected additionality, environmental benefits, and costs of available alternatives. If our estimate of additionality in conservation tillage is correct, for example, it implies that roughly half of the payments made in support of conservation tillage are not delivering additional environmental benefits. To slow soil erosion, structural practices are more expensive but are more likely to be additional. Including additionality when considering alternate modes for reducing soil erosion may (or may not) mean that structural practice are less expensive per unit of additional erosion reduction. Additionality estimates could help facilitate similar comparisons of alternate modes of addressing other resource concerns or when making decisions about which resource concerns to address (practices typically used to address one resource concern may be more or less likely to be additional than practices used to address another concern).

We also find significant risk of low additionality in a hypothetical greenhouse gas offset program that targets reductions in farm use of nitrogen fertilizers. In the hypothetical program of offset credits analyzed in chapters 3 and 4, which relies on a prevailing local average practice baseline, we find that a large majority of the offset credits generated would be nonadditional. For wheat farms, given the offset credit prices assumed in our analysis, total offsets of 2.9 million tonnes of CO_2-e were generated, but only 0.97 milion tonnes of CO_2-e in *additional* reductions would actually be generated. For corn farms, total offsets of 7.0 million tonnes of CO_2-e would be generated but would result in *additional* reductions of only 2.0 million tonnes of CO_2-e. While the hypothetical offset programs did yield some abatement cost savings ($7.3 million for wheat, $14.9 million for corn), regulatory requirements for GHG abatement could not be met because credit purchasers would use nonadditional credits, which would increase aggregate emissions.

A key source of nonadditionality is variation in fertilizer application rates across farms that are observationally similar given existing data (ARMS). These differences could be due to unobserved differences in soils, topography, farmer management skills, etc. In our analysis, we attempt to reduce the effect of variation in fertilizer application by limiting eligibility to regions where fertilizer application rates are less variable and including safety margins which, in effect, make the baseline more stringent (require lower nitrogen application rates before beginning to earn credits for reducing nitrogen application). Restricting eligibility to regions with relatively low variability did improve additionality (increased the ratio of additional credits to total credits), but also reduced the total number of additional credits produced and sold. This approach can increase additionality in reducing GHG emissions because location of GHG emission reductions does not matter in terms of overall levels of atmospheric concentrations of GHGs. This approach may not be effective for other offset credit markets (e.g., water quality) where the location of farms selling offsets can be very important to outcomes.

While making the baseline more stringent (e.g., using a safety margin) eliminated many nonadditional credits, it also reduced participation. The producers who would decline to participate under the more stringent baseline are those with nitrogen application rates above the baseline and, therefore, deliver only additional offset credits and may deliver emissions reduction in excess of credits earned. If the reduction in total credits means that the credit price increases, however, more additional credits would be produced and sold.

As credit prices rise, however, the level of additionality—measured as the proportion of total credits that are additional—would also rise. Once the baseline is established, the number of nonadditional credits is also fixed. As credit prices rise, producers will respond primarily by reducing nitrogen application rates to produce credits that are additional. Because credit markets do not yet exist, however, it is impossible to say what credit market prices would be.

Our results suggest that more research is needed to determine the relative merits of the prevailing-practices baseline and a past-practices baseline. While both are business-as-usual baselines, they take very different approaches to estimating the business-as-usual nitrogen application rate. A past-practices baseline would sharply reduce error due to variation in fertilizer application across observationally similar farms, conditional on a given set of past practices and participation, but such conditioning is not valid here because farmers can choose their past practices, including, in some cases, the option to choose between a past-practices or prevailing-practices baseline.

Furthermore, a past-practices approach would move the offset program farther from the low-transaction-cost market approach that would be expected to maximize trading gains. Any such gains will be realized in reality only if farmers can (and do) actually provide accurate fertilizer application records needed to establish these baselines. Not all farmers keep the type of detailed records that would be needed to establish a past-practices baseline, and the suggested fallback is a prevailing-practices baseline. Going forward, the cost of keeping records and verifying records could add considerably to the cost of offset market transactions. A past-practices approach could also involve substantial moral hazard—producers may increase their fertilizer applications before they start selling offsets to increase their baseline and thus the number of offset credits they can profitably sell. At present, however, there is little evidence to suggest how large an effect moral hazard would have on past-practices baselines.

In all of the contexts that we studied, nonadditionality arises because it is difficult to predict what practices farmers are using and how practice use may change over time. A critical question is why does input use and practice adoption vary across seemingly similar farms? Our offset market analysis shows that this variation makes it difficult to establish an appropriate baseline that ensures additionality. The conservation program analysis highlights similar questions: Why do some farmers forego conservation program payments to adopt practices that could be eligible for payments? To what extent do incentive payments simply hasten the adoption of practices that would eventually be adopted without payment support? Further research is needed to address these questions.

One promising direction for future research on practice adoption and input use is broader integration of data from producer surveys; conservation program contracts; conservation planning databases; and detailed information on climate, soils, topography, and landscape position (e.g., distance to water). As already noted in the “Additionality in Existing Conservation Payment Programs” chapter, specific information on nutrient management plans could help improve estimates of the role of nutrient plans in reducing fertilizer application rates and otherwise improve application timing or methods. Likewise, better information on soils and topography could lead to a clearer picture of why some farmers adopt soil conservation structures or conservation tillage while others do not. Finally, the decentralized nature of most conservation programs makes it difficult to control for variation in conservation program incentives for specific practices or resource concerns. In EQIP, for example, benefit-cost indices used for ranking farm conservation program applications vary across States and even across counties within States. While these variations are appropriate because of diversity in agriculture and related resource concerns, a centralized source of information on these differences could help sharpen estimates of practice adoption, the likelihood of practice adoption, and additionality.

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Appendix 1: Estimating Additionality Using Propensity Score Matching

The fundamental problem in measuring additionality is to estimate the unobserved counterfactual outcomes. That is, we must estimate what farms that received payments would have done in the absence of those payments. To the extent that these farms would have adopted the supported practice, even without the payment, supported practices are not additional. To estimate additionality, we use PSM (see Caliendo and Kopeinig, 2008; Heckman et al., 1998b; Heckman et al., 1997). While PSM and other matching methods are relatively new to agricultural economics, a number of applications exist (Chabé-Ferret and Subervie, 2013; Liu and Lynch, 2011; Lynch et al., 2007; Mezzatesta et al., 2013; Pufahl and Weiss, 2009) and are reviewed briefly in the main text.

Defining a Measure of Additionality

Our empirical measure of additionality is the ATT. The exact form of the ATT varies depending on the evaluation task but is generally used to measure the effect of a program on targeted outcomes. When evaluating a job training program, for example, the ATT may attempt to measure the effect of the training on the likelihood of employment or the wage rate earned by those who received the training. For those who received training, however, the employment they would have found or the wage rate they would have earned without the program is not observed. In a matching model, this missing counterfactual is estimated by observing employment and wages for other individuals who did not receive the training but who are otherwise very similar to (or “match”) those who did receive training. ATTs can be estimated as the difference in employment rate or wage rate between the participants and matching nonparticipants. To measure the effect of conservation programs on environmental outcomes, we define ATT in two ways. First, we consider the effect of payments on practice adoption by examining the difference in the likelihood of conservation practice adoption for farmers who received a payment for adoption and matching farmers who did not. Second, we estimate the effect of nutrient management payments on nutrient application rates and application timing in corn production. Here, the ATTs are the difference in nitrogen application rates, the proportion of fields that applied nitrogen in the fall, and the proportion that applied after planting for farms that received payments and matching farms that did not.

Formally, we let treatment (D) equal 1 when a farmer receives a payment for a particular conservation practice and 0 when no payment is received. The adoption outcome for farmer i when receiving a payment is denoted Y_{i1}. (Since the structure of the additionality measure is the same across conservation practices, we exclude subscripts indicating the type of conservation practice payment for clarity.) For the practice adoption models, farmers that receive payments for a particular conservation practice will always have adopted that conservation practice such that $Y_{i1} = 1$ for every farmer i when $D_i = 1$. The adoption outcome for farmer i under nontreatment is denoted Y_{i0} and can be either 0 or 1 because some farmers may choose to adopt a conservation practice without payment. For the nutrient application rate model, Y_{i1} is the application rate when the producer receives a nutrient management payment while Y_{i0} is the application rate when the producer does not receive a payment. For the nutrient application timing model, Y_{i1} is the proportion of nitrogen fertilizer applied in the fall (after planting) when the producer receives a nutrient management payment while Y_{i0} is the proportion of nitrogen fertilizer applied in the fall (after planting) when the producer does not receive a payment.

Upon conditioning on farmers who receive payments, the additionality of a particular conservation payment program is given by:

$$E[Y_{i1} - Y_{i0} \mid D = 1]. \tag{1}$$

The challenge in calculating this measure is that Y_{i0} represents the unobserved counterfactual behavior and must be estimated.

If payments to farmers were randomly assigned, additionality could simply be calculated as $E[Y_{i1} \mid D = 1] - E[Y_{i0} \mid D = 0]$ since the unobserved mean adoption outcome $E[Y_{i0} \mid D = 1]$ would equal $E[Y_{i0} \mid D = 0]$. If practice adoption and the receipt of payment both depend (at least in part) on the farmer, farm, and field, the likelihood of payment may be correlated with the outcome (adoption) so that $E[Y_{i0} \mid D = 0] \neq E[Y_{i0} \mid D = 1]$. If the relationship is positive, as we hypothesize, a model which improperly controls for factors which affect both adoption and payment will overstate the effectiveness of payments at inducing conservation practice adoption and our estimate of additionality would be biased upwards, i.e., $E\left[Y_{i0} | D = 0\right] < E[Y_{i0} \mid D = 1]$. Because conservation programs typically cover only a portion of adoption costs, producers for whom conservation practices are profitable or almost profitable are more likely than other producers to adopt the practice and to seek payments.

