Assessing the Impacts of Cap-and-Trade Climate Policy on Agricultural Producers in the Northern Plains: A Policy Simulation with Farmer Preferences and Adaptation

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Abstract

The purpose of this study is to examine the possible local impacts of cap-and-trade climate policy on agricultural producers in the Northern Plains. This study explicitly considers farmer behavior with respect to agricultural opportunity in carbon offset provision and ability of adaptation to mitigate the production cost impact under a cap-and-trade climate policy. Based on empirically estimated farmer behavior models, a policy simulation with agricultural census data identifies farmer acreage enrollment in carbon offset provision, carbon offset supplies and revenues, the production cost impacts of carbon prices, and impacts on net farm income and their distributions among heterogeneous farmers. Our analysis find that: 1) farmer ex ante preferences in general are biased against participating in carbon credit programs although farmer involvement increases with carbon prices; 2) with the fertilizer industry exempted from cap-and-trade regulation, the production cost impacts would be small, and more than half of the farms or farmland would probably gain for a carbon price higher than $10 per metric ton of carbon; and 3) the production cost impacts with a capped fertilizer industry would be 2 times higher, and more than half of the farms or farmland would lose unless the carbon price could reach beyond $55 per metric ton of carbon. This study sheds some light on agricultural potential to adapt to economy-wide climate change mitigation while providing a bottom-up economic assessment of the costs and benefits of a cap-and-trade climate policy to agricultural producers in the short run.

Keywords: greenhouse gas, cap-and-trade, climate change, agricultural impact, economics, carbon offsets.

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1. Introduction

Regulating greenhouse gas (GHG) emissions is of political interest in the U.S. With the power established under the Clean Air Act (*Massachusetts v. EPA* 2007), the Obama administration has already incorporated GHG cap-and-trade (CAT) in its budget plan for 2012-2019 (Scientific American 2009). In June 2009, the U.S. House of Representatives passed for the first time a climate bill titled *The American Clean Energy and Security Act* (HR 2454) (also known as the Waxman-Markey bill) that proposes a more comprehensive GHG CAT program while promoting improvement of energy efficiency. With more than 20 bills introduced in the 110th Congress calling for near-term, specific and mandatory GHG reductions, majority leaders in both the House and Senate have stated intentions to pass GHG control legislation in the 111th Congress (Leggett 2009). U.S. regulation on GHG emissions, probably by a CAT program, seems to be inevitable in the near future.

GHG emission regulation could affect many sectors in the U.S. economy. Traditional wisdom believes that a GHG CAT program in effect introduces a carbon price such that economic activities need to pay for their GHG emissions beyond the amounts permitted. Based on a general equilibrium analysis of the U.S economy, studies found that small sectors that are emissions-intensive would bear disproportionately large shares of the mitigation costs with the energy industries among the foremost (Goettle and Fawcett 2009, Jorgenson et al. 2009). Because of the potential economic impacts, many interest groups are seeking to affect the development of climate policy in favor of their respective interests. With pending climate legislation, understanding the impacts of GHG regulation becomes critical to designing an effective, welfare-improving climate policy that can achieve U.S. policy goals in both energy security and climate change mitigation at a minimum cost.

To the U.S. agricultural sector, what GHG regulation, particularly CAT, means is subject to debate with divided views. For example, Murray et al. (2009) developed a commentary on some previous studies that were considered characterized by a partial, incomplete assessment of the impact of a CAT program on agriculture. These studies, including Francl et al. (1998) and a report issued by Doane Advisory Services (2008), emphasized negative impacts from carbon prices, asserting that agriculture would suffer due to increase in production costs. In contrast, many resource economists appear more optimistic and believe that GHG CAT could bring many benefits that may be sufficient enough to more than offset the negative impact on production costs (Peters et al. 2001, Schneider and McCarl 2005, McCarl 2007, Babcock 2009, Murray et al. 2009, Baker et al. 2010).

The U.S. Department of Agriculture (USDA) Office of Chief Economist also conducted a preliminary analysis of the effects of GHG CAT on US agriculture (USDA 2009). Based on an EAP June study on the energy price effects of the Waxman-Markey bill (EPA 2009), the USDA study analyzed production cost impacts relative to farm income, assuming no technological change, no alteration of inputs in agriculture, and no increase in demand for bio-energy resulting from higher energy prices. Acknowledging overestimation of the production cost impacts, it concluded that the agricultural sector would have modest costs in the short term and net benefits – perhaps significant net benefits – over the long term. In a testimony to the House Subcommittee on Conservation, Credit, Energy and Research, McCarl (2009) was more focused on the opportunities enabled by a CAT program. He believed that agriculture could benefit from CAT climate legislation but adjustment would be needed for agriculture to obtain these benefits.

While all these studies or views reflect varying focus on the potential benefits and costs of a CAT climate policy, different assumptions on farmer behavior and policy design can affect estimation of the benefits and costs, leading to different policy impact assessment. On the cost side, if agriculture is exempted from GHG emission regulation, then the direct agricultural impact of CAT boils down to the production cost increase due to rising energy prices to cover carbon costs. With changing and increasing prices for energy-related inputs, will farmers be indifferent and still follow the same production practices using the same amount of inputs as before the price changes? If farmers are to reduce their use of energy and energy-related inputs, this production adjustment in effect may mitigate the cost impact of carbon prices. On the benefit side, if agriculture is allowed to provide carbon emission offsets in the carbon market, then GHG CAT may create income opportunity for farm carbon sequestration or emission reduction in addition to advancing agricultural potential to provide renewable energy and the market effect of rising commodity prices. Similarly, farmer responses to these opportunities and their market consequences affect estimation of the potential benefits.

This study is motivated to develop an economic analysis of the possible impacts of GHG CAT on agricultural producers in North Dakota (ND), an important production region in the Northern Great Plains. In this study, we consider a CAT climate policy that exempts agriculture from GHG emission regulation while allowing agriculture to provide carbon emission offsets in carbon markets. This study is focused on two possible direct impacts of the policy on net farm income: revenue from carbon offset provision and rising production costs due to GHG regulation. It intends to address four policy-relevant questions, including: 1) how farmers would respond to on-farm potential to provide marketable carbon emission offsets, 2) what would be the production cost impacts of CAT with farmer ability of adaptation, 3) to what extent the potential revenue from carbon offset provision could offset the increase in production costs such that agriculture would gain from CAT, and 4) how the CAT impact on net farm income would be distributed among heterogeneous farmers.

