Paying farmers to reduce nitrogen application on corn: The baseline approach

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Abstract

We model a simulated green-payment policy to reduce nitrogen application on corn. In contrast to other papers, we recognize that the farm's business-as-usual application rate cannot be known by the policymaker. We develop a structural model and data-driven approach to address this issue. We find that only one-third of the credits that would receive payments would be additional nitrogen reductions. The substantial volume of non-additional "reductions" leads the effective payment rate to be 3.5 times the price paid by the simulated policy. We discuss a further eligibility criterion that can improve policy performance.

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A large number of agricultural and environmental policies provide payments to induce landowners to adopt land management practices that provide environmental benefits. This payment-based approach is widely used because direct regulation – the typical approach for non-land-based environmental policy – is not considered sufficiently workable for agriculture, for various reasons. Policymakers have shown particular interest in developing policies that tie these conservation payments more closely to environmental outcomes. This approach may include providing payments tied to the farmer's actual nutrient use rather than simply for the filing of a nutrient management plan, which is the current approach of several Federal conservation programs.[1] Such policies have been widely discussed but many of their economic details have not been sufficiently explored. This paper attempts to fill this gap.

When the targeted practice is continuous – as the nitrogen fertilizer rate is – then this type of payment approach requires a benchmark or "baseline" against which nitrogen reductions are measured.[2] This paper analyzes the baseline approach and the economic tradeoff it entails. Under our proposed policy, the policy administrator would assign a baseline nitrogen rate to each field that is potentially eligible to receive a payment. The farmer would then be eligible to receive payments proportional to any reduction in nitrogen application below the policy-specified baseline. Farmers would not be penalized for application rates that are higher than the baseline.

In contrast to other papers on this topic (e.g., Ghosh, Ribaudo, and Shortle 2012;

[1] At some point, payments could be tied to actual environmental outcomes, providing a true pay-for-performance scheme. Our study of payments for reduced nitrogen use is a step in this direction.
[2] Many proposed environmentally friendly management practices are better characterized as discrete, such as adoption of no-till, using nitrogen inhibitors, or eliminating fall application of nitrogen. In a separate paper we discuss the baseline approach for these kinds of practices.

Ribaudo, Delgado, and Livingston 2011; Rosas, Babcock and Hayes, 2011) we explicitly build-in the fact that the farm's business-as-usual application rate cannot be known by the policy administrator ex ante and therefore that the baseline can, at best, approximate the business-as-usual rate. This is an essential assumption for policy realism. We show that this incomplete information substantially complicates the baseline issue, and by extension other pay-for-performance schemes.

We frame this uncertainty using a structural model and real data. We first develop a field-level structural model that ties business-as-usual nitrogen application rates to the marginal cost of nitrogen reduction. We simulate a payment of $0.07/lb. for nitrogen reductions below a farm-specific simulated baseline. We then use data from the 2010 Agricultural Resource Management Survey (ARMS), which surveyed 1,503 usable farms that grew corn in 2010, to estimate farmer participation and nitrogen supply. We construct the baselines using "prevailing" nitrogen application rates among similar farms, an approach analogous to proposals by Millar (2010), EPRI (2011) and others; this approach is also useful for understanding baselines for water quality trading (see Section 5.1). We also consider the effect of a safety margin or other eligibility criteria that can be incorporated into the baseline approach.

This data-driven approach makes several important contributions. We provide concrete estimates of the additionality and non-additionality likely to accompany our simulated policy. We provide a structural model, heretofore missing in the literature, which proves useful in understanding the source of the non-additionality and may, eventually, allow us to tie the farmer's participation and supply decisions to the aggregate prevailing practices that used to construct the baseline.[3] This tie provides a clear way to incorporate changes in input price,

[3] We ultimately fall short of being able to tie these empirically in our data, owing primarily to uncertainty over cross-sectional heterogeneity in the corn-nitrogen production function.

output prices, and crop productivity to changes in the policy's baseline and also to estimate the distribution of farmer types. Finally, we estimate the effective payment rate – the simulated policy's payment per unit of nitrogen actually reduced as a result of the policy – which has also received insufficient attention. We argue that for payment-based policies with a fixed budget, this effective payment rate is the key measure of program performance.

Our results are not encouraging. If we set the baseline equal to the expected application rate with no "safety margin" and offer a payment of $0.07 per pound of reduction (roughly $15/tonne CO2-e) then roughly 50 percent of corn acres are expected to participate and to receive payment for reducing 1,180 million pounds of nitrogen, which represent 16 percent of business-as-usual applications. However, only about one-third of these credits represent additional – that is, *actual* – nitrogen reductions. The substantial volume of non-additional "reductions" raises the effective payment rate to $0.26 per pound, or 3.5 times the price paid by the simulated policy. Note that this result does not, on its own, indicate that the policy is unsuccessful or would not pass a benefit-cost test, as we discuss below. A number of policy options are available to improve the proportion of additional reductions and reduce the effective payment rate. The most stringent policy that we analyze achieves an effective payment rate of $0.15 per pound, albeit with much smaller rates of participation.

The paper closest to ours is Horowitz (2012), which uses an offset market rather than a green payments approach and therefore does not explore the economics of the effective payment rate. Our paper also looks at corn, where nitrogen reduction is particularly policy-relevant, rather than wheat. The Horowitz (2012) paper does not consider the eligibility criteria we examine in Table 3. We show that these are particularly successful in increasing the proportional of additional nitrogen reductions.

In Table 4, we examine a safety margin that is a proportional reduction in the baseline below the prevailing nitrogen rate, also missing from previous papers. This safety margin had intuitive appeal but we find that it reduces, rather than increases, additionality.

2. Model

2.1 Supply

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

$$\text{(1)} \qquad \ln(x_n + R) = \frac{1}{\beta-1}\ln\left(\frac{w}{p\alpha\beta}\right)$$

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

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

$$\text{(2)} \qquad \ln(x_o + R) = \frac{1}{\beta-1}\ln\left(\frac{w+q}{p\alpha\beta}\right)$$

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_x as the reduction in applied nitrogen below the business-as-usual rate if the farm chooses to receive a payment, $\Delta_x = x_n - x_o > 0$. Note that

$$(3) \qquad \Delta_x / x_n = \frac{x_n - x_o}{x_n} \approx \ln(x_n) - \ln(x_o)$$

If R is small then the right hand side of (3) can be approximated by $\ln(x_n + R) - \ln(x_o + R)$. Expressions (1) and (2) then imply:

$$(4) \qquad \Delta_n / x_n \approx \frac{(\ln(w+q) - \ln(w))}{1-\beta}$$

Expression (4) 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.