One solution to the inference problem is to rely on the *conditional independence assumption* (CIA). If a set of covariates, *Z*, satisfies CIA the outcome (adoption) and payment assignment are independent. That is, $E\left[Y_{i0} | Z, D = 0\right] = E[Y_{i0} \mid Z, D = 1]$, so that additionality is measurable as:

$$E[Y_{i1} - Y_{i0} \mid Z, D = 1] = E[Y_{i1} \mid Z, D = 1] - E[Y_{i0} \mid Z, D = 0]. \tag{2}$$

The CIA is also known as "selection on observables" because, for the assumption to hold, *Z* must be observable to the researcher. [32] In other words, farms that are observationally similar are likely to make similar decisions about practice adoption in the absence of a payment. In our case, *Z* might include covariates such as characteristics about the field, farm, farmer, and controls for possible preferences of the agency and budget constraints. Because of budget constraints and differences in conservation program objectives at the State or local level, it is unlikely that all farms with covariates *Z* will receive a payment, making it possible to estimate additionality by (2). The independence of practice adoption and payments received is not directly testable. We discuss and perform common sensitivity checks to assess the robustness of the results to deviations from the assumption.

Estimation of the conditional difference between the expected outcomes is most commonly achieved in practice with matching estimators. The most basic type of matching is covariate matching, which requires matches to have identical values for all the possible covariates in Z. This type of matching estimator works best when there are a small number of potential covariates that have a relatively low number of discrete values.

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[32] A necessary condition for this assumption to hold and be able to identify the mean impact of treatment on the treated is for $E[Y_{i0} \mid Z, D = 1] = E[Y_{i0} \mid Z, D = 0]$.

Propensity Score Matching Estimation

Along with covariate matching, valid estimates of the ATT under CIA are also achievable with PSM (e.g., Caliendo and Kopeinig, 2008; Heckman et al., 1998b; Heckman et al., 1997). Instead of conditioning on Z, PSM conditions alternatively on propensity scores, $P = pr(D_i = 1 \mid Z_i) \in (0,1)$, estimated from a binary model for treatment (Rosenbaum and Rubin, 1983). Propensity scores also have the advantage of being one-dimensional, whereas conditioning on the multidimensional Z can make covariate matching estimators more difficult. In our model for the binary payment for each practice type, we allow Z to include factors that might affect the adoption of the particular practice, the willingness to seek payments from a conservation program, and the likelihood that farms would be selected by the program agency to receive payments.

In addition to the CIA, the validity of PSM as a policy evaluation method rests upon a second assumption often referred to as “overlap” or “common support.” Farms available for matching must have some positive probability of receiving conservation payments and not receiving conservation payments. Satisfying this condition ensures that farms in the payment group will not be compared to nonpayment farms that are inherently different. Farms with relevant field, farm, and farmer characteristics that lie outside a specified range of common support for payment and nonpayment farms are not used for matching. One way this is implemented in PSM is by restricting the set of observations available for matching so that the largest propensity score of the treated observations is no larger than the largest propensity score of the control observations and that the smallest propensity score for the control observations is no smaller than the smallest propensity score of the treated observations. In terms of policy, for example, this assumption excludes nonpayment farms from the comparison group if they are ineligible for conservation payments (in general or for a specific practice) or face regulations that do not apply to payment farms.

The basic matching estimator for obtaining the ATT (equation 2) can be formulated as the following:

$$\mathrm{ATT} = \frac{1}{n_1} \sum_{i \in \{T_i = 1\}} \left\{ \left(Y_i \mid D_i = 1\right) - \sum_{i \in \{T_j = 0\}} \omega_i \left(Y_j \mid D_j = 0\right) \right\}, \tag{3}$$

where n_1 is the number of payment farms, i indexes the payment farms, j indexes the nonpayment farms, and ω_{ij} is the weight given to the nonpayment farms j when matched to the i^{th} payment farms. Under simple nearest-neighbor matching, a treated observation is matched, as measure by predicted propensity scores from a treatment model, to the N nearest control observations. Weights in this case are just $\omega_{ij} = 1/N$. The ATT is then simply the average difference in the outcome of the treated observations and their respective weighted counterfactual estimates.

We use a kernel-based matching estimator to determine the weights. The weight that the practice adoption outcome for any given nonpayment farm has on the estimated counterfactual behavior for the payment farm declines with distance between the propensity score of the payment and nonpayment farms. Therefore, the estimated counterfactual behavior places a greater emphasis on control observations that are most similar in terms of probability of receiving a payment.[33] The advantage of

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[33] A disadvantage of kernel-based estimators is that they might overweight control observations that might more appropriately be considered as inappropriate for matching to treatment observations.

this approach is greater statistical efficiency than other types of matching estimators such as nearest-neighbor estimators (Heckman et al., 1998a; Heckman et al., 1998b; Heckman et al., 1997).

Control observations are weighted by the kernel weights, $\omega_{ij} = \dfrac{G\left((P_j - P_i)/\kappa\right)}{\sum_{k\in\{T_k=0\}} G\left((P_k - P_i)/\kappa\right)}$, where $G(\cdot)$ is a kernel density function (e.g., Gaussian, uniform, triangular, and Epanechnikov) and κ is the bandwidth parameter for smoothing. The bandwidth parameter is a choice parameter set by the researcher. Larger bandwidths lead to a smaller potential bias but larger variances for ATT estimates. Thus, the researcher must choose between bias and efficiency. We choose a bandwidth value that minimizes the mean squared error (MSE) of the ATT estimate with a leave-out-one cross-validation optimization algorithm (Black and Smith, 2004; Liu and Lynch, 2011). The optimization procedure we use searches over {.2, .1, .06, .05, .04, .03, .02, .01, .006} as the set of possible bandwidth values. Appendix table 1-4 reports the estimated optimal bandwidths.

We adopt a methodology proposed by Frölich (2007) to adjust equation (1) by the survey weights, ω_i^s, in our sample to obtain nationally representative estimates of additionality:

$$ATT = \sum_{i\in\{T_i=1\}} \tilde{\omega}_i \left\{ \left(Y_i \mid D_i = 1\right) - \sum_{j\in\{T_j=0\}} \tilde{\omega}_{ij} \left(Y_j \mid D_j = 0\right) \right\} \tag{4}$$

where $\tilde{\omega}_i = \dfrac{\omega_i^s}{\sum_{l\in\{T_l=1\}} \omega_l^s}$, $\tilde{\omega}_{ij} = \dfrac{\omega_{ij}^k \omega_j^s}{\sum_{m\in\{T_m=0\}} \omega_{im}^k \omega_m^s}$, ω_{ij}^k, and are the kernel weights.[34]

This adjustment provides estimates of additionality for the practice outcomes that are nationally representative. Survey-weights are unnecessary in treatment model estimation because the estimated propensity scores are used only for measuring the similarity of observations in the sample and not to infer behavior about the underlying population.

Data

The annual Agricultural Resource Management Survey (ARMS) consists of separate field-level and farm-level surveys that provide information about payments to farmers and practice adoption that we use to generate separate estimates of additionality for the conservation practice payments of nutrient management, conservation tillage, soil conservation, and buffer practices.[35] ARMS is sponsored jointly by USDA's Economic Research Service and National Agricultural Statistics Service. The field survey has been administered yearly since 1996, with the exception of 2008 when no survey was performed. Questions on payments for conservation practices were first included in the field survey in 2009. We use data for wheat operations in 2009, corn operations in 2010, and sorghum and barley

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[34] See Zanutto (2006) for a method to include survey weights under a stratified propensity score matching method. In that paper, the author found that ignoring the survey weights from a complex survey can substantially bias the estimated effects of a stratification estimator.

[35] Each of the practice groups are defined by subsets of practices. Buffer practices include field-edge filter strips, field borders, and riparian buffers. Soil conservation structures include terraces, grassed waterways, grade stabilization structures, and water and sediment basins. Conservation tillage includes no-till, mulch till, and ridge-till. Nutrient and manure management includes comprehensive nutrient management and manure management.

operations in 2011, with each year of the survey consisting of a unique cross-section of sampled farmers. Our estimation sample is the subsample of respondents who participated in both the field and farm surveys and consists of a unique cross-section for each year of the survey.

Respondents were asked in the ARMS field surveys whether a conservation practice was in use on the surveyed field when the practice was installed or first used and whether cost-sharing or an adoption incentive payment was received. We use whether a payment was received for a particular practice as the treatment status indicator in the estimation of propensity scores and consider whether a practice was adopted, the nitrogen application rate on the field, fall nitrogen application rates, and postplant nitrogen application rates as outcomes for measuring additionality of the payments. To satisfy CIA when modeling treatment status, our treatment models include information about practices on fields, farm operations, and farmer individual and household characteristics from the ARMS field and farm surveys.[36] With geo-coordinates of the field from the ARMS survey, we also were able to include information on the soil productivity of the field based upon the National Commodity Crops Productivity Index (NCCPI) produced by USDA's Natural Resources Conservation Service (NRCS).

Even though our propensity score models include numerous controls from ARMS to satisfy the CIA condition, the exact enrollment mechanism in USDA conservation programs is complex (Cattaneo et al., 2005). For instance, producers seeking payments must apply for a specific program, providing a proposal for the application of specific practices in specific fields, and may need to choose between programs because funding from multiple sources is not allowed in some cases. Producers may also differ in their propensity to seek funding, perhaps because of differences in general attitudes about government, familiarity with conservation, or willingness to install or use conservation practices as prescribed by government conservation practice standards. The resulting producer demand for payments from voluntary conservation programs is often in excess of available funding such that program managers must select proposals according to likely environmental benefits and costs. To control for the selection process that can vary by payment program and State goals, we include information on historical average Environmental Quality Incentives Program (EQIP) and Conservation Reserve Program (CRP) payments distributed to counties in our propensity score models, which we were able to construct using information from detailed contract data from NRCS.

After merging the two types of ARMS surveys, and keeping observations that have usable geo-coordinates, our final estimation sample consists of 1,381 observations for corn fields in 2000, 1,277 observations for wheat fields in 2009, and 565 observations for sorghum fields and 282 observations for barley fields in 2011.[37,38] We adjust the dataset in a number of ways to ensure that we are focusing on (1) conservation program and practice adoption decisions made by the surveyed producer, (2) ensuring that data meet the common support requirement, and (3) that program payments actually support the surveyed practices. Appendix table 1-1 summarizes the various restrictions we apply to obtain our estimation samples for each practice in the table for the treatment model estimates. The number of observations also varies across practice groups because the survey questions varied slightly across the 2009-11 years.