In this study, we conducted a mailing survey to elicit farmer preferences to participating in carbon credit programs to provide marketable carbon offsets. We used farmer stated preference to calibrate a behavior model that can predict the probabilities that farmers of given attributes would enroll land in carbon programs for different carbon prices. We drew on economic theory to specify and estimate farmer production costs as a reduced function of energy prices, which incorporates farmer ability of adaptation to manage production costs with changing energy prices. We applied the estimated farmer behavior models to agricultural census data to simulate farmer acreage enrollment in carbon offset provision, carbon offset supplies and revenues, the production cost impacts of carbon prices, and more importantly, impacts on net farm income and their distributional effects. By explicitly considering farmer behavior, this study attempts to shed some light on the agricultural potential of adaptation to economy-wide climate change mitigation while providing a bottom-up economic assessment of possible local impacts of CAT on agricultural producers.

This study contributes to improving understandings on the agricultural impacts of GHG CAT. First, it provides a local perspective on a CAT climate policy from a major agricultural production region in the U.S. that provides an ideal, specific agricultural setting for examining the policy. Second, it explicitly considers farmer behavior with respect to both carbon offset provision and adaptation to manage production costs, both of which affect assessment of the impacts of CAT on agriculture. Third, it accounts for farmer heterogeneity and reveals the distributional effects of carbon prices on net farm income. While existing analyses largely focus on broad economic impacts of CAT on agriculture, this study complements the literature by its local focus and explicit consideration of farmer preferences, adaptation, and heterogeneity in farm production.

This paper is organized as follows. Section 2 summarizes our modeling framework, including farmer behavior models and the structure of policy simulation based on the farmer behavior models. Section 3 describes our survey design, elicited farmer preferences to carbon offset provision, and other data collected for our analysis. Section 4 presents econometric estimation of the farm behavior models. Section 5 applies the estimated farmer behavior models to simulate the short-term cost and potential benefit of a CAT climate policy on agricultural producers. Section 6 concludes the paper with discussion.

2. Modeling Framework

Our method to assess the local agricultural impacts of a CAT climate policy is centered on farmer behavior with respect to carbon offset provision and production cost management. Based on farmer behavior modeling and agricultural census data, a policy simulation can be developed to account for farmer heterogeneity and to identify the distributional effect of GHG CAT on net farm income.

2.1. Economic rationale

To develop an economic analysis of the agricultural impacts of GHG CAT, the key is to understand farmer production behavior under the expected changes in market and economic conditions attributed to the policy. One important opportunity for farmers under CAT is the potential to reduce farm carbon emissions by adjusting production practices and sell the carbon emission reductions as offsets in the carbon market. Yet, on-farm carbon offset provision is a new concept with which farmers have no experience. While one could reasonably assume that farmers would produce carbon offsets if profitable, it is also fair to pay attention to the possibility that farmers might not always be willing to yield their flexibility in production management to regulation in exchange for carbon revenue from a volatile market while bearing certain transaction costs. Farmers may be risk-averse and may not be fully responsive to new market opportunities like carbon offset provision, which requires certain production practices with a commitment of at least 5 years. The extent of farmer participation in carbon offset provision will affect the benefit farmers could receive from CAT. Farmer preferences to provide carbon offsets remain an open question with many speculations that have not been addressed in the existing literature, though.

Farmer ability of production cost management is equally important as well. Economists have long recognized that farmers are responsive and can adapt to mitigate at certain degree any negative impacts caused by policy or biophysical or economic conditions that affect production costs or benefits. Indeed, farmer adaptation is the foundation for most economic assessments of the potential impact of climate change on agriculture (Mendelsohn et al. 1994, Antle 1996, Mendelsohn and Neumann 1999). With GHG CAT increasing prices for energy-related inputs, a profit-maximizing farmer will adjust production to reduce his consumption of these inputs substituted by other inputs with relatively low prices. While increased production costs may be expected resulting from CAT, farmer adaptation can mitigate the production cost impacts of carbon prices. To what extent farmers can adjust their production with increasing prices for energy-related inputs directly affects estimation of the production cost impacts of CAT.

A third challenge for analyzing the local impacts of GHG CAT is the heterogeneity among farms. It is well known that U.S. agriculture is characterized by high heterogeneity in farm production. Given that not all the farms are the same in terms of their production attributes, it is likely that some farms would gain while others might lose under a CAT climate policy. While estimation of the impact in aggregate may provide useful information on the economic efficiency of the policy, decision-makers are also concerned about its distributional effect and the possible magnitudes of economic gains or losses for individual farmers. Given the larger number of farms with high heterogeneity, identifying the distribution of the policy impact among farms is important and can be approached by statistical simulation with approximation if modeling hundreds of thousands of individual farms is impossible.

2.2. Modeling farmer decision on carbon offset provision

To model farmer decision to provide carbon emission offsets, we use the discrete choice method, which is a popular approach increasingly used to study people preferences by observing their choice behavior (McFadden 2001). Consider the farmer decision of whether or not to participate in carbon credit programs to provide carbon offsets. If farmers are profit-maximizing, then farmer decision on carbon offset provision can be modeled by examining how participation in carbon credit programs would affect farmer profit.

With an active carbon market, farmer profit may be expressed as

$$\pi = \mathbf{PQ}(y) + p_c y - C(\mathbf{Q}, y) \tag{1}$$

where **P** represents the vector of market prices for agricultural commodities, **Q** denotes the vector of production outputs for these commodities, *y* denotes the amount of carbon offsets produced, and C(**Q,** *y*) is the production cost for commodity output **Q** with carbon offset yield *y*, and p_c is the price for carbon. Because producing carbon offsets usually involves changing practices or land use, the production outputs of commodities **Q** and their production cost C may be affected by carbon offset yield *y*.

For profit-maximizing farmers to produce carbon offsets (i.e., $y > 0$), the Kuhn-Tucker condition requires $\left.\frac{\partial \pi}{\partial y}\right|_{y=0} > 0$, i.e.,

$$\left.\frac{\partial \pi}{\partial y}\right|_{y=0} = \mathbf{P}\frac{\partial \mathbf{Q}(y)}{\partial y} + p_c - \frac{\partial C(\mathbf{Q}, y)}{\partial \mathbf{Q}}\frac{\partial \mathbf{Q}}{\partial y} - \left.\frac{\partial C(\mathbf{Q}, y)}{\partial y}\right|_{y=0} > 0 \tag{2}$$

Denote $\Delta C^{\mathbf{Q}}$ as the production cost increment attributed to the commodity output effect of changing production practices for producing carbon offsets and ΔC^{y} as the cost increment directly linked to the provision of carbon offsets. For a positive carbon yield $\Delta y > 0$, the Kuhn-Tucker condition (2) in discrete case can be written as

$$\Delta\pi = p_c - [-(\mathbf{P}\Delta\mathbf{Q} - \Delta C^{\mathbf{Q}}) + \Delta C^{y}] > 0 \tag{3}$$

The expression (3) indicates that profit-maximizing farmers will produce carbon offsets if the marginal benefit is greater than the marginal cost including both the opportunity cost of commodity production and the direct cost of carbon offset production. This condition establishes our theoretical foundation for specifying and estimating a farmer behavior model with respect to on-farm provision of carbon emission offsets.