We assume the policy administrator can detect compliance with a farmer contract to apply to x_o. This assumption is worth future examination since it may be particularly difficult for an administrator to ensure that continuous practices such as nitrogen application rates are being followed. We do not address this issue in this paper. (Administrators may be able to ensure compliance more readily for contracts for discrete practices. See footnote 2.)

2.2 Econometric model

Expression (1) provides a prediction of the farm's business-as-usual application rate. 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 $x_{ni} = 1/(\beta - 1)\ \left[\ln\left(\frac{w}{p\bar{\alpha}\beta}\right) - \ln(\theta_i)\right] - R$. This variable has expectation:

$$E[x_{ni}] = \frac{1}{\beta-1}\left[\ln\left(\frac{w}{p\bar{\alpha}\beta}\right)\right] - R_i. \tag{5}$$

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

In theory, it is possible to construct $E[x_{ni}]$ based on estimates of $p, \bar{\alpha}, \beta$, w and R_i. In practice, both $\bar{\alpha}$ and β are difficult to pin down, primarily because the set of farms for which (5) 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. In the application below we estimate (5) 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, $E[x_{ni}]$, 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 (5) we have $\ln(\theta_i) = x_{ni} - E[x_{ni}]$ and this expression could in theory be used to estimate the distribution of $\ln(\theta_i)$'s. Since we estimate (5) 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 his distribution to represent uncertainty over business-as-usual nitrogen rates.

An equally important lesson is that our structural model, through (1) and (5), 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 $E[x_{ni}]$ through (5). This time series variation could be implemented in a baseline policy regardless of how estimates of $E[x_{ni}]$ 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.

We use our constructed baselines and the observed set of nitrogen rates to simulate farmer participation in a hypothetical nitrogen payment program. We assume that all farms with $B \geq x_{ni}$ participate since it is costless for them to do so; this is also a reasonable empirical assumption given our low-transaction-cost approach (see Section 5.1). Some set of farms with $x_{ni} > B$ also choose to participate because the payment exceeds the farm's marginal cost of reducing nitrogen. In theory, we could use the profit functions to identify the "cut-off" business-as-usual practice, call in x_c, such that farms with $x_{ni} < x_c$ will participate and farms with $x_{ni} > x_c$ will not. Again, it is difficult in practice to identify x_c since it is a function of all of the model's parameters; the problem is the same we faced in constructing (5) directly.

Given this discussion, and noting that no farms with $x_{ni} - \Delta_x > B$ 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 $x_{ni} - \zeta\Delta_x < B$ participate and farms with $x_{ni} - \zeta\Delta_x > B$ 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 ($B \geq x_{ni}$) 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.

2.3 Policy performance: Additionality

This section constructs the variables used to assess policy performance. Nitrogen reductions are *additional* if they would not have occurred without the payment. Additional reductions for are equal to $x_n - x_o$, conditional on participation. Payments to participating farmers are said to be *non-additional* if the nitrogen "reductions" would have occurred even without the payment; these are $B - x_n$, conditional on participation. Non-additional payments arise because the policy administrator, in setting the baseline, cannot know the farm's business-as-usual nitrogen rate with certainty.[4] When the designated baseline ends up above the business-as-usual rate, the difference between the baseline and nitrogen (up to the business-as-usual rate) is illusory – it does not represent a true reduction – but is still eligible for payment. Because business-as-usual rates cannot be observed by the policymaker, the risk that some payments will be non-additional is unavoidable. The baseline approach thus involves a policy tradeoff between

[4] "Baseline" is used in multiple ways in agricultural and environmental policy and therefore its use in any particular context can be confusing. We use "baseline" to refer to a policy-designated payment threshold, as shown in our model. Some policies use baseline as a synonym for business-as-usual activities, a usage that is confusing because either a separate term must then be developed to describe the payment threshold or the payment threshold must necessarily be set to equal to the presumed business-as-usual activity, an unwarranted constraint. Policy discussion may also assume that business-as-usual activities can be observed by policymakers with near-certainty, thus obviating the need to separate the payment baseline from business-as-usual activities; this is a false assumption.

getting environmental benefits at a cost that is below the social benefit or below the cost of alternative abatement strategies, represented by q, and the risk of payments going to non-additional "reductions." In both cases, the economic cost of the government payments for nitrogen reduction is the deadweight loss from taxation.

The additional reduction in nitrogen resulting from the payment policy is

$$A = \sum_{i \in Participants} n_i \cdot (x_{ni} - x_{oi}) \tag{6}$$

where n_i is the number of acres operated in field i.[5] Total nitrogen that receives payment is:

$$TN = \sum_{i \in Participants} n_i \cdot (B - x_{oi}) \tag{7}$$

Total payment for this nitrogen – that is, the budgetary expenditure for this payment program – is $q \times TN$. We call the payment per pound of true – that is, additional – nitrogen reduction the "effective payment." The effective payment is given by:

(8) Payment per unit of true nitrogen reduction = $(q \times TN)/A$.

This calculation is the focus of Section 4.

Because participants receive a fixed per-unit nitrogen payment, payments are above the actual cost of nitrogen reduction; this feature could be remedied in part by having farmers bid to enter the program. These costs can be inferred from the nitrogen supply curve shown in Figure 1. Note that the supply curve is close to linear, so true costs are approximately half of the aggregate payment for additional nitrogen. We focus primarily on budgetary costs in this paper,

[5] The weight n_i depends on the survey methodology and whether the variables in (1) and (2) are denominated per-acre or per-field. This weighting scheme is not important to the structural model so we do not dwell on it here.

however because of the role budgetary costs play in policy formulation and because additionality has not been much explored in the context of budgetary costs.