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[36] More specific types of information include operation size, commodities produced, production expenses, overall government payments, land tenure (for the farm, overall), operator age and education, off-farm work, and many other characteristics of the farm, the farmer, and his or her household.

[37] The size of the sample in each year of the field and farm surveys varies by year.

[38] Not all fields have known geographic coordinates, and we lose some additional observations in the geocoding process.

Appendix table 1-1

Number of observations by crop and practice group

	Wheat 2009	Corn 2010	Barley 2011	Sorghum 2011	Totals	Estimation sample
Total, field-level survey[a]	1,895	2,084	940	425		
Exclusions by merging						
With farm-level data	1,300	1,492	636	284		
With soil and MLRA data	1,277	1,381	565	282		
Other exclusions by practice type:[b]						
Soil conservation structures[1]	166	203	All	All		
Buffer practices[1]	169	203	All	All		
Conservation tillage[2]	All	139	190	32		
Nutrient management[3]	130	194	219	33		
Final count:						
Soil conservation structures	1,111	1,178	-	-	2,289	1,192
Buffer practices	1,108	1,168	-	-	2,276	2,195
Conservation tillage	-	1,242	375	250	1,867	1,179
Nutrient management	1,147	1,187	346	249	2,929	2,672

MLRA = major land resource area.

[a] Of the 2,303 field-level corn observations, 78 were dropped because of missing information on either year of adoption or fertilizer application. For wheat, we dropped 1,070 observations that reported zero acres planted and another 512 after merging with information on fertilizer use. Similarly, there were 1,266 original observations for barley and 548 for sorghum.

[b] Observations are excluded when the field is irrigated and has a reported nitrogen application rate of over 300 lbs N/acre.

[1] Additional observations are also excluded if practices were adopted before the beginning of current farmer's tenure.

[2] The 2009 survey did not have questions about conservation tillage.

[3] Observations are also excluded if farm includes confined animal feeding operations (CAFOs) subject to regulation.

Source: USDA, Economic Research Service and USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey, 2009-11.

We focus on the role of incentives in conservation practice adoption by considering only those adoption decisions made by the current producer (the survey respondent). Many of the soil conservation structures on survey fields have been in place since before the beginning of the current producer's tenure due to 75 years of promotion and cost-sharing by USDA for these types of structures.[39] Thus, we exclude structural and vegetative practices (e.g., terraces, filter strips) that were installed before the beginning of the current farmer's tenure. We also assume that management practices are readopted annually. When the reported date of initial adoption precedes the current producer's tenure, the date of initial adoption is assumed to be the first year of the current producer's tenure and it is assumed that the current producer did not receive a payment for initial adoption.

The data for our treatment models must also be suitable for satisfying the common support condition. To address these concerns, we collected information on State-level regulations to identify ineligible farms. Farms that are required by regulation to adopt a particular practice are excluded from the matching process. Matches would otherwise be more likely to occur between an unregulated farmer with payment to adopt and a regulated farmer without payment who was required to adopt.

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[39] For roughly 40 percent of respondents (in both the wheat and corn surveys) who reported one or more structural or vegetative practices, the practices were installed before the beginning of the current farmer's tenure.

This would bias the estimated counterfactual to receiving a payment as one of adoption and, thus, bias downwards our additionality estimates.

Most conservation payments made through Federal and State programs are based on standards published by USDA's Natural Resources Conservation Service in the National Handbook of Conservation Practices (NHCP).[40] There are significant exceptions, however, and we adjust our data accordingly. Specifically, payments made through the Conservation Security Program (CSP; 2004-2008) and Conservation Stewardship Program (CSP; 2009-present) do not necessarily support the adoption of practices from the NHCP. A portion of the payments made through these programs are based on stewardship—conservation efforts begun prior to program enrollment. These payments are not additional because they do not require the adoption of new practices. “Enhancements” to existing practices accounted for roughly 85 percent of payments made through the CSP (2004-2008). A wide range of enhancements were supported, including widening field borders and riparian buffers, injecting manure, postplanting application of fertilizer, and spot spraying to limit pesticide use. While these payments can often be linked to the conservation practices that are typically supported by other conservation programs, they are not well matched to ARMS questions, which are based on full adoption of standard conservation practices.

Our analysis also excludes observations that had high self-reported levels of nitrogen application rates (N>300), irrigated farms, farms that were likely required by States to implement a practice because of State regulations, or farms that received a CSP payment. We also excluded an observation if the farmer reported adopting any of the practices, except buffers, and received a CRP payment.

Finally, practice adoption and payment questions varied across survey years. Wheat data are excluded from the conservation tillage analysis because conservation tillage payment questions were not included in the 2009 survey. Data for barley and sorghum are excluded from the buffer practice and soil conservation structures analysis because the 2011 survey omitted questions that we used to determine whether practices were already in place at the beginning of the current farmer’s tenure.

Appendix table 1-2 summarizes means of the variables we consider in our analysis by treatment status and practice type, where treated observations are those observations for which producers reported receiving a payment. The means reported are based on the estimation sample of the respective treatment models. Each field-level observation in ARMS includes a survey-weight for generating population estimates that are representative of U.S. farmers. We use these survey weights in the estimation of the means in appendix table 1-2 and in our additionality estimates.

We control for the soil productivity of a field (*NCCPI;* Dobos et al.), whether a field was classified as highly erodible (*Highly erodible*) by NRCS, and if the field was adjacent to a wetland (*Wetland*). We include farm-specific variables on size (*Log(acres)*) of the farm and whether manure had been applied to the field (*Manure*). Since adoption and payment patterns may depend on characteristics about the farmer, our treatment models also include information on whether a farmer’s primary occupation is farming (*Primarily a farmer*), if the farmer has a college degree (*College degree*), his or her age (*Age of operator*), and whether the farmer owns the surveyed field (*Owns field*).

To capture possible differences in payment determination across regions and States, we include binary indicators for unobserved State-level factors. These could be due to differences in regulatory environ-

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[40] Accessed at: http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/cp/ncps/

Appendix table 1-2

Summary of variables by treatment status and practice type[a]

Type	Variable	Nutrient management		Conservation tillage		Soil conservation structures		Buffer practices	
	Treated	Treated	Controls	Treated	Controls	Treated	Controls	Treated	Controls
Field	*Productivity (NCCPI, unit interval)*	0.51	0.49	0.48	0.55	0.56	0.6	0.59	0.51
		(0.22)	(0.21)	(0.19)	(0.21)	(0.23)	(0.18)	(0.15)	(0.22)
	Highly erodible (=1)	0.22	0.13	0.04	0.13	0.17	0.11	0.17	0.11
		(0.41)	(0.33)	(0.20)	(0.34)	(0.38)	(0.32)	(0.38)	(0.31)
	Wetland (=1)	0.01	0.04	0.01	0.03	0.06	0.02	0	0.04
		(0.11)	(0.18)	(0.09)	(0.16)	(0.23)	(0.14)	(0.04)	(0.19)
Farm	*Log operation size (1,000 ac.)*	6.76	6.84	6.93	6.58	7.2	6.72	6.69	6.8
		(0.92)	(1.14)	(0.77)	(1.07)	(0.85)	(1.08)	(0.93)	(1.13)
	Manure (=1)	0.45	0.17	0.07	0.26	0.04	0.11	0.12	0.19
		(0.50)	(0.38)	(0.25)	(0.44)	(0.19)	(0.31)	(0.33)	(0.39)
	Primarily a farmer (=1)	0.98	0.91	0.97	0.92	0.91	0.89	0.92	0.9
		(0.14)	(0.29)	(0.18)	(0.28)	(0.29)	(0.32)	(0.27)	(0.29)
Farmer	*Age of operator*	54.5	55.91	56.64	55.35	62.41	55.89	60.29	55.59
		(7.43)	(11.60)	(7.40)	(11.52)	(11.18)	(11.82)	(9.76)	(11.42)
	College degree (=1)	0.26	0.22	0.22	0.2	0.24	0.23	0.35	0.2
		(0.44)	(0.42)	(0.42)	(0.40)	(0.43)	(0.42)	(0.48)	(0.40)
	Owns field (=1)	0.66	0.51	0.71	0.52	0.58	0.47	0.69	0.51
		(0.48)	(0.50)	(0.46)	(0.50)	(0.50)	(0.50)	(0.46)	(0.50)
Other	*EQIP payments in county ($/acre)*	0.12	0.07	0.05	0.03	0.15	0.06	0.03	0.02
		(0.11)	(0.08)	(0.08)	(0.06)	(0.26)	(0.11)	(0.03)	(0.04)
	“ in adjacent counties	0.7	0.4	0.45	0.23	0.82	0.39	0.15	0.11
		(0.40)	(0.35)	(0.42)	(0.24)	(1.03)	(0.56)	(0.15)	(0.13)
	CRP payments in county ($/acre)	n/a	n/a	n/a	n/a	n/a	n/a	0.28	0.21
								(0.27)	(0.35)
	“ in adjacent counties	n/a	n/a	n/a	n/a	n/a	n/a	1.88	1.48
								(1.66)	(1.81)
	Population density (1,000/acre)	0.09	0.09	0.06	0.11	0.04	0.1	0.06	0.09
		(0.10)	(0.16)	(0.06)	(0.17)	(0.04)	(0.18)	(0.07)	(0.16)
	MLRA adoption rate (unit interval)	0.15	0.09	0.28	0.33	0.25	0.13	0.31	0.22
	Number of observations	75	2,598	37	1,142	60	1,132	110	2,085

NCCPI = National Commodity Crop Productivity Indicator (see Dobos et al.); CRP = USDA Conservation Reserve Program; EQIP = USDA Environmental Quality Incentives Program; MLRA = major land resource area.