The Kuhn-Tucker condition (3) shows that farmer provision of carbon offsets can be predicted if its opportunity cost and production cost are known for a given carbon price and farmers are profit-maximizing. Although individual farmers may have their own perceptions about the private costs of producing offsets on their land, these private costs are not observed in general. To measure farmer private costs for producing carbon offsets, we introduce an index function

$$C = \overline{C}(\mathbf{J}) + \varepsilon \tag{4}$$

where **J** is a vector of farmer observable attributes, $\overline{C}(\mathbf{J})$ represents the expected private costs for producing carbon offsets as perceived by farmers, and ε is a random error accounting for unobserved or stochastic factors that affect farmer perception of the private cost. By this index function, we assume that the expected farmer private cost for producing carbon offsets $\overline{C}(\mathbf{J})$ depends on observable farm attributes **J**. These attributes can include land use, production practices, land ownership, land location, and farmer demographics and attitudes to climate change legislation. Substituting (4) into to (3) yields

$$\Delta\pi = p_c - \overline{C}(\mathbf{J}) - \varepsilon \tag{5}$$

With this model setting, the probability that a farmer j will provide carbon offsets is

$$\Pr_j(carbon) = \Pr_j(\Delta\pi_j > 0) = \Pr_j(\varepsilon_j < p_c - \overline{C}(J)) \tag{6}$$

Assume that the cumulative density function of ε_j can be approximated by a logistic function. The above probability can be expressed as

$$\Pr_j(carbon) = \Pr_j(\varepsilon_j < p_c - \overline{C}(\mathbf{J})) = \frac{e^{(p_c - \overline{C}(\mathbf{J}))}}{1 + e^{(p_c - \overline{C}(\mathbf{J}))}} \tag{7}$$

So the probability of farmer j observed behavior on carbon offset provision can be expressed as $\Pr_j = \Pr_j^{Z}(1-\Pr_j)^{(1-Z)}$, where Z is a 0-1 variable indicating farmer j decision of whether or not to participate in carbon credit program to provide offsets. If the choices of n farmers are observed, the farmer behavior model can be estimated by maximizing the log-likelihood function of the observed choices of n farmers:

$$\Pr(carbon) = \sum_n [Z_j \ln(\Pr_j) + (1 - Z_j)\ln(1 - \Pr_j)] \tag{8}$$

2.3. Modeling farmer adaptation in production cost management

In this study, we focus on farmer variable production costs to capture their ability of adaptation in production cost management in response to changing input prices. In economic theory, the production cost function can be specified as C = C(**Q**, **W**) with output vector **Q** and input price vector **W**. This function reveals how the production cost of a profit-maximizing agent varies with input prices, and it incorporates and reflects production adjustment in optimum that minimizes the production cost for different input prices. Consequently, modeling farmer adaptation in production cost management may be approached by identifying the production cost function of farmers.

Assume the maximum agricultural output per unit land is fixed over a finite period. On a per unit land basis with fixed output, farmer production cost function may be written as C = C(**W**). Because we consider variable production costs and because agricultural production relies directly and indirectly on energy inputs, farmer variable production costs for per unit land may be regarded econometrically as a reduced function of energy prices, i.e., $C = C(\mathbf{w}_e)$. We expect that farmer reduced production cost function, if estimated using historical observations on how variable production costs have varied with energy prices, would capture farmer adaptation behavior in face of soaring and volatile prices for energy and energy-related inputs. As GHG CAT is expected to impose a carbon cost on energy consumption, the production cost impact of carbon price p_c can be expressed as

$$\frac{\partial C}{\partial p_c} = \frac{\partial C}{\partial \mathbf{w}_e} \times \frac{\partial \mathbf{w}_e}{\partial p_c} \tag{9}$$

How to specify farmer reduced production cost function is an empirical question. We hypothesize that variable production costs for per unit land in reduced form be a quadratic function of energy prices, i.e.,

$$C = b_0 + \mathbf{b}_1 \mathbf{w}_e + \mathbf{b}_2 \mathbf{w}_e^2 \tag{10}$$

This hypothesis is based on economic rationale on production and farmer ability to manage production costs within a finite period. When prices for energy-related inputs increase with rising energy prices, farmers may initially be able to mitigate a corresponding increase in production costs by reducing consumption of those energy-related inputs via production adjustment or better management. Farmer ability to mitigate the production cost impact of rising input prices, however, is not unlimited within a finite period. The increase in energy prices eventually will lead to higher production costs. Consequently, farmer production costs for per unit land may decrease initially before increasing with rising energy prices. The specified farmer production cost function in its reduced form leads to the production cost impact of carbon price p_c expressed as

$$\frac{\partial C}{\partial p_c} = (\mathbf{b}_1 + 2\mathbf{w}_e \mathbf{b}_2) \frac{\partial \mathbf{w}_e}{\partial p_c} \tag{11}$$

This equation incorporates farmer ability of adaptation in production cost management with rising energy prices.

2.4. Statistical policy simulation

Based on the above farmer behavior models, a statistic simulation with county-level agricultural census data can estimate the distributional effects of carbon prices on net farm income. We first classify farmers into different types by their production attributes vector **J**. We assume that agricultural production is homogeneous among farmers of a same type with the same production attributes and heterogeneous across different farmer types with varying production attributes. Once a farmer is identified by his production vector **J**, we can predict his provision of carbon emission offsets and the production cost impact for a carbon price. In each county, there are many types of farmers with varying production attributes vector **J**; and the distribution of farmers by type differs among counties. With agricultural census data available to estimate the distribution of farmer types for each county, we can simulate the distributional effects of carbon prices on net farm income.