Our payment policy is similar, from the participating farmer's standpoint, to an offset market in which regulated point sources buy eligible nitrogen credits (equivalent to the nitrogen eligible for payment in our model) which can be used to increase point source emissions (Bento, Kanbur, and Leard 2012; Horowitz and Just 2012). In this situation, non-additional emissions impose a social cost equal to the social damages from pollution (Horowitz and Just 2012) and thus the volume of non-additional nitrogen, $NA = \sum_{i \in Participants} n_i \cdot (B - x_{ni})$, is especially relevant. To facilitate comparison of our results with offset-market results (e.g., Horowitz, 2012), Table 3 also reports the ratio of additional reductions to non-additional credits, A/NA.

Note that total nitrogen eligible for payment is less than the sum of additional reductions and non-additional credits, $A + NA \geq TN$. This occurs because some farms are willing to reduce infra-marginal units of nitrogen without receiving credits in order to receive payment on the marginal unit.

3. Data

3.1 Data

To estimate (4) – (7), we use data from the 2010 Agricultural Resource Management Survey (ARMS), which surveyed 2,692 farms that grew corn in 2010. The ARMS provides some of the most reliable nationwide information on production practices and considerable effort has been devoted to making the data representative of acres planted to corn in the survey year. The representativeness of the data for acres planted to corn in other years is not well known, however. We restricted attention to non-organic, non-irrigated corn because production practices and environmental effects differ substantially for irrigated and organic production systems. There are 2,075 remaining observations, representing practices on 71.7 million acres in 2010.

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 categorize prevailing practices primarily by Major Land Resource Areas (MLRA). (Other variables were also used, depending on the context; see below.) MLRAs were devised by the U.S. Department of Agriculture in 1965 to characterize the suitability of land for farming, ranching, forestry, engineering, recreation, and other land uses. Horowitz (2012) showed that these areas were relatively accurate in predicting farming practices on wheat and were more predictive than county indicators, for example. 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 percent sand are taken from SSURGO (Soil Survey Geographic Database). 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 cut-off 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 Table 1.

3.2 Prevailing practices

Under our simulated policy, the regulator would assign each cropland acre a baseline, denominated as a nitrogen application rate, derived from prevailing practices. 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 Table 2. The magnitudes, statistical significance, and even 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. Instead, goodness-of-fit is the key result in terms of the performance of the baseline, since it reflects how well the prevailing-practice approach will predict individual farm practices. Our main result, regression #5, yields an R^2 of 0.32. We use this regression to create the baselines analyzed in Section 4.

Alternative functional forms (for climate and NCCPI) or different soil and climate variables had little effect on this R^2 "ceiling." (Regression results not shown.) Interestingly, these goodness-of-fit measures are almost identical to the R^2 of the same regressions applied to wheat (Horowitz, 2012), which suggests similar levels of unexplained heterogeneity across the two crops. We take this as weak evidence in favor of our θ-based approach.

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 (5) or other evidence.

Note that it is possible to estimate non-additionality at this point, without further behavioral assumptions beyond the assumption that the participation decision per se is costless. The substantive economic decision is for the farm to provide additional nitrogen reduction, estimation of which requires us to parameterize the behavioral assumptions behind (2). This is the subject of Section 4.

Technically, it is not necessary to use the same data set to both estimate prevailing nitrogen application rates and simulate individual-level participation. Using the same data set ensures that the prevailing-rates estimates provide the best case for our baseline policy. This data-source question arises because a payment policy would need to assess prevailing rates before each current year's application takes place and therefore must be based on historical data; in other words, prevailing rates calculations for the baselines must be made based on practices from previous years and then adjusted for expected rates in the current year. The necessity of adjusting average nitrogen rates across years arises under other baseline approaches than the one we simulate, of course.

4. Results

4.1 Additionality

We simulate results (additionality, non-additionality, costs, supply) as if a payment program had been operating in 2010 and prevailing practices were known with certainty based on previous analysis and adjustments for 2010 input and output prices. Non-additionality can be estimated directly from the baselines and observed nitrogen rates. Further parameter and policy assumptions are needed for those aspects with greater economic content: additionality, costs, and supply. We set w = \$0.40 per pound, roughly the prevailing nitrogen price in 2010, and let $\beta = 0.33$. Let q = \$0.07 per pound of nitrogen. If these payments were targeted to reduce agricultural greenhouse gas emissions, q = \$0.07 corresponds to \$15 per tonne of carbon dioxide equivalent, CO2-e.[6] Thus, using equation (4), participating farms reduce nitrogen by 12 percent below their non-payment nitrogen rate. Given this Δ_n, a farm participates if $x_n - \zeta\Delta_x < B$, with x_n taken from the ARMS data. In the analysis below, we set ζ = 0.5. Because we have no programmatic data to estimate ζ and because we are unable to reliably construct the distribution of θ_i, this assumption is unfortunately *ad hoc*. We discuss this, tangentially, in Section 5.2.

Given these parameters and the behavioral assumptions they embody, we calculate total additional nitrogen reductions, non-additional "reductions" receiving payments, and total nitrogen amounts receiving payments. For ease of discussion, we refer to quantities that receive payments as *credits*. It is potentially misleading to refer to all credited nitrogen as *reductions* since a portion of them is non-additional; as far as we can tell, no term exists in the literature for this distinction. Note that the sum of additional reductions and non-additional credits exceeds total credits because some inframarginal additional reductions are made without payment so that

[6] Each kilogram of applied nitrogen yields contributes 0.01 kilograms of nitrogen in emitted nitrous oxide. We multiply this by 1.57 to convert to N_2O, then multiply by 310, its global warming potential (in CO_2 equivalents).

the farmer will be eligible for payment for marginal reductions.

Results are shown in Table 3. If we set the baseline equal to the expected application rate (column 1) with no further adjustments then roughly 50 percent of corn acres are expected to participate and to supply 1,180 million pounds of credits, which represent 16 percent of business-as-usual application.

Only about one-third of these credits represent additional – that is, *actual* – nitrogen reductions. This low level of additionality can be expected when the baseline is equal to the expected application rate and no further eligibility criterion or safety margin is applied: Roughly half of all acres have business-as-usual application rates above the mean and all of this nitrogen enters the market as non-additional credits. Because the program necessarily ends up issuing credits that are non-additional, the average payment per unit of actual nitrogen reduction is higher than the program payment of \$0.07 per pound. We find that the average payment for true nitrogen reduction is \$0.26 per pound, or 3.5 times the price paid by the simulated policy.