Notes: Standard deviations in parentheses; survey weights used in calculations; n/a = not applicable; CRP does not fund nutrient management, conservation tillage, or soil conservation structures.

Source: USDA, Economic Research Service and USDA, National Agricultural Statistics Service.

ments and overall conservation goals of States.[41] As noted, within-State variation in EQIP and CRP goals could also affect who receives payment. Appendix table 1-2 also summarizes the rate of EQIP and/or CRP payments (*EQIP* and *CRP*; in dollars per cropland acre) made to all farms in the same county of the surveyed field and the rate of payments to all farms in adjacent counties. Since within-State differences in geography, environmental conditions, and local regulations might affect demand for conservation practices, we include controls for population density (*Population density*; from the 2010 Population Census) and the average adoption level of the conservation practice for the major land resource area (*MLRA adoption rate*) of the county in which the surveyed field resides.[42,43]

Propensity Score Estimates

Appendix table 1-3 reports the estimated coefficients for the binary treatment models of the four conservation payment types—nutrient management, soil conservation, buffer practices, and conservation tillage. The controls in these models include the variables of appendix table 1-2 and interactions of the MLRA adoption rate with characteristics of the field to predict the likelihood that a farmer receives a payment. Also included are indicators for crops and States, and interactions of the EQIP and CRP average county payments.

The consistent predictors across the four payment types include whether a farmer owns the field (positive effect), which suggests the incentive to seek payment is greatest for those farmers who are owners, and the operation size of the farm (positive effect). In general, we find consistent signs for the effects of most other variables across the different types of payments but they are not always significant. High erodibility, for instance, leads to a significantly ($p<.01$) greater likelihood that farmers receive a payment for nutrient management (for adoption rate) and soil conservation but insignificant positive effects for the other types of payments. The age of the operator is the only factor which appears to have inconsistent signs, but we reason that this effect is primarily due to the more recent time period for which nutrient management conservation practices have been targeted by programs.

The goodness-of-fit measures of binary models we report at the bottom of appendix table 1-3 indicate a modest ability of our models to successfully predict which farmers receive payment. The pseudo-R^2 values range between .16 for payments to buffer practices and .26 for the nutrient management (timing). Pseudo-R^2 is calculated based on the likelihood ratio of the estimated model and a restricted model with just a constant. The advantage of *% of treated predicted correctly* is that it places greater emphasis on the goodness-of-fit for the less likely occurring outcomes, which are receiving payments based on our data. A probability threshold is adjusted until the fraction of observations with predictions as receiving payment is approximately equal to the observed fraction of treated observations. The *% of treated predicted correctly* is then the fraction of those treat-

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[41] An alternative approach in the PSM literature for controlling for differences that might exist across strata such as States is to run separate treatment models for each State, restrict matches to be within States, and then average estimated additionality levels across States. We attempted this with our data but found that the small number of treated observations in our sample led to several instances of perfect multicollinearity between our payment indicator variable and some of our binary explanatory variables when using State-level treatment models. This was also the case for some practices when we considered the spatially more aggregate Farm Resource Regions (USDA/ERS, 2010).

[42] MLRAs are geographic associations of large areas defined by common geology, climate, water, soils, biological resources, and land use. Definitions are maintained by NRCS. http://soils.usda.gov/survey/geography/mlra/

[43] We considered weather variables such as temperature and precipitation in an initial analysis but found these variables to be statistically insignificant in their ability to explain treatment status after controlling for States' effects.

Appendix table 1-3

Estimated coefficients for treatment models

	Nutrient management	Conservation tillage	Soil conservation	Buffer practices
NCCPI (unit interval)	1.97*	-0.14	0.48	2.02***
	(1.76)	(-0.12)	(0.64)	(3.05)
Highly erodible (=1)	0.67	0.28	0.98***	0.31
	(1.45)	(0.41)	(3.53)	(1.14)
Wetland (=1)	-0.21	1.18	0.14	1.28
	(-0.17)	(0.70)	(0.18)	(1.55)
Log operation size (1,000 ac.)	0.21*	0.16*	0.29***	0.069
	(1.66)	(1.71)	(3.23)	(1.19)
Manure (=1)	1.26***	-0.55	-0.81	-0.31
	(3.16)	(-0.74)	(-1.36)	(-0.90)
Primarily a farmer (=1)	-0.024	-0.31	-0.16	-0.19
	(-0.06)	(-1.09)	(-0.63)	(-1.13)
Age of operator	-0.012	0.0052	0.015**	0.016***
	(-1.28)	(0.68)	(2.28)	(3.42)
College degree (=1)	0.36	0.46**	0.034	0.23**
	(1.42)	(2.47)	(0.20)	(2.02)
Owns field (=1)	0.64***	0.15	0.30*	0.18*
	(2.63)	(0.81)	(1.88)	(1.67)
State indicators	Yes	Yes	Yes	Yes
Crops included	Corn	Corn, sorghum, barley	Corn, wheat	Corn, wheat
Payment programs	EQIP, other	EQIP, other	EQIP, other	CRP, EQIP, other
Regulated farms	Excluded	n/a	n/a	n/a
Adopted before tenure	n/a	Excluded	Excluded	n/a
Observations	1,024	1,179	2,195	1,192
# of treated	26	37	110	60
Pseudo-R2	0.25	0.19	0.16	0.24
Percent predicted correctly	0.3	0.24	0.24	0.32
EQIP $/acre	1.91	0.020	1.20	-3.17
	(1.58)	(0.01)	(1.10)	(-0.52)
“ in adjacent counties	1.15	15.0*	8.78**	3.22
	(0.22)	(1.90)	(2.19)	(0.21)
CRP $/acre	-	-	-	-0.061
				(-0.30)
“ in adjacent counties	-	-	-	1.45*
				(1.81)
Pop. density (1,000/acre)	-1.09	-1.31	-2.30	-0.54
	(-1.02)	(-1.18)	(-1.58)	(-1.04)
MLRA adoption rate, “AR”	12.0***	0.75	0.40	5.73***
	(2.87)	(0.45)	(0.18)	(3.78)

continued—

Appendix table 1-3

Estimated coefficients for treatment models—continued

	Nutrient management	Conservation tillage	Soil conservation	Buffer practices
Corn field (=1)	-	-	0.17	0.20
			(0.50)	(0.68)
Sorg. or barley field (=1)	-	-0.025	-	-
		(-0.03)		
AR x NCCPI	-11.7*	0.17	2.87	-6.08***
	(-1.84)	(0.06)	(0.86)	(-2.72)
AR x highly erodible	-0.92	-0.047	-2.35*	0.60
	(-0.32)	(-0.03)	(-1.79)	(0.71)
AR x wetland	10.9	-3.99	-2.54	-15.0
	(0.91)	(-0.74)	(-0.54)	(-1.49)
State indicators	Yes	Yes	Yes	Yes
Crops included	Corn	Corn, sorghum, barley	Corn, wheat	Corn, wheat
Payment programs	EQIP, other	EQIP, other	EQIP, other	CRP, EQIP, other
Regulated farms	Excluded	n/a	n/a	n/a
Adopted before tenure	n/a	Excluded	Excluded	n/a
Observations	1,024	1,179	2,195	1,192
# of treated	26	37	110	60
Pseudo-R2	0.25	0.19	0.16	0.24
Percent predicted correctly	0.3	0.24	0.24	0.32
AR x log(acres)	-0.78	-0.11	-0.70	0.041
	(-0.23)	(-0.37)	(-1.63)	(0.20)
AR x corn field	-	-	-1.05	-0.55
			(-0.71)	(-0.48)
AR x s/b field	-	-0.20	-	-
		(-0.13)		
AR x manure	-4.91**	-0.16	2.58	-0.0098
	(-1.99)	(-0.10)	(1.22)	(-0.01)
EQIP x corn field	-	-	-4.19	-7.35
			(-0.88)	(-0.41)
EQIP adj x corn field	-	0.43	-	-
		(0.19)		
EQIP adj x s/b field	-	-14.8*	-	-
		(-1.78)		
CRP x corn field	-	-	-	-0.075
				(-0.23)
CRP adj x corn field	-	-	-	-1.33
				(-1.31)
Constant	-4.27***	-3.50***	-4.92***	-4.78***
	(-3.29)	(-2.92)	(-4.65)	(-5.69)

continued—

Appendix table 1-3

Estimated coefficients for treatment models—continued

	Nutrient management	Conservation tillage	Soil conservation	Buffer practices
State indicators	Yes	Yes	Yes	Yes
Crops included	Corn	Corn, sorghum, barley	Corn, wheat	Corn, wheat
Payment programs	EQIP, other	EQIP, other	EQIP, other	CRP, EQIP, other
Regulated farms	Excluded	n/a	n/a	n/a
Adopted before tenure	n/a	Excluded	Excluded	n/a
Observations	1,024	1,179	2,195	1,192
# of treated	26	37	110	60
Pseudo-R2	0.25	0.19	0.16	0.24
Percent predicted correctly	0.3	0.24	0.24	0.32

CRP = USDA Conservation Reserve Program; EQIP = USDA Environmental Quality Incentives Program; MLRA = major land resource area.
n/a = not applicable.
Notes: * p<0.1, ** p<0.05, *** p<0.01; t-statistics in parentheses.

Source: USDA, Economic Research Service.

ment predictions that are observed with actual payments (see page 581, Wooldridge, 4th edition). Appendix table 1-4 reports the estimated optimal bandwidths for the kernel matching under the leave-out-one cross-validation procedure for each additionality estimate. The corresponding additionality estimates for each outcome we consider under the full sample of observations for each treatment model are reported in tables 3 and 4 in the main text.