Consider a farmer type described by production vector **J.** Denote **a**(**J**) as the vector of farmland acreages in different land use operated by farmers of type **J**. With **Pr**(**J**, p_c) representing the vector of probabilities of participating in different carbon credit programs, the amounts of land in different use that farmers of type **J** would enroll in carbon programs to produce carbon offsets can be calculated as **Pr**(**J**, p_c)**a**(**J**)′. Suppose the probability distribution of farmer type **J** in county i is F_i(**J**). If the county i has a total number of N_i farmers, the county-level acreages used to produce carbon offsets for a given carbon price *w* can be estimated as:

$$\sum_{\mathbf{J}} \mathbf{Pr}(\mathbf{J}, p_c)\mathbf{a}_i(\mathbf{J})F_i(\mathbf{J})N_i \tag{12}$$

The state total acreages of farmland for carbon offset provision would be

$$\sum_{i}\sum_{\mathbf{J}} \mathbf{Pr}(\mathbf{J}, p_c)a_i(\mathbf{J})F_i(\mathbf{J})N_i \tag{13}$$

If each acre of farmland in different carbon programs can sequester **α** metric ton of carbon, the state-level total carbon supply can be calculated as

$$\boldsymbol{\alpha}\sum_{i}\sum_{\mathbf{J}} \mathbf{Pr}(\mathbf{J}, p_c)a_i(\mathbf{J})F_i(\mathbf{J})N_i \tag{14}$$

For a carbon price p_c, the total revenue from carbon offset provision in a state would be

$$p_c\boldsymbol{\alpha}\sum_{i}\sum_{\mathbf{J}} \mathbf{Pr}(\mathbf{J}, p_c)a_i(\mathbf{J})F_i(\mathbf{J})N_i \tag{15}$$

To examine the distributional effects of carbon prices on net farm income, we compare the revenue from carbon offset provision with the production cost impact under different carbon prices for all farmer types. Consider a farmer with production profit π = R – C, where R represents farm revenue and C, as before, is the total production cost. With an emerging carbon market, we assume that farmers produce carbon emission offsets by enrolling land in different carbon credit programs that their land are qualified for and that would not require shifts among land use incurring significant opportunity costs. In this case, the impacts on net farm income of carbon prices can be calculated as the increased revenue from provision of carbon offsets minus the increased production cost due to rising input prices caused by a carbon cost, i.e.,

$$\Delta\pi = \Delta R - \Delta C = p_c y - \frac{\partial C}{\partial p_c} p_c \tag{16}$$

Note that this calculation considers the short-term rather than long-term market equilibrium effect of introducing a carbon price in the economy. The state-level aggregate impact on net farm income d∏ would be

$$d\Pi = \sum_i d\Pi_i = \sum_i \sum_{\mathbf{J}} d\pi_i(\mathbf{J}) = \sum_i \sum_{\mathbf{J}} (\mathbf{Pr}(\mathbf{J}, p_c)\mathbf{a}_i^{'}(\mathbf{J}) F_i(\mathbf{J}) N_i \boldsymbol{\alpha} p_c - \frac{\partial C}{\partial p_c} p_c) \tag{17}$$

3. Farmer Preference Survey and Data

To calibrate the farmer behavior model regarding carbon offset provision, we conducted a mailing survey to elicit farmer preferences to the carbon opportunity under CAT. The survey questionnaire is composed of three sections. Section 1 is intended to elicit farmer willingness to enroll in carbon credit programs. In the survey, we present fiver carbon credit programs including conservation tillage, cropland conversion to grass, rangeland management, tree planting, and methane management project (Table 1). Section 2 is designed with questions to collect information on farmer social economic background and their attitudes to climate change and legislation. In section 3, questions are raised on farmer current production practices. These questions focus on crop types and acreages, seeding rates, yields, tillage practices, crop rotation, gasoline and diesel consumption, and fertilizer and pesticide application. Data collected by sections 2 and 3 are intended to be used as surrogates to measure farmer perceived private costs for producing carbon offsets on their land.

The survey was administered by the USDA National Agricultural Statistics Service (NASS) field office in North Dakota. We designed six different versions of survey questionnaires to incorporate different levels of the carbon price ranging from \$5/metric ton to \$70/metric ton (and thus varying profitability for carbon program enrollment). For each version of the questionnaire, a sample of 500 farmers across ND was randomly selected from the USDA NASS database to take the survey. The survey questionnaires were mailed out on January 15, 2010, followed by a postcard reminder after two weeks. A total of 316 survey questionnaires were returned. Among those returned, 35 were not filled out, and the remaining 281 had at least one question answered.

Other data needed for this study include production costs, total acreages of planted cropland and rangeland, and energy prices. These data are used to estimate farmer reduced production cost function. Although county-level time series of annual variable production costs and acreages of production farmland are desirable for our analysis, they are not available. Instead, we collected state-level annual variable production costs and acreages of production farmland over the period from 1968 to 2008 (USDA ERS 2010). We use variable production costs rather than full production costs including land rent and farm overhead because variable production costs are more closely related to input prices that reflect energy costs. We divided variable production costs by acreages of production farmland to get variable production costs for per unit land.

We collected prices data for two major energy sources directly or indirectly consumed in agricultural production. These energy sources include natural gas and crude oil. Natural gas accounts for the majority of the production costs of fertilizers, which are an important input for agriculture. Crude oil is the major ingredient of diesel and gasoline, which are directly or indirectly consumed in agricultural production operation. Natural gas prices collected are nominal prices for the industrial sector. Crude oil prices are combined nominal refiner acquisition costs of domestic and imported crude oil. All energy prices are annual averages for the period of 1968-2008 from the U.S. Department of Energy Energy Information Administration (EIA 2010). Figure 1 depicts the variable production costs for per unit land and energy prices.

4. Model Estimation

This section presents our model estimation results for farmer decision on carbon offset provision and farmer reduced production cost function. We estimated the farmer behavior models by using the computer program Matlab.

4.1. Farmer decision on carbon offset provision

Table 2 defines the independent variables included in our discrete choice model (8) of farmer decision to participate in carbon credit programs. We estimated the discrete choice model by maximizing the log-likelihood function (9). Table 3 presents the modeling results, including estimates of the elasticities of the likelihood that farmers would enroll land in carbon credit programs with respect to different factors. As demonstrated by Table 3, the binary logit model fits farmer choices reasonably well. Indeed, it correctly predicts 75% of farmer choices in the survey sample.

Many factors can affect farmer decision to provide carbon emission offsets. As expected, available carbon prices could significantly increase the odds of farmer enrollment. Farmer current land use practices, land tenure, age, and attitudes toward climate change and legislation could also increase the probability of carbon program participation. Specifically, if a farmer has land in CRP or manages rangeland, owns cropland, is less than 45 years old, is concerned about climate change, and supports climate change legislation, he will be more likely to participate in carbon credit programs to provide carbon offsets.

Interestingly, farmers in general are biased against carbon program participation as indicated by the estimated negative and significant coefficient for the dummy variable denoting carbon program enrollment. From the perspective of farmer profit-maximizing behavior, the negative coefficient implies a threshold level for the private costs perceived by farmers for enrolling in carbon programs. Farmers would consider to participate in carbon programs, only if the potential benefit exceeds the threshold of private costs, which depends on farmers production attributes. The cost threshold may be attributed to farmer perceptions of uncertainties associated with program enrollment or simply the loss of flexibility in land use and management with a 5 year commitment once enrolled in the carbon program. It may also reflect the option value that farmers might enjoy by not entering any programs with binding contracts on their land use practices.