This result does not, on its own, indicate that the policy is unsuccessful or would not pass a benefit-cost test. First, this calculation includes only budgetary costs, only a portion of which are deadweight loss. Second, it does not count the true cost of nitrogen reduction which, for additional nitrogen, will necessarily be below the payment rate of \$0.07 per pound. Third, this analysis has not made claims about judgment on the social benefit from nitrogen reduction, which may be greater than the posted payment rate. (It is worth recalling that the risk of paying for non-additional credits cannot be eliminated and, in practice, there will always be some volume of non-additional credits.) This means that a welfare-improving policy may choose a payment rate that is below the social value of nitrogen reduction, if the baseline is restricted to equal the expected business-as-usual rate with no further safety margin or eligibility criteria. All of these factors would need to be considered for a true benefit-cost test of the payment policy.

The budgetary payment per additional nitrogen remains an important calculation, however, because many such programs work with a fixed budget and are restricted to some sort of fixed-payment method. They must therefore attempt to maximize nitrogen reductions within that budget. In such situations, budgetary payment per additional nitrogen is the key measure of policy performance.

(This conclusion is weaker when policymakers have the option of using a competition-based approach, such as having farms compete for payments. Farm competition can reduce abatement costs, and therefore allow greater program enrollment, without necessarily changing the payment per additional nitrogen. In this case, aggregate farm abatement costs must be considered along with payment per additional nitrogen in judging policy performance. Since this paper has focused on a policy-specified payment rate with no opportunity for further discriminating between lower and higher cost abatement, we gauge relative performance through payment per additional nitrogen only.)

4.2 Policy options to enhance additionality: Safety-margins and further eligibility criteria

We examine several policy design options that might be expected to enhance additionality. The Waxman-Markey bill, in its specification of a greenhouse gas offset program, called for the policy administrator to set activity baselines that reflected “a conservative estimate of performance or activities for the relevant type of practice.. such that the baseline provides an adequate margin of safety to ensure the environmental integrity of offset credits calculated in reference to such a baseline” (pp. 1396-97). This issue would presumably be similarly relevant for our payment-based policy. We consider a safety-margin and an eligibility criterion that we consider sufficiently simple. As Horowitz (2012) demonstrates, there are in fact an extremely wide number of options for addressing additionality through choice of baselines, safety margins, and eligibility criteria; we leave analysis of these richer options for a separate paper.

Non-additionality arises because there is a great deal of cross-sectional heterogeneity in farming practices even when conditioned on a wide side of contractible covariates, as the Table 2 results demonstrate. Therefore, we first consider an eligibility criterion that censors supply based on the magnitude of this heterogeneity. Under this criterion, the program would be available only in regions (based on the MLRA group) that have a coefficient-of-variation ($CV_j = \sigma_j/\overline{N}_j$, where the j subscript indicates the statistic for region j) in nitrogen rates below a specified threshold. As this threshold becomes lower, farms in the remaining, eligible regions have less cross-sectional heterogeneity in nitrogen rates, which should lead to baselines that more closely approximate business-as-usual rates and therefore lead to a higher proportion of additional reductions. Choice of the CV threshold thus becomes a policy decision to adjust the expected level of additionality.

Results are shown in Table 3 for an array of policy stringencies, where increasing stringency means a lower cut-off CV. A tighter eligibility criterion increases the proportion of additional nitrogen reductions relative to non-additional credits and reduces the payment per pound of additional nitrogen, as expected. Under the most stringent eligibility criterion we analyze, the payment is \$0.15 per pound of additional nitrogen (based on a policy payment of \$0.07 per pound), which is a little over half the budgetary per-unit cost as when no eligibility criterion is imposed. Of course, this increasing stringency comes at the cost of a reduction in eligible acres, participating acres, and total additional nitrogen.

This CV approach is not explicitly derived from an underlying structural model and its empirical performance is not well known. Horowitz (2012) shows that adjusting baselines based on the skewness or an adjustment that is nonlinear in sigma can perform better than the CV approach in improving the ratio of additional reductions to non-additional credits, a slightly different focus from the current paper. Furthermore, without a firm budget constraint or benefit-cost calculation, it is difficult to compare policies across scenarios. We chose the CV approach because it seemed the most straightforward to explain in public discussion. More complex approaches are available but risk being too opaque at the policy level.

We then introduce a further safety margin under which we reduce each individual baseline below its expected nitrogen rate by a fixed proportion, γ, an adjustment meant to yield a "conservative" estimate of prevailing application rates. This adjustment too is not explicitly derived from an underlying structural model but derives from public understanding of what conservative might mean in this context. Table 4 shows the results, with the proportional adjustment ranging from 0 (which corresponds to the 4th column of Table 3), to 0.3.
We continue to we restrict payment offerings to regions with CV_j < 0.5.

This second safety margin approach is not successful in reducing the payment per pound of additional nitrogen. We find that higher magnitude adjustments reduce, rather than increasing, the proportion of credits that are additional. The reason is that a tighter baseline puts farms higher on their cost curve, making it more expensive to reduce nitrogen, and this higher cost and reduced participation outweighs the reduction in non-additional credits. This result is not general but depends on the steepness of the cost curve and the distribution of non-additional credits between $\widehat{N}_i$ and $(1 - \gamma)\ \widehat{N}_i$.

4.3 Supply

We next examine nitrogen supply in response to the program payment rate. Table 3 uses a program payment of \$0.07/lb. N. We now vary this rate under the restriction that the program is offered only in regions with $CV_j < 0.5$ and examine the effect on both additional nitrogen reduction and total supplied credits. Both of these supply curves are potentially of interest to policy-makers. Results are shown in Figure 1. We chose the stringency level $CV_j < 0.5$ because it yields a relatively high proportion of additional reductions to non-additional credits while maintaining a sufficient number of acres eligible for the program (see Table 3).