An important step in matching is assessing the quality of proposed matches. One empirical test is *covariate balancing*, which tests for the similarity of the covariates Z for the treated and control groups. This entails performing a *t-test* of equality of the means for each covariate. If equality of means is not rejected for any of the covariates, then the proposed matching control observations are observationally equivalent (based on the selection of observable explanatory variables) to the treatment observations. In our test of the full sample, we found a number of variables that had statistically significant differences in means across the treatment and controls. To address the concern that these differences might indicate a violation of CIA and a potential bias in our additionality estimates, we re-estimated additionality based on just the upper quintile of the propensity score distributions. This is similar in technique and purpose to stratification methods for matching estimators (see Rosenbaum and Rubin (1984)).[44] The primary advantage of stratification is that it reduces covariate imbalance between the treatments and control observations and, thereby, reduces the potential for a violation of CIA. Appendix figure 1-1 shows the distribution of propensity scores by treatment status for each of the conservation practices and the upper quintiles. Although the propensity score distributions are right-skewed for both the treatment and control observations, the treated observations for all models have distributions that are significantly less right-skewed than controls. We find modest downward changes (not reported) in the levels of each additionality estimate under the sample for just the upper quintile distribution.

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[44] We ignore other quintiles to focus on those observations must likely to be predicted as receiving a payment.

Appendix table 1-4

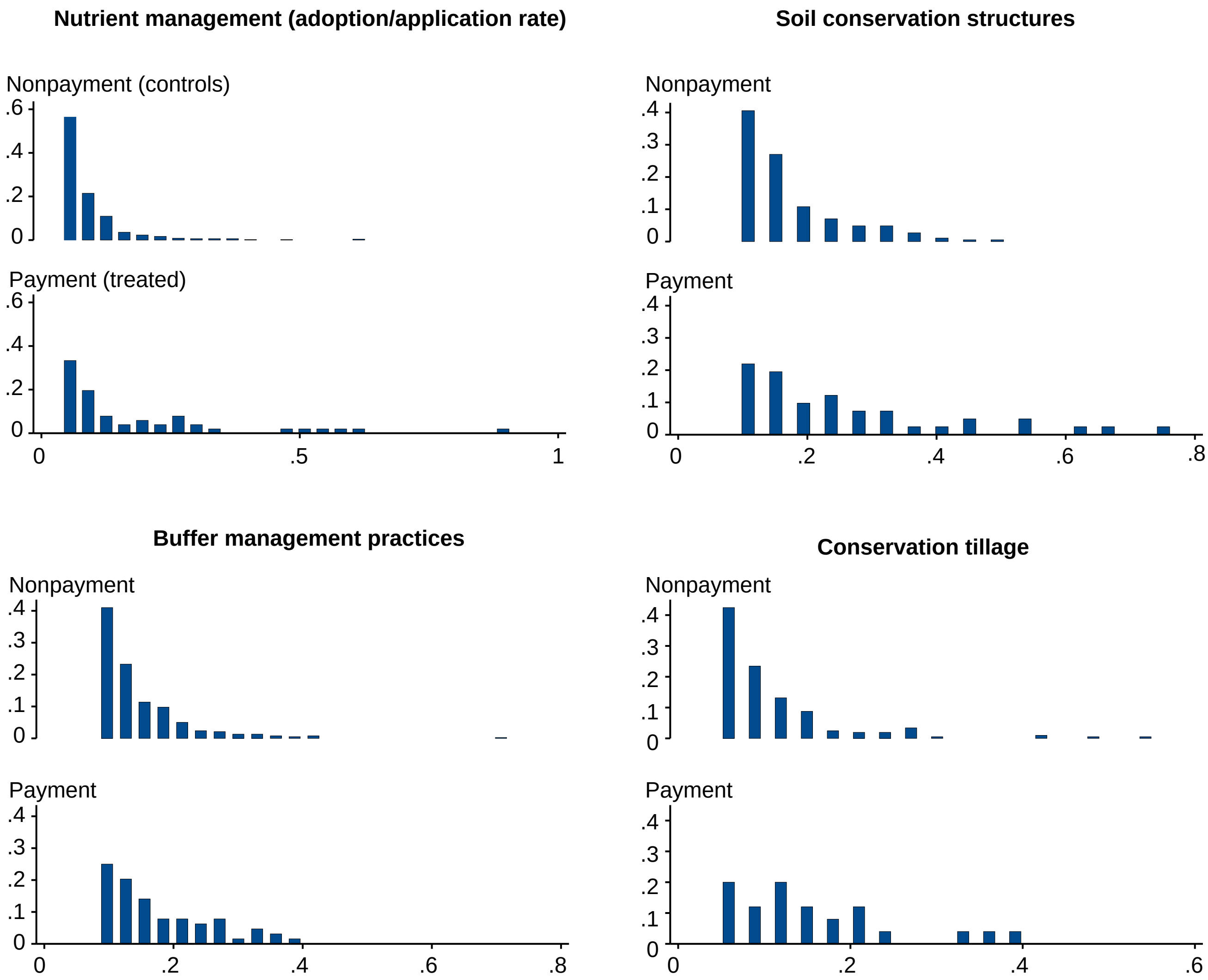
Optimal bandwidth selection under leave-out-one cross-validation

Conservation practice	Type	Crops	MSE	Optimal bandwidth
Nutrient management	Adoption rate	Corn	0.052	0.02
"	Application rate	Corn	0.279	0.01
"	Fall application	Corn	0.097	0.01
"	Postplanting	Corn	0.136	0.006
Soil conservation	Adoption rate	Corn, wheat	0.086	0.04
Buffer management	Adoption rate	Corn, wheat	0.120	0.04
Conservation tillage	Adoption rate	Corn, barley, sorghum	0.239	0.1

Source: USDA, Economic Research Service.

Appendix figure 1-1

Upper quintile propensity score distributions



Notes: Fraction of control observations (nonpayment farmers) and treatment observations (payment farmers) by propensity score bins for each of the five types of conservation practices. Only bins in the upper quintile of the propensity score distributions are shown. The fraction of observations is calculated with treatment status for the full distributions. Upper quintile propensity score thresholds for nutrient management (adoption rate), soil conservation, buffer management, and conservation tillage are .0373, .0848, .0816, and .0432, respectively.

Source: USDA, Economic Research Service.

Appendix 2: Simulating a Greenhouse Gas Offset Market

This appendix provides the technical details of the simulation models employed in chapters 3 and 4 to analyze additionality in a greenhouse gas (GHG) offset market. Both the wheat and corn models are based on yield nitrogen response functions drawn from the literature. We assume that farmers seek to maximize profit and that program managers use a prevailing practices approach to establishing crop-specific baselines. Estimates of participation, total offsets, additional nitrogen (and CO_2-e) reduction on farms, and the benefits and costs of the offset program are estimated.

Wheat Model

Expected yield per acre y is assumed generated by the Mitscherlich production function

$$y = \alpha(1 - \gamma e^{-\beta(N+R)}) \tag{1}$$

where N is the application rate, R is residual soil nitrogen, and β and γ are production parameters. The parameter α captures both production and behavioral aspects and may consist of both observable (i.e., contractible) production characteristics such as soil and climate and unobservable (noncontractible) characteristics of both the farmer (risk aversion, time preference, other behavioral attributes, access to nonfarming opportunities) and the farm (other soil and climate variables). The Mitscherlich production function is widely used to model fertilizer responses by wheat and other grains (Boldea et al., 2010; Brorsen and Richter, 2010; Farquharson et al., 2008; Holford et al., Sonar and Babhulkar 2002, Tumusiime et al. 2010.)

Let profits from production be $py - wN$ where p is wheat price and w is price per unit N. Profit maximization in the absence of an offset sale gives nitrogen application

$$N_n = \max\left[-R + 1/\beta \cdot (\ln\left(p\alpha\beta\gamma\right) - \ln(w)), 0\right] \tag{2}$$

The subscript n denotes “no offset.” In most of the expressions below, we restrict attention to positive application rates, but all empirical analyses and numerical calculations properly include applications rates that may equal zero.

Farmer profits, when participating in an offset market, are $py - wN + q \cdot (b - e(N))$, where b is the baseline, q is the CO_2 price, and $e(N)$ are greenhouse gas emissions in CO_2 equivalents. The farm participates only if $b - e(N) > 0$ at the profit-maximizing N. Farm emissions above the baseline are not penalized.

Nitrous oxide emissions are assumed linear in nitrogen, yielding $e(N) = \lambda N$ where λ is the emissions coefficient. The Intergovernmental Panel on Climate Change (IPCC) Tier 1 specification is linear for nitrous oxide emission. Further evidence for linearity comes from Rosas et al., (2011), who graphed results from an extensive literature review by Bouwman, et al., (2002) that showed a roughly linear relationship except at extremely high N levels. Some contradictory evidence to linearity exists, however. For example, Rosas et al. (2011) looked at N_2O emissions from 20 field experiment studies and argued that emissions were nonlinear in N on corn. Millar et al. (2010) explore the effects of difference between linear (Tier 1) and nonlinear (Tier 2) fertilizer-to-greenhouse gas relationships.

For administrative purposes and also for analytical ease, it is useful to write the baseline in terms of the N application rate, in which case profits including offset sales can be written:

$$\pi_o = py - wN + q\lambda \cdot \left(B - N\right) \tag{3}$$

where $B = b / \lambda$, and the farmer participates only if $B > R$. The o subscript denotes "offset." The maximization of π_o yields $N_o = \max\left[-R + \frac{1}{\beta}\left(\ln\left(p\alpha\beta\gamma\right) - \ln\left(w + \lambda q\right)\right), 0\right]$. Note that the baseline can be specified either in terms of the minimum practice (nitrogen rate) or an emissions threshold (in greenhouse gas units).