To examine the effects of different factors on farmer decision, Table 3 also reports in the fourth column the elasticities of the probability of farmer enrollment in carbon programs. Specifically, ownership of cropland has the strongest effect that increases the probability of carbon program participation by approximately 68%. The effects of farmer age, engagement in rangeland management and CRP, farming experience, and farmer attitude to climate change are also sizable that increase the probability of carbon program participation by 58%, 56%, 51%, 43%, and 37%, respectively. As to the effect of carbon prices, Table 4 shows that the probability of carbon program enrollment on average would increase 0.54% for a 1% increase in the carbon price at $34/metric ton.

4.2. Farmer reduced production cost function

Our empirical estimation of farmer reduced production cost function reveals a quadratic relationship between variable production costs on a per acre basis and energy prices. As demonstrated by Table 4, all the estimated coefficients for the independent variables are significant at the 0.01 level. The adjusted R square statistic indicates that energy prices can account for up to 91% of the variation in variable production costs for the considered time period. This result is consistent with the visualization of the trends of variable production costs for per unit land and energy prices illustrated by Figure 1.

Figure 2 depicts the reduced production cost function with energy prices. It is interesting to note how variable production costs for per unit land vary differentially with prices for crude oil and for natural gas. As illustrated by Figure 2, the distribution of variable production costs for per unit land appears to be a U shaped curve with respect to crude oil prices, which is in contrast with an inverse U shaped curve with respect to natural gas prices. Table 4 confirms the varying relationships. This result suggests differential marginal cost effects between energy sources: for natural gas, it is positive and decreasing; for crude oil, it is negative and increasing.

The estimated production cost function has important implications on farmer vulnerability or ability to adapt to the price impacts of different energy sources. When crude oil prices are low, agricultural consumption of crude oil may be extensive with low energy efficiency. Consequently, when crude oil prices rise, farmers may be able to easily cut crude oil consumption by improving energy efficiency so as to mitigate its production cost impact. However, farmer ability to mitigate the cost impact of energy prices appears not as strong for natural gas as for crude oil. Farmer may see increased production costs with rising natural gas prices. Because agricultural consumption of natural gas is indirectly through fertilizer use and because fertilizer costs account for a sizable portion of agricultural production costs, the above result seems to imply that fertilizer consumption in the U.S. is relatively efficient such that farmers has limited ability to mitigate the production cost impact of any increase in natural gas prices.

With a quadratic production cost function, the marginal cost impact of energy prices depends on the level of energy prices in the base year considered. In this study, the base year to examine the CAT impact is 2009. Figure 2 shows how the 2009 production cost and energy prices compare to those in other years. At the 2009 price level, Figure 2 suggests that the marginal impact on production costs of energy prices is limited for crude oil, which is less than for natural gas.

5. Policy Simulation

Based on the estimated farmer behavior models, we conducted a statistical simulation with agricultural census data to estimate farmer acreage enrollment in carbon offset provision, carbon supply and revenue, production cost impact with farmer adaptation, and impact on ND farm income for varying carbon prices. Table 5 summarizes the 2007 ND agricultural census data for the production attributes used to stratify farmers in our policy simulation. A total of 768 farmer types (or vector **J**) was identified and used in simulation.

5.1. Acreage enrollment in carbon offset provision and carbon supply

To simulate county-level farmer responses to the carbon market requires information of not only farmer production attributes but also the available amount of land that has the capacity to produce carbon offsets. The estimated farmer choice model quantitatively links farmer production attributes to the probability of participating in carbon credit programs, while the total acreage of farmland that a farmer would enroll in carbon programs depends on the amount of land qualified for the available carbon programs. As farmland capacity to provide carbon offsets is measured by the difference in carbon net fluxes associated with different land use and management practices, the amount of land potentially qualified for carbon credit programs depends on its use and management history and the target carbon program. Consistent with our survey on farmer preferences, we consider the carbon credit programs administered by NFU (except methane projects) as available options to simulate farmer acreage enrollment. The current land use and management determines potentially available amounts of farmland qualified for individual carbon credit programs.

In this study, we consider five types of land use and management that cover the majority of farmland with carbon offset provision potential and that are incorporated in farmer production attributes with available agricultural census data. These land use and management types include harvested cropland, cropland used only for pasture or grazing, cropland on which all crops failed or were abandoned, cropland in cultivated summer fallow, permanent pasture and rangeland, and land in conservation. We consider conservation as a land use type because conservation programs (such as CRP) has implications on opportunity costs and allowed land use by their enrollment rules and land management requirements. We use conservation land here to collect all marginal land that is not covered by the other land use types and that may have high potential for certain carbon credit programs such as tree planting.

Not all land in their current use are equally qualified for the carbon credit programs. Table 6 summarizes our mapping of farmland with its current land use into each carbon credit program. While different assumptions can be made for the potentially available amount of land for each carbon program, Table 6 assumes that farmers enroll their land in a way that does not incur much opportunity costs while reducing potential uncertainties and risks associated with program enrollment. As different carbon credit programs are targeted at different land use types and management practices, we assume that the considered carbon prices would not be sufficient to cause shifts among land use except for changes in management practices entailed by the target suitable carbon program.

As listed in Table 6, harvested cropland is considered only for conservation tillage. This is based on the assumption that harvested cropland represents prime cropland for farming and, if converted to solely produce carbon offsets, would incur high opportunity costs as well as loss of option value if it is costly to put it back to crop farming. As not all harvested cropland might be suitable for conservation tillage and some cropland might have adopted conservation tillage already, the acreage of harvested cropland may represent the upper bound of available land for conservation tillage. Cropland failed or abandoned and cropland in cultivated summer fallow cover land with lower quality for farming than harvested cropland but are not qualified for CRP. These land use types may be good candidates for cropland conversion to grass while retaining the flexibility of being used for crop farming. For cropland used only for pasture or grazing and permanent pasture and rangeland, the rangeland management program can be a good option without involving major land use change. With a similar long term commitment and attracting carbon prices, tree planting may represent a promising use competing with CRP for current CRP land once they are released.

Table 7 presents our simulation results on farmer acreage enrollment in carbon credit programs and amounts of carbon sequestered. As expected, the acreage of farmland enrolled in carbon programs increases with carbon prices. Table 7 shows that the total acreage in carbon programs expands from around 8.5 million to 23 million when the carbon price rises from $5 to $70 per metric ton of carbon. While all carbon programs see increased farmland enrollment with rising carbon prices, their contributions to the total acreage are uneven across programs. Conservation tillage constitutes nearly half of the farmland in carbon offset provision, and its contribution increases from 45% to 52% with carbon prices. Although accounting for around 42% of the acreage in carbon programs for a carbon price of $5/metric ton, rangeland management contributes less than conservation tillage with a decreasing share as the carbon price rises. Cropland conversion to grass accounts for a small share (2-3%) of the enrolled farmland and its contribution goes up for a high carbon price. Farmland enrolled in tree planting makes up around 10% of the total land enrolled, and its percentage decreases with carbon prices.