Both additional reductions and total supplied credits are of course increasing in the payment, with the supply curve of additional reductions lying to the left of the total credit supply curve. We have two observations: (i) As the price increases, the two supply curves converge, and at very high prices we would expect them to be very close. The reason is that at very high prices, the supply of additional credits is high. Since non-additional credits are supplied inelastically (because (5) does not depend on the payment rate q), they become a smaller and smaller component of total credit supply, while the potential supply of additional credits is much larger. This result suggests that for very high payment rates, the issue of non-additional credits is less important, although the exact tradeoffs depend on the situation.

(ii) The supply curve of additional reductions can be used to infer the costs of abatement, just as with other supply curves. We calculated the area under the simulated supply curve of additional reductions and obtain the estimated total cost of the policy as \$9.2 million, given the payment of \$0.07/lb. of nitrogen. This is the economic cost of nitrogen reduction, borne by farmers, and is a separate calculation from the budgetary cost.

Figure 2 shows how the effective payment rate and total expenditures change with the program payment rate. By effective payment rate, we mean the total government payment per additional reduction. As is clear from the model and the supply curve, total payments from the government increase as the per unit payment rises. These expenditures are useful for assessing overall budgetary costs but are not relevant to our additionality analysis.

Of greater interest is the behavior of the effective payment rate. The effective payment increases with the program payment, but at a decreasing rate as additional reductions become a larger proportion of the payment pool. As the two supply curves in Figure 1 converge, the effective payment rate converges to q.

4.4 Literature

The literature on green payments is voluminous. We focus on the small set of articles that explicitly cover the baseline issue, conceptually or empirically. In the context of our paper, those articles that look at continuous activities are particularly relevant. (The distinction between continuous practices and activities, such as nitrogen application or overall emissions, and discrete practices, such as tree-planting or no-till adoption, has not been widely recognized. Most conceptual models are written in terms of a continuous contribution, which is generally interpreted as emissions. But most policies involve payments for adopting discrete practices. See Horowitz and Ueda (2013) for discussion of the baseline approach under a discrete practice and Smith and Horowitz (2013) for discussion of payments based on emissions versus practices, which also entails addressing the baseline issue. As Smith and Horowitz point out, framing the policy purely in terms of emissions rather than practices does not eliminate the issues we have discussed and can in fact lead to greater non-additionality problems.)

Horan and Claassen (2007) analyze a conceptual model of green payments in which each participant is assigned a benchmark, which corresponds to our baseline. They assume that both business-as-usual emissions and individual abatement costs can be observed. They examine one case in which the benchmark is required to be the same for everyone, which is a step toward recognizing that the policymaker may not be able to set the benchmark equal to business-as-usual, but they then allow a different payment rate to different farms. Since this again makes use of the regulator's ability to observe farm types, we did not attempt to use their results.

Fell et al. (2012) examine conceptually a cap-and-trade market with offsets; offsets are equivalent to our green payment approach. They model baseline uncertainty, but their baseline is a shifter of covered-source abatement costs, not offset supply. Their model of offset supply assumes no non-additionality. In our model, this is consistent with $\alpha, \beta, \theta, R, p$ and w being perfectly observed at the time farm-level baselines are chosen, but with time-series randomness in p or w (for example) affecting the overall emissions market.

Marshall and Weinberg (2012) discuss the different types of baselines and refer to our prevailing-practices approach as "sector-level," to be compared to farm-level baselines which are based on historical patterns of production for the farm or field. They do not analyze the specific performance of these baseline approaches. Section 5.1 for further discussion of different baseline approaches.

A second relevant set of articles has measured the additionality achieved by existing conservation programs. Mezzatesta, Newburn, and Woodward (2013) study adoption of conservation practices in Ohio. These practices may have been received funding from any of a number of Federal conservation programs. They find rather high levels of additionality for a set of discrete practices; farms that were paid to adopt the practices were predicted to be rather unlikely to have adopted them without payment. Similar results were found by Claassen, Duquette, and Horowitz (2013) in a nationwide study of practice adoption. These results are a bit hard to square with the reality of the programs, however, which have no explicit conditions meant to separate additional from non-additional participants.

Claassen, Duquette, and Horowitz (2013) further examine additionality for nitrogen application on corn (i.e., a continuous practice), but because none of the programs has an explicit per-unit payment and because the authors do not have data on the total farm-level payment, it is not possible to infer the payment per additional nitrogen that the program achieves.

Another relevant study comes from Lubowski, Plantinga, and Stavins (2008), who estimated that "91 percent of land in the Conservation Reserve Program in 1997 constituted additional reductions in crop acreage." Unlike other federal conservation programs, the CRP contains explicit additionality conditions: the land must have been cropped in 4 out of the preceding 6 years. Note that this sort of plot-specific condition can be relatively easily imposed and does not likely invoke much moral hazard or transaction costs. Millard-Ball (2013) provides a useful analysis in an international context.

5. Further issues

5.1 Alternative approaches for constructing baselines

In water quality trading, a policy similar to our payment-based model, baselines are typically based on past practices on the farm (sometimes augmented by an exogenous standard).[7] It is tempting to presume that such "past practices" baselines would lead to higher levels of additionality than our prevailing-practices approach since past practices should be closer to the farm's business-as-usual management than regional prevailing practices.

The past-practices approach has several conceptual drawbacks, however; flaws that are

[7] Even more confusingly, these past practices are sometimes called, "current practices."

not shared by our prevailing-practices approach. We see three such issues: (i) Moral hazard arises because past practices are endogenous and thus farmers can influence their baseline through their choice of management practices in the years leading up to the program participation. The prevailing-practices approach is exogenous and therefore avoids this problem.

(ii) High transactions costs are involved in verifying and standardizing past practices and incorporating them into a baseline; the prevailing-practices approach invokes none of these steps or their costs. Current farm programs do sometimes request farm records or may rely on farmer statements of past practices, but these programs have not been much concerned about additionality and therefore have not tested the rigor of the current approaches. Inaccuracies, whether deliberate or inadvertent, in farmer reporting of past practices fall into this category, since those inaccuracies can only be remedied by enforcement or high recordkeeping standards. On the other hand, advances in remote sensing may reduce these transactions costs by providing easily accessible, verifiable data on past practices.