Under this model, any farm that participates will reduce its nitrogen rate by:

$$\Delta_N = N_n - N_o = \frac{1}{\beta}\left(\ln\left(w + \lambda q\right) - \ln\left(w\right)\right) \tag{4}$$

for the set of farms with $N_o > 0$. The reduction for farms with N_n or $N_o = 0$ can be similarly derived.[45]

Suppose that farms differ only by the parameter α. We can then write optimal nitrogen levels and production as $N_n(\alpha)$, $N_o(\alpha)$ and $y\ (N_o(\alpha), \alpha$; these are uniquely defined under the Mitscherlich functional form. Define optimized profits from production for a farm that does not supply offsets as $\pi_n = \pi_n(\alpha) = py\ (N_n(\alpha), \alpha) - wN_n(\alpha)$ and for a farm that supplies offsets as $\pi_o^p = \pi_o^p(\alpha) = py\left(N_o(\alpha), \alpha\right) - wN_o(\alpha)$. A farm supplies offsets if and only if profits from production plus offset sales exceed profits when no offsets are supplied, $\pi_o^p + q \cdot (b - e\left(N_o\right)) - \pi_n \geq 0$. Under the Mitscherlich production function, the participation condition yields a cutoff value, α_c, such that all farms with $\alpha \leq \alpha_c$ participate and all farms with $\alpha_c > \alpha$ do not. When $R = 0$, the participation condition yields $\ln\left(\alpha_c\right) = \left(B\beta - 1\right) + \frac{w + \lambda q}{\lambda q}\ln\left((w + \lambda q) / p\gamma\beta\right) - \frac{w}{\lambda q}\ln\left(w / p\gamma\beta\right)$.

Simulating participation requires us to compare this expression to farm-specific estimates of α, which are difficult to construct. As an alternative approach, we bound α_c and predict offset participation based on assumptions about where α_c falls within these bounds. First, all farms with $N_n \leq B$ participate; thus, $B = N_n$ forms a lower bound for participation. Second, no farms with $N_n \geq B + \Delta_N$ participate since even if they reduced nitrogen by an optimal amount they would not generate positive offsets. We therefore select a participation parameter, ζ, such that all farms with $N_{ni} - \zeta\Delta_N < B$ participate and farms with $N_{ni} - \zeta\Delta_N > B$ do not. This parameter essentially tells us whether the marginal cost curve for nitrogen reductions (beyond the baseline) is flat or steep. If ζ is close to zero, almost no farms beyond those for which supply is costless ($B \geq N_{ni}$) will participate; the supply curve is relatively steep. If ζ is close to one, almost all farms that could conceivably participate will do so; the supply curve is relatively flat.

Supply cost is the reduction in profits from production due to reductions in nitrogen below its no-offsets optimum, N_n. This cost does not include revenue from offset sales since these are

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[45] The production function in (1) does not include other inputs. Substitution of other inputs would allow reductions in N to be made more cheaply, so that the actual reduction, $N_n - N_o$, should be greater than our expression for Δ_n.

a transfer from point sources to nonpoint sources. We calculated emissions abatement costs two ways. First, we used the structural model to calculate the yield reductions and fertilizer cost savings the farmer would experience when selling an offset. The cost per unit area is $\pi_n\left(\alpha\right) - \pi_o^p(\alpha) = 1/\beta\left[q\lambda + w\left(\ln\left(w\right) - \ln\left(w + q\lambda\right)\right)\right]$. Second, we calculated the area under the additional-reductions supply curve, which also provides an estimate of supply costs based on fundamental economic principles. In theory, these two calculations should be identical, although they sometimes differ due to practical considerations. We repeatedly found that the estimates were quite close and, in fact, were typically close to one-half the imputed revenue. That is, if the price for an offset was \$15/tonne CO_2-e, the average cost of reducing emissions over all offset providers was \$7.50/tonne CO_2-e. We therefore used this one-half figure for all of the main calculations.

The total quantity of offsets, both additional and nonadditional, is:

$$O = \sum^{a_c} n(\alpha)\cdot\left(B - N_o(\alpha)\right), \tag{5}$$

nonadditional credits are:

$$NA = \sum^{a_c} n(\alpha)\cdot(B - N_n(\alpha))_{>0} \tag{6}$$

And the additional reduction in nitrogen resulting from the operation of the offsets market is:

$$A = \sum^{a_c} n(\alpha)\cdot\left(N_n\left(\alpha\right) - N_o(\alpha)\right) \tag{7}$$

Since it is possible to have $N_n > B$ for some participants, these expressions yield $A + NA \geq 0$; the sum of additional emissions reductions and nonadditional emissions credits may be greater than the total volume of offsets. This situation arises because some farms with $N_n > B$ will find it profitable to reduce emissions below the baseline even though they do not receive payment for the first $N_n - B$ units; they make sufficient profits from the $B - N_o$ offsets. The offsets market generates additional emissions reductions that do not receive credits.

Expression (2) provides a reduced-form prediction of the farm's business-as-usual application rate. The model is most straightforward if we assume that farms differ only in α. We decompose α into $\bar{\alpha}$, an observable and contractible component capturing farm-level productivity components, and θ_ι, an unobservable or noncontractible component representing both farmer preferences and unobserved farm-level productivity elements. We write $\alpha_i = \bar{\alpha}\cdot\theta_i$. Then N_n for farm i can be rewritten $N_{ni} = 1/\beta[\ln\left(p\bar{\alpha}\beta\gamma\right) + \ln\left(\theta_i\right)] - \ln(w)]$, assuming $R = 0$ and $N_n > 0$. This variable has expectation:

$$E[N_{ni}] = \frac{1}{\beta}[\ln\left(p\bar{\alpha}\beta\gamma\right)] - \ln(w)]\cdot \tag{8}$$

where the expectation is taken over the distribution of farmer types, θ, and $E[\ln(\theta_i)] = 0$ by construction. (Because R is presumably a function of both the $\bar{\alpha}$ and θ_ι components of α, our methods implicitly include $E[R_i]$; in other words, the assumption $R = 0$ is not generally necessary. Alternatively, eligibility for offset credits could conceivably require a soil sample for residual nitrogen, so that the baseline following from (8) could include actual R.)

In theory, it is possible to construct $E[N_{ni}]$ based on estimates of p, $\bar{\alpha}$, β, y, and w. In practice, $\bar{\alpha}$ is difficult to pin down, especially since the set of farms for which (8) applies (that is, the set of farms that share mean productivity $\bar{\alpha}$) is unknown and because of potential cross-sectional variation in the other variables that is also difficult to characterize. In the application, we instead estimate (8) through a regression of N_{ni} on a set of variables likely to influence $\bar{\alpha}$ and to capture cross-sectional variation in the other parameters.

Our estimate uses both the expected nitrogen application and its variance, which forms the basis of the margin of safety. Given the constructed mean in (8), we have $\ln(\theta_i) = N_{ni} - E[N_{ni}]$ and this calculation gives a distribution of $\ln(\theta_i)$'s over the set of farms, which can then, in theory, be used to construct the needed variance. Practical considerations, however, again limit this role for the model. Since we estimate (8) through a regression of N_{ni} rather than construct it, we necessarily impose an (asymptotically) normal distribution on $\ln(\theta_i)$. We use the variance of this distribution as the basis of the margin of safety in the baseline.

Finally, (8) shows how the business-as-usual could vary from year to year. A change in output price, p, would increase expected nitrogen use and would imply an upward adjustment in administrator's assessment of average nitrogen application rates $E[N_{ni}]$. This could lead to an upward adjustment in the baseline. A change in the nitrogen fertilizer price would imply a reduction in $E[N_{ni}]$. Finally, change in the underlying yield potential, as represented by parameters α and γ—possibly the result of climate change—also implies a change in $E[N_{ni}]$.

Wheat Data

To estimate (1) – (4) and (8), we use data from the 2009 Agricultural Resource Management Survey (ARMS), which surveyed approximately 2,200 farms that grew wheat in 2009. The 2009 ARMS surveyed 2,146 farmers growing winter wheat (1,304), spring non-durum wheat (630), and durum wheat (212). Because only a relatively small number of observations (196) are for irrigated wheat and because production practices and greenhouse gas emissions differ substantially between irrigated and nonirrigated acres, we focus on nonirrigated acres. There are 1,950 nonirrigated observations, representing production practices on 49.1 million acres of nonirrigated wheat grown in 2009.

Under ARMS, for each surveyed farm, one field planted to wheat is randomly selected to provide detailed production practices, input use, and yield. To measure nitrogen application, the survey asks farmers to list for the specified field the quantity of N applied per acre (including commercially prepared manure or compost but not unprocessed manure) and number of acres treated for each of potentially multiple applications. We converted these to total pounds applied and summed, then divided by total field acres summed to create NPERACRE, denominated in pounds per acre.

Attrition in the data occurs in several places. First, a number of nonirrigated respondents either left the nitrogen application question blank or reported application rates that were so large their validity was suspect. We dropped all observations with NPERACRE greater than 150 pounds per acre, which is roughly the 97th percentile, a cutoff chosen somewhat arbitrarily. With these removed, the sample drops to 1,661 observations (appendix table 2-1, column 1).

Our primary explanatory variable is the major land resource area (MLRA), which was available either directly or with a close approximation for all observations. MLRAs were initially devised by USDA in 1965 to characterize the suitability of land for farming, ranching, forestry, engineering, recreation, and other land uses.

Appendix table 2-1

Nitrogen applied per acre, various samples

	Nonirrigated (N ≤ 150)	Nonirrigated; w/ geocode (N ≤ 150)	Nonirrigated, some MLRAs dropped (N ≤ 150)	Main sample (N ≤ 150; some MLRAs dropped; some NCCPI & SSURGO missing)
Mean	64.3	63.8	64.3	63.9
Min	0	0	0	0
25th percentile	40	38.8	40	40
Median	62.5	62.1	62.5	62.1
75th percentile	89.7	88.3	89.7	88.4
Max	150	150	150	150
Mode	100	100	100	100
Acres represented (millions)	41.1	36.5	40.9	35.8
Observations	1,661	1,491	1,652	1,468

MLRA = major land resource area; NCCPI = National Commodity Crop Productivity Indicator (see Dobos et al.); SSURGO = Soil Survey Geographic (SSURGO) database, USDA, Natural Resources Conservation Service.

Source: USDA, Economic Research Service.

For a few observations (n = 51) the geographic identifier ("geocode") that would allow us to tie the field to the MLRA was missing. Because we know the county the field is in, we used the prevailing MLRA in the county to assign an MLRA. The geocode, even when available, does not precisely identify the field, and a given geocode can encompass multiple soil types or conceivably even MLRAs. Of course, soil can also differ within a given farm field. We cannot tackle these possibilities.