The total amount of carbon offsets increases from 3.3 million metric ton to 9.1 million metric ton as the carbon price rises from $5 to $70 per metric ton of ton. The share of the contribution from each program varies. Conservation tillage still is the major source for provided carbon offsets with its share ranging from 46% to 51%, which is consistent with their acreage contribution. In contrast, rangeland management provides only 10-13% of carbon offsets although its acreage contribution accounts for 35-42%. Tree planting and cropland conversion to grass provide, respectively, about 31-34% and 7% of the total provided carbon offsets, more than their acreage contributions.

In all, conservation tillage and tree planting represent the major source for potential carbon offset supply in ND. Although conservation tillage may not sequester as much carbon as tree planting does, it can be applied to harvested cropland - the majority of farmland - without incurring significant opportunity costs. The acreage available for planting tree may be limited due to significant conversion costs, uncertainties in carbon markets, or loss of option value. Yet the large amount of carbon that can potentially be sequestered in tree makes tree planting also a significant option for carbon offset provision. Both rangeland management and cropland conversion to grass deserve consideration by their sizable amounts of carbon offset provision potential without incurring significant opportunity costs.

5.2. CAT Impact on farm income and distributional effect

Table 8 summarizes the impact of carbon prices on production costs for ND farms. Note that the estimates of energy price increases relative to the 2009 levels were based on the carbon contents of energy sources without considering the market equilibrium effect of carbon prices. As the carbon cost for energy consumption is likely to be shared jointly between energy producers and consumers, the estimated energy price increase represents an upper bound for the price impact of carbon pricing. However, given that energy consumption is less elastic than energy supply, those estimates are likely to be close to those accounting for the market equilibrium price effect.

As illustrated by Table 8, carbon pricing appears to have a relatively stronger effect on prices for natural gas than for crude oil. The differential effects between natural gas and crude oil tend to be more prominent when the carbon price is high. For a carbon price of $5/metric ton, prices for natural gas and crude oil both increase 1% relative to their 2009 levels. In contrast, if the carbon price is $70/metric ton, the natural gas price will increase by 19% while the crude oil price will increase by 14% relative to their 2009 levels.

Historical observations have revealed that farmers are less able to mitigate the production cost impact of a price increase for natural gas as compared to for crude oil. Farmer vulnerability to natural gas prices, combined with the stronger effect of carbon costs on natural gas prices, suggests that farmers would suffer more severe cost impact for any price increase for natural gas than for crude oil. Indeed, estimates of the production cost impact confirm the reasoning. Agricultural consumption of natural gas is indirectly through fertilizer use. If the fertilizer industry is exempted from CAT regulation, the production cost impact will come largely from the consumption of crude oil, with an estimated cost increase ranging from $0.54 to $7.62 per acre (or a 0.69% to 9.69% increase relative to the variable production costs for per unit land in 2009) for a carbon price between $5 and $70 per metric ton of carbon. However, if the fertilizer industry is capped under CAT, the production cost impact for ND farmers will be 2 times higher, with an estimate cost increase ranging between $1.14 and $15.99 per acre (or a 1.45% to 20.34% increase relative to the variable production costs for per unit land in 2009) for the same range of carbon prices.

Figure 3 compares aggregate revenue from carbon offset provision and production cost impact for ND farms. As demonstrated by Figure 3, if the fertilizer industry is capped under CAT, the production cost impact will exceed the carbon revenue unless the carbon price is greater than $55 per metric ton of carbon. As the carbon revenue is not sufficient to offset the increase in production costs for a carbon price below $55/metric ton, ND farms in aggregate would suffer a loss from CAT. However, if the fertilizer industry is exempted from CAT, the production cost impact on ND farms would be much smaller. In this case, for any carbon prices greater than $10/metric ton, the carbon revenue more than offset the increase in production costs such that ND farms in aggregate would gain from CAT by participating in carbon credit programs. It is worth noting that the production cost impacts were estimated relative to the 2009 ND production costs for different carbon prices. These estimates may vary depending on the base year selected as the comparison benchmark.

The impact of CAT on individual farms can be different, depending on specific farmer attributes including their production practices. Some farmers may have a large amount of idle land or land in conservation with only a small portion in production. These farmers may benefit from CAT by participating in carbon credit programs while not paying much for production cost increase. Other farmers may have land mainly in production, and would be severely affected by production cost increase with limited revenue from carbon offset provision, particularly if the opportunity cost to produce carbon offsets is high for these farmers. Figures 4 and 5 depict the cumulative distributions of net farm profits by farm and by acreage for different carbon prices and CAT regulation on the fertilizer industry.

One type of information delivered by the cumulative distributions of net farm profits is the percentage of farms or the proportion of total acreage that would suffer a loss from CAT. If the fertilizer industry is capped, as demonstrated by panel a in Figure 4, around 73% of ND farms will incur a loss if the carbon price is \$5 per metric ton. The percentage of farms with a non-positive net profit is reduced from 73% to 41% if the carbon price is \$65 instead of \$5 per metric ton of carbon. If the fertilizer industry is exempted from CAT, panel b in Figure 4 shows that the percentage of farms that will suffer a loss falls dramatically as compared to panel a for each carbon price. For a low carbon price of \$5/metric ton, 69% instead of 73% of ND farms will be negatively affected by CAT. For a high carbon price of up to \$65/metric ton, the percentage of ND farms that will see negative net farm profits drops from 41% with a capped fertilizer industry to 14% if the fertilizer industry is exempted. Both carbon prices and fertilizer industry regulation significantly affect the distributional effect of CAT among heterogeneous farmers.

The distributions of net farm profits may be different by acreage than by farm as individual farmers may operate different amounts of farmland. The distributional effect by acreage is equally important because a large portion of farmland acreage might still gain even if a large percentage of farms suffered a loss for a given carbon price. Figure 5, however, does not show dramatically different distributions for net farm profits by acreage than by farm. If the fertilizer industry is capped under CAT, the proportion of land by acreage that will suffer a loss ranges from 88% for a carbon price of \$5/metric ton to 50% for a carbon price of \$65/metric ton, little higher than the proportions by farm. If the fertilizer industry is exempted from CAT, the proportion of land by acreage that will suffer a loss drops, respectively, to 57% and 15% for a carbon price at low of \$5/metric ton and at high of \$65/metric ton. In this case, however, the proportions of land by acreage that will suffer a loss are slightly lower than those by farm.