(iii) Adverse selection remains even if both of the first two issues are resolved: The ability of past practices to predict future practices are unknown, and uncertainty about this relationship raises the same sort of adverse selection described here. Farms that would have reduced future nitrogen use as a matter of course could apply for payments that would then be non-additional. (This prediction error, between last year's practices and current practices, is on top of any systematic year-to-year change, as captured by equation (5), which could be accounted for equally under both types of baselines.) Note that using a "base year's" practices rather than the preceding years' practices reduces moral hazard but increase transactions costs and adverse selection.

We recognize that these arguments are conceptual and we cannot say how large an effect they may have in real world applications. There is a tradeoff between the adverse selection arising from imprecise prevailing practice baselines and the moral hazard and transactions costs occurring under a past-practices baseline.

Other proposed baseline approaches use exogenous baselines not necessarily based on prevailing practices. Millar et al. 2010 suggested a corn-nitrogen baseline equal to the rate that was calculated to maximize the return to nitrogen, by rotation and state, based on field trials. Canadian nitrous oxide protocols have proposed baselines based on performance standards constructed from a “historical database of purchased fertilizer N, which could be used to calculate a standard N balance… for farms in eco-geographical regions” (Climate Change Central 2008, p. 10); in other words, a version of the prevailing-practices approach. For water quality trading in the Chesapeake Bay, credits can be earned for application rates that fall below the minimum of past application rates and the rate that would achieve desired runoff levels, called the Total Maximum Daily Load (TMDL). Since the TMDL is largely exogenous to the farm and is conditioned primarily on soil and slope variables, the economics are similar to the issues covered above; it is also conditioned on farm type, which is not truly exogenous. The TMDL is thought to build in a large safety margin, however, and if there are few farms that would meet the TMDL under business-as-usual practices, then all enrolled parcels would count as additional. The economics of these baseline approaches are similar to our paper’s analysis.

A third approach is to denominate the baseline in terms of emissions rather than practices. Under an emissions baseline approach, farms would be eligible for payments for a commitment to follow any set of practices that yielded lower emissions than their designated baseline. The policy could construct emissions baselines using either a prevailing emissions approach (what are average emissions from similar type farms?) or a past emissions approach (what were the farm's emissions in the preceding year?),[8] with the tradeoff between these similar to the tradeoff when only practices are considered. Smith and Horowitz (2013) analyze the difference between emissions baselines and baselines written in terms of specific practices, and point out that emissions baselines are not necessarily superior.

5.2 *The corn-nitrogen production function and the economics of Δ_n*

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 5 corn-nitrogen models, none of which included Cobb-Douglas (C-D), and Finger and Hediger (2008) compared 3 production models, also without considering C-D; neither of these papers explain why C-D was not considered. Given this background, we consider the justification for and, more importantly, 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 β = 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 (4) and (5) and our

[8] We assume in both cases that emissions are not measured but are constructed based on practices, soils, and climate.

hypothesized source of heterogeneity, θ, all 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.

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 (1) or (2). Our value, which is higher than those found by Weliwita and Govindasamy, also counterbalances the approximations used in (3) and (4), which tend to increase the simulated percentage reduction.

There are several points relevant to this discussion. First, under a standard conceptual market-based environmental policy, the policy administrator sets an environmental price, individual farmers voluntarily decide whether to participate, and the resulting efficiency is independent of the actual level of participation. Estimates of (6) or (7) would be informative in this scenario but not essential to the proper functioning of the policy, assuming the marginal environmental value is roughly constant which is reasonable for a non-local problem such as greenhouse gases. A market-based policy that does not cover increases in agricultural emissions, however, requires a baseline, and when we recognize that the baseline is necessarily an imprecise measure of business-as-usual emissions then potential non-additionality affects program performance. This means that participation and reductions are not necessarily efficient. In such a situation, estimates of additionality and policy performance are key; they are more than "information." When the risk of non-additionality is large, it may be desirable for the policy administrator not to offer payments for that particular practice.

Second, estimates of non-additionality require very little in terms of economic assumptions; in particular, they are independent of assumptions about the production function, Δ_n, or ζ. Estimates of additionality, however, rely on all of these factors. Most of these factors have not been subject to previous analysis and are essentially unknown. Research is needed to begin to elucidate the economic variables.

Third, 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 non-additionality unchanged. More difficult to gauge are the potential effects of either (i) reductions that are not monotonic in x_n; one virtue of both Cobb-Douglas and Mitscherlich production functions is that x_n and $x_n - x_o$ move together; or (ii) reductions that are monotonic in x_n but are not a uniform percentage. It makes most sense to consider reductions that are a lower percentage for lower levels of x_n and, possibly, equal to zero for x_n below some cut-off, which means that no farmer with x_n below this cut-off participates. These features have more complex and less predictable effects on supply responses and we leave analysis for a subsequent paper.

5.3 Possible unintended consequences

As with all policy prescriptions, it is worth considering possible unintended consequences and their implications for design of the current policy or needed new policies.

Three such possible consequences are particularly easy to identify. First, if payments are offered for nitrogen reduction only on corn and not on other crops then this program provides incentives for farmers to switch from other crops into corn, since the payments raise the profits on corn for all farms with $x_{ni} - \zeta\Delta_x < B_i$, where x_{ni} is the nitrogen the farmer would have applied if he had decided to grow corn without the payment. If the nitrogen applied to corn under the policy, x_{oi}, is greater than the nitrogen that would have been applied to the substituted crop, then the policy has had a deleterious unintended consequence, at least in terms of nitrogen. A mostly-successful remedy to this possibility is to offer the nitrogen payment to all crops, with baselines that are specific to the chosen crop. Some smaller complications remain under this policy variation: (i) poorly formulated baselines can still cause the policy to lead to crop-switching; presumably there would be fewer such switches; and (ii) policy administration is more complex, as policy administrators have to develop estimates of prevailing fertilizer practices for multiple crops (a time-consuming process that may delay implementation of the policy), adjust these over time, and construct multiple safety margins or eligibility criteria.

Second, if payments are offered only for reductions in nitrogen application but not for changes in other management practices, then this program may be accompanied by changes in production practices that have further environmental effects. These production practices changes may include the fertilizer type (ammonia vs. urea), application timing, and tillage method, and further production practices that accompany these. The analog to the remedy suggested above – baselines and payments for each of these practices – is more complex than for crop-changes only. Further analysis is needed to estimate the potential magnitude of the effects and to identify other possible unintended consequences.