We calculate summary statistics for the sample that lacked geocode information to investigate how these observations might have differed from the broader sample, but we continue to use these observations (substituting in county-level MLRA and soil assignments) since we feel the substitutions are unlikely to affect data quality (appendix table 2-1, column 2).

The large number of MLRAs represented in the data and the sometimes small numbers of ARMS observations within an MLRA led us to combine MLRAs and to assign fields to *MLRA groups.* We designed the groups to have 30-50 observations except where (i) a single MLRA had more than 30-50 observations, in which case we kept the MLRA intact (i.e., in its own group), or (ii) an MLRA had below 30 observations and there was no similar MLRA to combine it with. This latter case led us to drop a handful of observations. The remaining data set has 34 MLRA groups and 1,652 observations.[46] Appendix table 2-2 shows how the MLRA groups were constructed and the mean and variance of N application rates within each group.

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[46] This MLRA-based approach is amenable to more sophisticated analysis in which the MLRA groupings would be constructed to minimize the mean squared error in predicted nitrogen application rates given a fixed number of groups. Since the literature lacks any experience with using MLRAs to construct baselines as shown in section 3, we stick with a simpler aggregation of MLRAs and do not attempt to optimize construction of MLRA groups.

Finally, we also use the National Commodity Crops Productivity Index (NCCPI) for wheat. We are missing the wheat NCCPI for a small number of data points that were included in the ARMS. In addition, we use soil information such as slope gradient, and clay and sand weight percentages from the Soil Survey Geographic Database. The final sample has 1,468 observations representing 35.8 million acres. To represent the 41.1 million acres of nonirrigated wheat production where nitrogen fertilizer was used in 2009, empirical results presented here and in the text have been multiplied by 1.15=41.1/35.8.

Estimating Expected Nitrogen Application

Under our practice-denominated approach, the regulator would assign each cropland acre a baseline, denominated as a nitrogen application rate. We estimate field-level nitrogen application per acre using the MLRA group, State, soil (slope, percent clay, percent sand), and climate (average annual precipitation, Spring-quarter growing degree days) variables and NCCPI wheat rating; this is the prevailing practice. This straightforward mapping of region and soil and climate characteristics to a baseline is administratively feasible.

Appendix table 2-3 shows R^2s and regression standard errors using various sets of explanatory variables. The signs and statistical significance of the individual variables are irrelevant under this approach since there is no null hypothesis. Standard errors and t-statistics for the coefficients are not included to emphasize this point.

To predict supply of additional nitrogen reductions, we construct Δ_N (equation 4) and N_c (equation 5). Let q = \$15/tonne CO_2-e = \$0.015/kg CO_2-e (1 tonne=1000kg). Next price per pound of CO_2-e is converted to a price per pound of applied end using $\lambda = 4.87$, which is the IPCC's Tier 1 standard for N emissions per unit of applied N, 0.01 (N emission/N applied), multiplied first by the N content of N_2O, 1.57 (N_2O-e/N emission), and then by the global warming potential of N_2O of 310. Thus, λq =\$ 0.073/ kg N applied or \$0.033/ lb. N. We use $\beta = 0.0084$ kg/ha from Boldea et al. 2010 and w = \$0.88/kg (=\$0.40/lb.), roughly the prevailing nitrogen price in 2009. (This makes the offset payment roughly equivalent to an 18-percent tax on nitrogen.) Together these yield $\Delta_N = 9.50$ kg/ha = 8.46 lbs/acre. To construct N_c, we start with $\zeta = 0.5$. All farms that participate are assumed to apply new nitrogen levels $N_o = \max(N_n - 8.46, 0)$.

Corn

Let production be a single-variable Cobb-Douglas. Output y is a function of a single nutrient, nitrogen, composed of applied nitrogen, N, and residual soil nitrogen, R, is $y = \alpha(N + R)^{\beta}$. Profits are given by $py - wx$ where p is the output price and w is the input price. Thus, the profit-maximizing x satisfies:

$$\ln\left(N_n + R\right) = \frac{1}{\beta - 1}\ln\left(\frac{w}{p\alpha\beta}\right) \quad (9)$$

Appendix table 2-2

Summary statistics by MLRA group (main sample)

MLRA group (constituent MLRAs)	Number of observations	Nitrogen applied (lbs/acre)	
		Mean	Std. error
1 (2,5)	11	90.36	38.33
2 (6,7)	9	38.95	12.01
3 (8)	128	53.69	26.38
4 (9)	106	93.53	22.88
5 (10,11,12)	7	30.01	12.33
6 (43A-C,44)	26	85.84	30.28
7 (46,47,48A,49,51)	21	54.78	15.10
8 (52)	96	41.19	26.58
9 (53A)	97	49.00	23.17
10 (53B-C)	87	71.78	25.40
11 (54)	80	59.66	28.13
12 (55A)	42	87.61	19.60
13 (55B-C)	59	76.60	36.42
14 (56)	69	93.16	32.18
15 (58A-D,60A-B)	29	42.06	30.51
16 (63A-B,64,65,66)	34	43.14	22.26
17 (67A-B,69)	27	36.92	28.38
18 (71,72)	49	38.61	16.37
19 (73)	44	56.63	23.68
20 (74,75,76)	30	67.40	30.19
21 (77A-E)	11	34.15	22.58
22 (78A-C)	33	33.52	21.10
23 (79,80A-B)	46	57.80	31.46
24 (82B,84A-C,86A,87A)	10	64.65	33.74
25 (57,88,90B,91A,94A,95B)	13	56.22	28.87
26 (97,98,99,139)	57	77.63	35.33
27 (102A-C,103,105)	33	86.62	24.93
28 (106,107B,108A-B,108D,109,110)	32	77.44	27.04
29 (111A-B,111E)	30	86.94	27.45
30 (112)	25	70.79	34.91
31 (113,114B)	43	85.71	33.14
32 (115A-C)	43	84.62	30.58
33 (116A-B,118B,119,120A,124,126)	16	73.54	35.12
34 (131A,133B,134)	25	106.36	26.68
All	1,468	63.89	33.67

MLRA = major land resource area.

Source: USDA, Economic Research Service.

Appendix table 2-3

Goodness-of-fit for N application on nonirrigated wheat (n = 1,468)

	Model of nitrogen rate[1]					
Variables (number of categories)	#1	#2	#3	#4	#5	#6
Constant	Yes[2]	Yes	Yes	Yes	Yes	Yes
MLRA groups (34)	--	Yes	Yes	--	Yes	Yes
State (16)	--	--	Yes	Yes	Yes	Yes
Soil, climate (5)	--	--	--	--	Yes	--
Productivity index (NCCPI)	--	--	--	Yes	Yes	--
R^2	--	0.29	0.30	0.19	0.33	0.30
Root M.S.E.	33.68	28.62	28.56	30.53	28.16	28.76
Number of observations	1,468	1,468	1,468	1,468	1,468	1,652

[1] The R^2 and Root M.S.E. indicate how well each of the six models explains the variation in nitrogen rates across farms. For example, a model that explained all of the variation would have an R^2 of 1.

[2] Yes means that variable(s) in left-hand column are included in the model represented by the column.

MLRA = major land resource area; NCCPI = National Commodity Crop Productivity Indicator (see Dobos et al.). M.S.E. = Mean Squared Error.

Source: USDA, Economic Research Service.

The subscript *n* signifies a situation in which the farmer does not receive payment for changing input use. This situation therefore represents the farm's business-as-usual decisions.

The corn-nitrogen production function has been the subject of voluminous research, with little consensus over the appropriate functional form. Weliwita and Govindasamy (1997) note that "although [Cobb-Douglas] has been quite popular in the production economics literature, it has not been used in N fertilizer response studies" (p. 1430). Cerrato and Blackmer (1990), for example, estimated five corn-nitrogen models, none of which included Cobb-Douglas (C-D), and Finger and Hediger (2008) compared three production models, also without considering C-D; neither of these papers explained why C-D was not considered. Given this background, we consider the justification for and, more importantly, the broader implications of our Cobb-Douglas assumption.

The Cobb-Douglas production function has been the subject of at least some corn-nitrogen research. Just and Pope (1979) estimated a C-D form for mean yield and found $\beta = 0.31$. Weliwita and Govindasamy used a C-D to estimate β's ranging from 0.10 to 0.19, but note that the predicted optimal nitrogen levels are quite high—almost twice as high as the optimal levels predicted by the square root model, which tends to be preferred in other studies (e.g., Finger and Hediger, 2008). Lower β's imply higher profit-maximizing nitrogen application.

We chose the Cobb-Douglas because it yields a percentage reduction in nitrogen use from participants, a reasonable prediction, and has a form that makes much of our model especially transparent. An alternative form that shares the latter properties is the Mitscherlich function, which is widely used for fertilizer modeling (although not so often for corn), but it implies that all payment recipients reduce nitrogen by the same absolute amount, an unrealistic assumption for corn, where nitrogen can range from near zero to 300 lbs per acre. If the percentage-reduction assumption is reasonable, then the rest of the Cobb-Douglas evidence is unimportant; C-D provides merely a convenient way to motivate a percentage reduction.

Suppose the farmer is eligible to receive a per-unit payment q for the amount by which the nitrogen falls below a policy-specified baseline, denoted B. Thus, the payment he or she receives is $q \cdot (B - N)$ and this payment is available only when $(B - N) > 0$. Profits for a farmer who receives a payment for a reduced nitrogen rate are $py - wx + q(B - N)$. The profit-maximizing x satisfies:

$$\ln(N_o + R) = \frac{1}{\beta - 1} \ln\left(\frac{w + q}{p\alpha\beta}\right) \tag{10}$$

The subscript o signifies a situation in which the farmer receives a payment. We use o because the most prominent proposed green payment schemes have been in the context of offsets to a cap-and-trade system.