The cumulative distributions of net farm profits, either by farm or by acreage, also show the magnitudes of possible economic gains or losses for ND farms. As illustrated by Figures 4 and 5, for a carbon price between \$5 and \$65 per metric ton of carbon, the economic loss on a per acre basis ranges between 0 and -$15 with the fertilizer industry capped or between 0 and -$8 with the fertilizer industry exempted from CAT. However, the effects of the carbon prices are not symmetric between economic gains and losses. The economic gain from CAT can increase dramatically relative to the economic loss with rising carbon prices. Both Figures 4 and 5 show that, the economic gain for some farms can reach up to $80 per acre for a carbon price of $65/metric ton, which is in contrast with a maximum economic loss of around $15 or $8 per acre depending on CAT regulation on the fertilizer industry. The asymmetric effects of carbon prices reflect farmer capacity of adaptation to manage production costs while benefiting from providing marketable carbon emission offsets.

6. Conclusion and Discussion

This study is motivated to examine the possible local impacts of a CAT climate policy on agricultural producers in a Northern Plains region. It draws on economic theory and the existing literature attempting to develop an economically sound analysis of possible CAT impacts, particularly revenue from provision of carbon emission offsets and the production cost impact of carbon pricing. It focuses on farmer production behavior and explicitly considers farmer preferences to provide carbon offsets, adaptation to manage production costs, and heterogeneity in production attributes. Based on empirically estimated farmer behavior models, a statistical simulation with agricultural census data provides important implications on agricultural potential to adapt to climate change mitigation and capacity building to improve agricultural adaptation to climate policy.

Farmers are reluctant ex ante to participate in carbon sequestration. With agriculture exempted from regulation on GHG emissions, CAT creates opportunities for farmers to make profits by providing carbon emission offsets. Based on our survey, however, we found that farmers in general are biased against participating in carbon credit programs. This result may be attributed to farmer unfamiliarity with the concept of carbon offset provision and their perceived private costs of farm management to produce carbon offsets while maintaining commodity production. Indeed, it was quite common that survey respondents expressed their concerns over regulation on farm management and loss of control of farmland implied by participating in carbon programs. Better education and extension to disseminate on-farm potential to provide carbon emission offsets are needed for agriculture to adapt to societal climate change mitigation. Nonetheless, conservation tillage and tree planting appear promising to play a major role in the Northern Plains region to contribute a large portion of carbon emission offsets without incurring significant opportunity costs.

Farmers have the ability to mitigate the production cost impact of a CAT climate policy. Our theory-driven, production cost approach based on historical observations reveal that farmers can effectively manage their operation costs to mitigate the impact of energy price increase, possibly by improving production efficiency. However, farmer ability of production cost management varies depending on specific energy sources and the level of energy prices. Our study confirms, from a local perspective, existing findings that CAT has limited impact on agricultural production costs (see USDA 2010). With their ability to manage production costs, farmers may gain from CAT by optimal farm management to produce both food and carbon offsets. System design and integration are needed to reconstruct agricultural production to better adapt to societal movement to an energy-efficient, low-carbon economy.

Specific policy design can affect the agricultural impact of GHG CAT. While fertilizer costs make up an important portion of farmer production expenditures, a CAT policy with an exempted fertilizer industry could dramatically reduce its cost impact on agriculture. On a per acre basis, the production cost impact on ND farms averages 2 times higher with a capped fertilizer industry as compared to a policy that exempts the fertilizer industry. In aggregate, with an exempted fertilizer industry, revenue from carbon offset provision would be greater than the production cost impact for a carbon price over $10/metric ton for ND farms even if farmers were in general reluctant to participate in carbon sequestration. Without the exemption on the fertilizer industry, the carbon price needs to reach at least $55/metric ton for ND farms to break even with carbon offset revenue offsetting increased production costs. A policy design with a schedule to gradually phase out the exemption on the fertilizer industry may help softly land the U.S. agricultural sector with government efforts in climate change mitigation.

The impact of CAT on ND farm income is unevenly distributed. With the fertilizer industry exempted, the CAT impact on production costs would be small. Most farms or the majority (> 50%) of farmland acreage in ND would probably gain for a carbon price over $20 per metric ton of carbon with farmer ex ante preferences to carbon offset provision. With the fertilizer industry being capped, the CAT impact on production costs would be bigger. Most farms or the majority of farmland acreage in ND would lose for any carbon prices probably below $50/metric ton. In both cases, on a per acre basis, the economic losses are limited as compared to the economic gains across farms.

While we strive to develop an economically sound analysis of some of the possible local impacts of CAT on agriculture, this study like many others has some caveats that arise mainly due to our local focus in research scale. First, in this study, we did not consider two other effects that can affect the assessment of a CAT climate policy. Some existing studies indicated that CAT might have economy-wide market consequences including increased demand for bio-energy feedstock and rising prices for agricultural commodities, both of which could increase farm income (Schneider and McCarl 2005, Murray et al. 2009). To quantify these two market equilibrium effects requires an equilibrium analysis at the national scale which is beyond the scope of this study. We understand that it is highly challenging to accurately quantify the benefits from both effects with complex market dynamics interacting with farmer behavior and US energy and agricultural policies, including the indirect land use effect. Focused on agricultural potential to provide carbon offsets without considering the other two market effects, this study likely underestimates the benefit that GHG CAT would bring to agriculture.

Second, this study did not consider the cost impact of carbon pricing on inputs that are not energy intensive. GHG CAT can have an economy-wide effect by introducing a carbon cost. Prices for agricultural inputs that are not energy intensive might be affected as well due to the carbon footprint of these inputs. In this sense, our estimation of the production cost impact of carbon pricing represents a lower bound on the true cost impact. Yet, with our reduced production cost function, we remain skeptical on the possibility that the cost impact of carbon pricing on non-energy intensive inputs such as machinery would outnumber that for energy-intensive inputs. Indeed, the reduced production cost function of energy prices explains 91% of the variation of observed production costs over the past 4 decades. Based on an economically sound approach accounting for farm adaptation, our estimation of the production cost impact appears reasonable while might underestimate the true impact by a small margin. In addition, we did not consider the pass-through of the production cost increase to consumers in the form of higher commodity prices, which means our estimates might overestimate the production cost impact. To what extent that the cost impact could be passed to consumer prices remains an empirical question requiring a national study. Our estimates could be regarded as representing a short-term rather than a long-term impact fully accounting for market equilibrium effects. Farmers with much market experience perhaps need not to worry about at all the cost impact of CAT if production cost increase can be easily passed on to consumers, or need they?