Third, if payments are offered year-by-year, with farmers allowed to opt in or out of the program on an annual basis, then this program may lead farmers to participate only periodically and to apply more nitrogen in the years in which they do not participate, with the goal of having higher residual soil nitrogen levels for the years in which they do participate. The overall effect on nitrogen would then be less than the program is crediting.

One remedy that weakens this incentive is to require multi-year enrollment; farms that enroll in a given year must also be willing to receive payment and be subject to the contract's conditions for a number of future years. Obviously, our cost estimates are not necessarily accurate for this dynamic situation. An alternative is to allow year-by-year enrollment but to condition payments on a nitrogen test or some estimate of residual soil nitrogen based on, say, previous crops. The incentives of such a condition have not yet been examined.

In each of these cases, the empirical magnitude of the possible effects is not well known, nor do we know their effects on the cost estimates we provide. The remedies are not conceptually complex but in all case they would lead to a substantially more comprehensive program than our analysis has considered. We presume that these possible consequences and their complications would arise with other types of pay-for-performance programs.

6. Further Research

Technological advances in remote sensing should provide a richer set of variables with which to construct baselines. The scope for reducing non-additionality in proposed payment schemes represents an important subject for empirical analysis. We continue to think that the possibility of moral hazard (regardless of its potential empirical magnitude) will mean that a base-year approach (rather than a preceding-year approach) will best characterize the baseline. The base-year approach makes for more challenging empirical analysis and also heightens the challenge for adjusting the baseline based on exogenous economic variables, as we argued for expression (5).

The ability of green payment policies to cover multiple practices, multiple crops and multiple time has not yet received much attention. More attention is warranted.

Table 1. Nitrogen application rate on corn, pounds per acre (2010)

	Non-irrigated, non-organic; application rates below 300 lbs./acre	Main sample (excludes observations with missing covariates or insufficient neighboring farms)
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

Table 2. Goodness-of-fit for N application on corn

Variables (number of categories)	#1	#2	#3	#4	#5	#6
Constant	Yes	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

Table 3. Additional reductions and non-additional payments under different eligibility stringencies[1]

	Baseline:[2] $B = \widehat{N}_i$ (regression #5)					
	Eligibility criterion, by region.[3] Increasing eligibility stringency ⟶					
	Program offered in all regions	$CV_j < 0.75$	$CV_j < 0.625$	$CV_j < 0.5$	$CV_j < 0.375$	$CV_j < 0.30$
Acres excluded from eligibility	0	1.2	2.7	13.4	23.3	46.5
Mean baseline, all eligible acres	120.1	122.9	128.2	136.6	142.9	158.8
Participating acres	27.4	26.7	26.0	20.8	16.2	4.8
Proportion of corn acres participating	0.50	0.49	0.48	0.38	0.30	0.09
Nitrogen eligible for payment ($B - N_o$), million lbs.	1,180	1,154	1,128	859	655	168
Additional nitrogen, million pounds	333.8	331.2	327.7	280.3	231.5	80.2
Payment per pound of additional nitrogen (assuming program payment of $0.07/lb.)	$0.26	$0.25	$0.25	$0.22	$0.21	$0.15
Additional/ Non-additional	0.38	0.39	0.40	0.47	0.52	0.80

[1] Based on 1,503 observations of 2010 non-irrigated, non-organic corn representing 7,341 million pounds of nitrogen applied to54.4 million acres.
[2] $\widehat{N}_i$ from regression #5, Table 2. Offset supply based on $N_c = B + 0.5\Delta_N$ with $\Delta_{\boldsymbol{N}} = 0.12 \times N_n$.
[3] Program payments 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, $CV_j = \sigma_j / \overline{N}_j$.

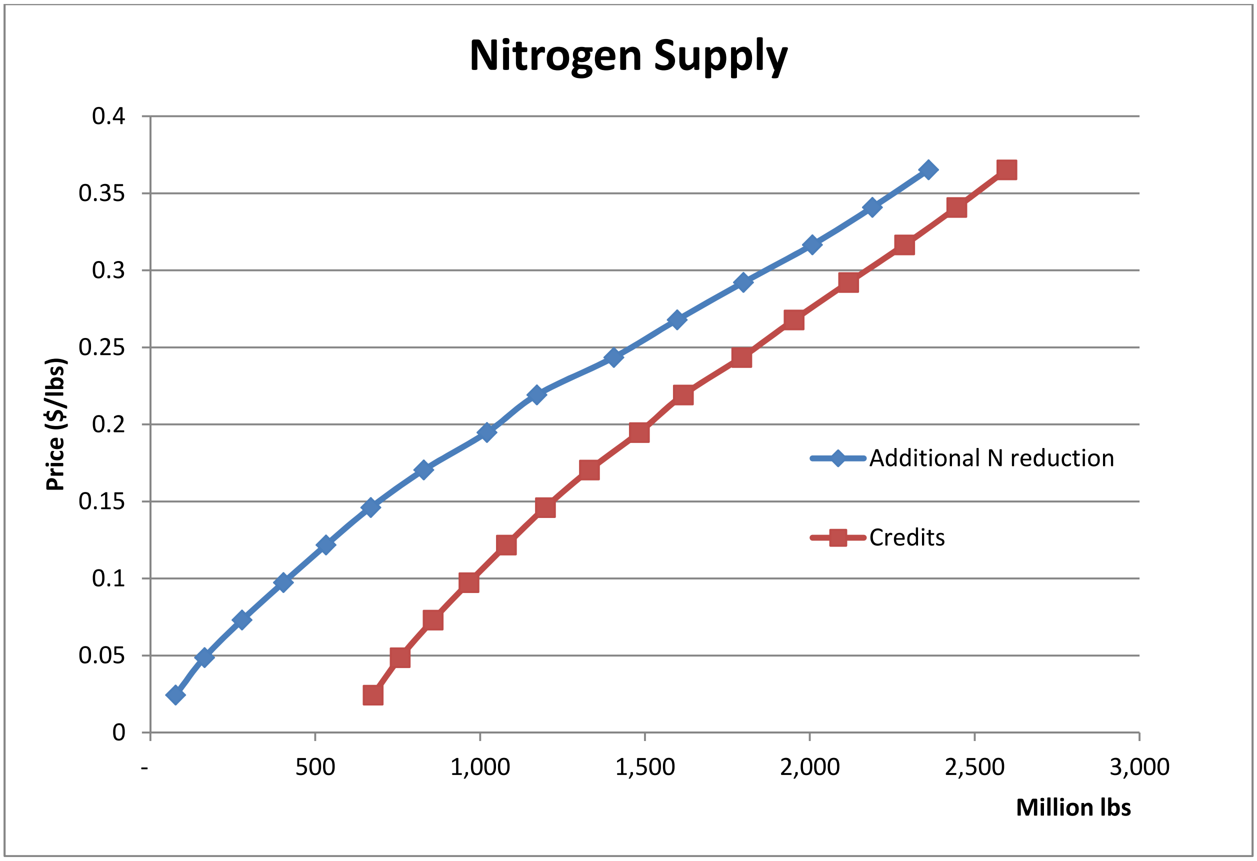
Table 4. Additional reductions and non-additional payments under different safety margins, under eligibility criterion $CV_j < 0.5$.[1]