Define Δ_N as the reduction in applied nitrogen below the business-as-usual rate if the farm chooses to receive a payment, $\Delta_N = N_n - N_o > 0$. Note that

$$\Delta_N / N_n = \frac{N_n - N_o}{N_n} \approx \ln(N_n) - \ln(N_o) \tag{11}$$

If R is small then the right hand side of (11) can be approximated by $\ln(N_n + R) - \ln(N_o + R)$. Expressions (9) and (10) then imply:

$$\Delta_N / N_n \approx \frac{\left(\ln(w + q) - \ln(w)\right)}{1 - \beta} \tag{12}$$

Expression (12) gives a rough approximation of the proportional reduction in input use due to the payment as a function of the input price, the environmental price, and a single production parameter, β.

Suppose production function parameters differ across farms only in α, a multiplicative factor that affects both yield and the marginal production of nitrogen. Following Horowitz (2012), we decompose α into $\bar{\alpha}$, an observable and contractible component capturing farm-level productivity components, and θ_i, an unobservable or noncontractible component representing both farmer preferences and unobserved farm-level productivity elements. Write $\alpha_i = \bar{\alpha} \cdot \theta_i$. Then x_n for farm i can be rewritten $N_{ni} = 1/(\beta - 1)\left[\ln\left(\frac{w}{p\bar{\alpha}\beta}\right) - \ln(\theta_i)\right] - R$. This variable has an expectation:

$$E[N_{ni}] = \frac{1}{\beta - 1}\left[\ln\left(\frac{w}{p\bar{\alpha}\beta}\right)\right] - R_i \tag{13}$$

where the expectation is taken over the distribution of farmer types, θ, and $E[\ln(\theta_i) = 0$ by construction.

In theory, it is again possible to construct $E[N_{ni}]$ based on estimates of p, $\bar{\alpha}$, β, w and R_i. In practice, both $\bar{\alpha}$ and β are difficult to pin down, primarily because the set of farms for which (13) applies (that is, the set of farms that share mean productivity $\bar{\alpha}$ or a common β) is unknown and because R_i is similarly unobserved by the econometrician. For our report, we estimate (13) through a regression of X_{ni} on a set of variables likely to influence $\bar{\alpha}$ and R. Such variables also capture cross-sectional variation in the other parameters.

In a standard neoclassical model, the optimal baseline depends on both the expected business-as-usual nitrogen rate, $E[N_{ni}]$ and the distribution of rates around this value (Horowitz and Just, 2012). Even outside of this context, the baseline will likely be closely linked to expected business-as-usual rates and the distribution of rates around that expectation. To assess this distribution, note that given a constructed mean from (13), we have $\ln(\theta_i) = N_{ni} - E[N_{ni}]$, and this expression could, in theory, be used to estimate the distribution of $\ln(\theta_i)$s. Since we estimate (13) through a regression rather than by constructing it, however, we necessarily impose an (asymptotically) normal distribution on $\ln(\theta_i)$. We use the coefficient-of-variation of this distribution to represent uncertainty over business-as-usual nitrogen rates.

An equally important lesson is that our structural model, through (9) and (13), provides a systematic way for policymakers to adjust the business-as-usual component of the baseline from year to year. Time series changes in output and input prices, p and w, and in underlying crop productivity, α and β—these latter possibly the result of climate change—imply straightforward changes in $E[N_{ni}]$ through (13). This time series variation could be implemented in a baseline policy regardless of how estimates of $E[N_{ni}]$ are derived. Alternative approaches mentioned for year-to-year adjustments in the baseline—called a dynamic baseline—include historical extrapolation, estimates of technology development and adoption rates over time, and changes in cost effectiveness (Marshall and Weinberg, 2012). Our structural model provides a more systematic approach.

Given this discussion, and noting that no farms with $N_{ni} - \Delta_N > B$ participate (because even with their optimal supply response, these farms would not be eligible for payment), we select a participation parameter, ζ, such that all farms with $N_{ni} - \zeta\Delta_N < B$ participate and farms with $N_{ni} - \zeta\Delta_N > B$ do not. This parameter essentially tells us whether the marginal cost curve for nitrogen reductions (beyond the baseline) is flat or steep. If ζ is close to zero, almost no farms beyond those for which supply is costless ($B \geq N_{ni}$) will participate; the supply curve is relatively steep. If ζ is close to one, almost all farms that could conceivably participate will do so; the supply curve is relatively flat.

Data

To estimate these equations, we used data from the 2010 ARMS, which surveyed 2,692 farms that grew corn in 2010. We restricted attention to nonorganic, nonirrigated corn because production practices and environmental effects differ substantially for irrigated and organic production systems.

In the ARMS, for each surveyed farm, one field planted to corn is randomly selected to solicit detailed production practices, input use, and yield. To measure nitrogen application, the survey asks farmers to list for the specified field the quantity of nitrogen applied per acre (including commercially prepared manure or compost; unprocessed manure is counted separately) and number of acres treated for each of potentially multiple applications. We converted these to total pounds applied and summed, then divided by total field acres summed to create NPERACRE, denominated in pounds per acre. Farms do not necessarily apply the same level of nitrogen throughout the field. Our data report total nitrogen applied to a given field; we divide this by number of acres in the field. We excluded observation where respondents either left the nitrogen application question blank or reported application rates that were so large their validity was suspect. We dropped all observations with NPERACRE greater than 300 pounds per acre. There are 1,872 remaining observations representing 66.6 million acres in 2010.

We categorize prevailing practices primarily by MLRA. The small numbers of ARMS observations within some MLRAs led us to combine MLRAs and assign fields to 38 *MLRA groups*. (A list of how MLRAs were assigned to MLRA groups is available from the authors.)

Data on slope, soil percent clay, and soil percent sand are taken from SSURGO. Data on growing season precipitation and temperature are taken from PRISM (Parameter-elevation Regressions on Independent Slopes Model) data sets. We also use corn productivity in the form of the NCCPI (National Commodity Crops Productivity Index).

Given this approach, further loss of observations occurred because (i) some respondents left the nitrogen application question blank; (ii) some application rates were so large their validity was suspect (we dropped all observations with NPERACRE greater than 300 pounds per acre, a cutoff chosen somewhat arbitrarily); (iii) other covariates are missing, and (iv) the number of nearby farms was too small to estimate “prevailing practices” for that farm region. The final sample has 1,503 observation representing 7,341 million pounds of nitrogen applied to 54.4 million acres. Summary statistics are shown in appendix table 2-4. To represent the 66.6 million acres of nonorganic, nonirrigated corn production where nitrogen fertilizer was used in 2010, empirical results presented here and in the text have been multiplied by 1.22=66.6/54.4.

To assign this baseline, we regressed each observation’s nitrogen application per acre on MLRA group, State dummies, soil (slope, percent clay, percent sand), climate (average annual precipitation, Spring-quarter growing degree days), and a corn productivity index (NCCPI). Basic information from these regressions is shown in appendix table 2-5. The magnitudes, statistical significance, and signs of the individual regression coefficients are irrelevant under this approach since there is no null hypothesis; to emphasize this point, coefficients and t-ratios are not shown.

Our regressions do not include input or output prices because the data are cross-sectional and there is little meaningful cross-sectional variation in these prices. Our estimated nitrogen rates are therefore applicable to any year in which input and output prices are roughly similar to 2010 but should be modified for predicting business-as-usual rates in subsequent years, following equation (13) or other evidence.

Appendix table 2-4

Nitrogen application rate on corn, pounds per acre (2010)

	Nonirrigated, nonorganic; application rates below 300 lbs/acre	Main sample
Mean	116.7	120.1
Min	0	0
25th percentile	67.4	71.6
Median	123.8	128.9
75th percentile	160	160.1
Max	300	300
Mode	150	150
Acres represented (millions)	66.6	54.4
Observations	1,872	1,503

Source: USDA, Economic Research Service.

Appendix table 2-5

Goodness-of-fit for N application on corn

	Model of nitrogen rate[1]					
Variables (number of categories)	#1	#2	#3	#4	#5	#6
Constant	Yes[2]	Yes	Yes	Yes	Yes	Yes
MLRA groups (39)	--	Yes	Yes	--	Yes	Yes
State (18)	--	--	Yes	Yes	Yes	Yes
Soil, climate (6)	--	--	--	--	Yes	--
Productivity index (NCCPI)	--	--	--	Yes	Yes	--
R^2	--	0.25	0.30	0.27	0.32	0.29
Root M.S.E.	60.46	53.12	51.44	52.06	50.89	51.36
Number of observations	1,503	1,503	1,503	1,503	1,503	1,872

[1] The R^2 and Root M.S.E. indicate how well each of the six models explains the variation in nitrogen rates across farms. For example, a model that explained all of the variation would have an R^2 of 1.

[2] Yes means that variable(s) in left-hand column are included in the model represented by the column.

MLRA = major land resource area; NCCPI = National Commodity Crop Productivity Indicator (see Dobos et al.). M.S.E. = Mean Squared Error.

Source: USDA, Economic Research Service.

The economics of Δ_N

For the C-D function, we chose $\beta = 0.33$ because it yields a reasonable magnitude for this percentage reduction, is widely used as a generic production parameter, and is consistent with at least some empirical studies. A lower coefficient would imply too-high levels for predicted nitrogen, an undesirable implication even though we do not directly predict nitrogen from (9) or (10). Our value, which is higher than those found by Weliwita and Govindasamy, also counterbalances the approximations used in (11) and (12), which tend to increase the simulated percentage reduction.

Although our structural model and estimates are based on numerous assumptions, it is possible to gauge the general consequences of most them. A higher percentage reduction from participants, due to a different β or input price w, or a flatter participation cost curve, resulting in a higher ζ, unambiguously shifts the additionality supply curve to the right and leaves nonadditionality unchanged. More difficult to gauge are the potential effects of either (i) reductions that are not monotonic in N_n; one virtue of both Cobb-Douglas and Mitscherlich production functions is that N_n and $N_n - N_o$ move together; or (ii) reductions that are monotonic in N_n but are not a uniform percentage. It makes most sense to consider reductions that are a lower percentage for lower levels of N_n and, possibly, equal to zero for N_n below some cutoff, which means that no farmer with N_n below this cutoff participates. These features have more complex and less predictable effects on supply responses and we leave analysis for subsequent research.