	Safety margin γ Baseline:[2] $B = (1-\gamma)\,\widehat{N}_i$			
	$\gamma = 0.05$	$\gamma = 0.1$	$\gamma = 0.2$	$\gamma = 0.3$
Mean baseline, all eligible acres	129.7	122.9	109.3	95.6
Proportion of corn acres participating	0.32	0.25	0.17	0.11
Additional nitrogen, million pounds	211.9	155.2	84.9	40.9
Payment per pound of additional nitrogen (assuming program payment of $0.07/lb.)	$0.23	$0.26	$0.32	$0.45
Additional/ Non-additional	0.43	0.37	0.29	0.19

[1] Based on 1,503 observations of 2010 non-irrigated, non-organic corn representing 7,341 million pounds of nitrogen applied to54.4 million acres. Program payments are offered only in regions with coefficients of variation below 0.5.

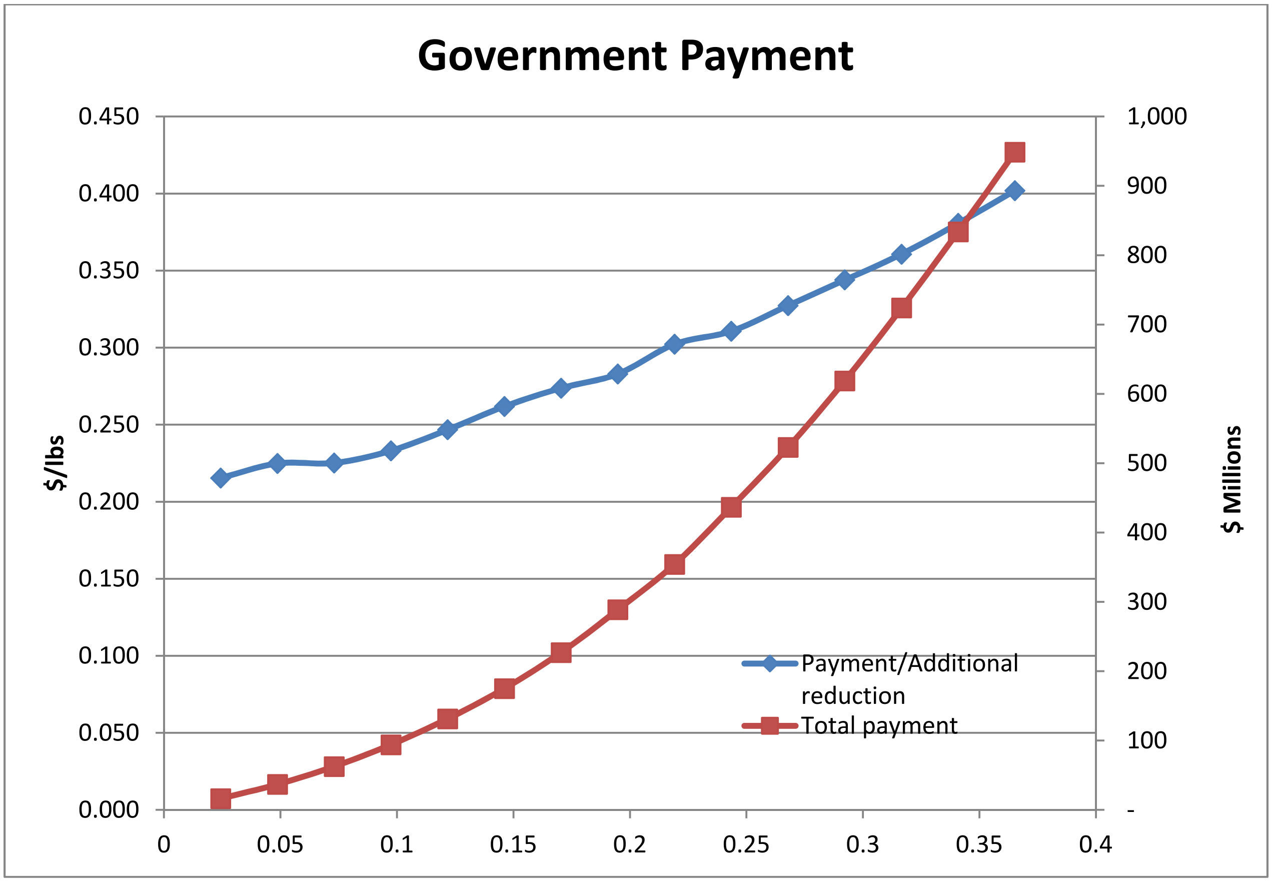
[2] $\widehat{N}_i$ from regression #5, Table 2. Offset supply based on $N_c = B + 0.5\Delta_N$ with $\Delta_{\boldsymbol{N}} = 0.12 \times N_n$.

Figure 1. Nitrogen and credit supply



Note: Supply curves assume offsets are allowed only in regions with $CV_j < 0.5$.

Figure 2. Effective payment and total budgetary payment as a function of program payment rate



Note: These curves assume offsets are allowed only in regions with $CV_j < 0.5$.

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