Third, it would not be surprising if this study underestimated the agricultural potential of carbon offset provision. The estimation of the agricultural potential to provide carbon offsets is based on our survey of farmer ex ante preferences. As mentioned above, the on-farm potential of carbon offset provision is a new concept with which farmers do not have much experience. A risk-averse farmer tends to overweight the uncertainty and risk for involving in a new production option, particularly if it requires a long-time commitment while subject to regulation. As a result, while understanding that revenue from carbon offset provision would come together with rising production costs under GHG CAT, farmers were less willing to be involved in carbon programs, as indicated by our survey. With this recognition, it is also economically reasonable to expect more active farmer involvement in carbon programs once the production cost impact becomes a sunk cost with an effective CAT climate policy and once farmers become more familiar with on-farm management that can produce both crop or animals and carbon offsets. After all, providing carbon offsets does not have to compete with crop or animal production (although they could under high carbon prices) and may more than offset the sunk cost of agricultural production under CAT while also bring other joint farm benefits such as increased soil fertility.

Fourth, this study did not consider the environmental benefits or costs of GHG CAT. Studies have suggested that providing carbon offsets can bring many other environmental benefits or costs due to its implied change on land use and production practices (Jackson et al. 2005, Pattanayak et al. 2005, Elbakidze and McCarl 2007, Feng et al. 2007). These environmental benefits and costs arise from the effects of land use change on soil fertility, water quality, in-stream flow, wildlife habitat, biodiversity, and so on. We did not incorporate these effects because this study is from the farmer perspective to maximize production profits and there is no market (except CRP or WRP) that currently exists to provide incentives for farmers to consider those benefits or costs. If an environmental market can be established in combination with the carbon market that rewards provision of those farm environmental credits, different estimates of the benefits and costs of CAT may be expected.

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Table 1. Example of carbon credit programs included in survey questionnaire[a]

Carbon credit program[b]	Available carbon credits	Market return rate (carbon credits earned × carbon price[f])
Conservation tillage[c]	0.4 metric ton/acre/year	$10/acre/year
Cropland conversion to grass	1.0 metric ton/acre/year	$25/acre/year
Rangeland management	0.12 metric ton/acre/year	$3/acre/year
Tree planting[d]	0.7-1.8 metric ton/acre/year[e]	$17.5-45/acre/year
Methane management	21 metric ton/metric ton methane/year	$525/metric ton methane/year

a. Carbon credit programs are adopted from the voluntary programs managed by the National Farmer Union (2009)
b. All programs require at least 5 year commitment.
c. Including planting methods commonly referred to as: no till, strip till, direct seed, zero till, slot till, and zone till.
d. Tree planting may require a contract longer than 5 years.
e. Depending on tree age and species; at least 20 acres enrollment required.
f. Assume a carbon price of $25/metric ton.

Table 2. Definition of independent variables

Independent Variable	Definition
EnrollDummy	Choice specific dummy, 1 indicating carbon program enrollment and 0 otherwise
Price	Specified market price for per metric ton of sequestered carbon
Farming	Land use dummy, 1 denoting land in crop farming and 0 otherwise
Rangeland	Land use dummy, 1 denoting rangeland management and 0 otherwise
CRP	Land use dummy, 1 denoting CRP land and 0 otherwise
NW	Farm location dummy, 1 denoting the northwest region of ND and 0 otherwise
NC	Farm location dummy, 1 denoting the north central region of ND and 0 otherwise
NE	Farm location dummy, 1 denoting the northeast region of ND and 0 otherwise
WC	Farm location dummy, 1 denoting the west central region of ND and 0 otherwise
CT	Farm location dummy, 1 denoting the central region of ND and 0 otherwise
EC	Farm location dummy, 1 denoting the east central region of ND and 0 otherwise
SW	Farm location dummy, 1 denoting the southwest region of ND and 0 otherwise
SC	Farm location dummy, 1 denoting the south central region of ND and 0 otherwise
SE	Farm location dummy, 1 denoting the southeast region of ND and 0 otherwise
Ownland	Land tenure dummy, 1 denoting owning farmland and 0 otherwise
Rentland	Land tenure dummy, 1 denoting renting farmland and 0 otherwise
Agel45	Age group dummy, 1 denoting the group of 45 years old or younger and 0 otherwise
Age4659	Age group dummy, 1 denoting the group of 46 to 59 years old and 0 otherwise
Ageg60	Age group dummy, 1 denoting the group of over 60 years old and 0 otherwise
FExpl10	Farming experience dummy, 1 denoting less than 10 years of experience and 0 otherwise
FExp11-19	Farming experience dummy, 1 denoting 11 to 19 years of experience and 0 otherwise
FExpg20	Farming experience dummy, 1 denoting more than 20 years of experience and 0 otherwise
ClimA	Farmer attitude dummy, 1 denoting being concerned about climate change and 0 otherwise
ClimAP	Farmer attitude dummy, 1 denoting supporting climate legislation and 0 otherwise

Table 3. Estimated coefficient parameters for the binary logit model of farmer choice to participate in carbon credit programs and estimated elasticities of the probability of carbon program participation with respect to farmer attributes.

Independent Variable	Estimated Coefficient	Standard Error	Choice Elasticity[a]
EnrollDummy	-4.8371***	0.9673	
Price	0.0329***	0.0087	0.5381***
Farming	0.5386	0.4278	0.2538
CRP	1.1145***	0.3741	0.5103***
Rangeland	1.2091***	0.3664	0.5562***
NW	0.2307	0.6290	0.1083
NC	-1.4858**	0.7084	-0.6367**
NE	-0.3916	0.6349	-0.1850
WC	0.8428	0.7508	0.3735
EC	0.0315	0.6893	0.0149
SW	-0.0654	0.6856	-0.0309
SC	0.7058	0.6855	0.3196
SE	-0.8671	0.6358	-0.4007
Ownland	1.5954***	0.6609	0.6779***
Rentland	-0.7575**	0.4113	-0.3513**
Agel45	1.3405***	0.5428	0.5784***
Ageg60	-0.2815	0.3784	-0.1331
FExpg20	0.9280**	0.4712	0.4306**
ClimA	0.8139**	0.3675	0.3783**
ClimAP	0.8038*	0.4879	0.3642*
Log-likelihood	-121.066		
Sample prediction	75%		

a. For dummy variables, the elasticity estimates were calculated as:

$$\varepsilon = (\mathrm{Pr}_1 - \mathrm{Pr}_0) / \mathrm{Pr}_0$$

where Pr_1 is the probability estimated with the focal variable being 1 and all other variables at their sample means; and Pr_0 is the probability estimated with the focal variable being 0 and all other variables at their sample means. For carbon price, the elasticity estimate was calculated as:

$$\varepsilon = \frac{(\mathrm{Pr}_1 - \mathrm{Pr}_0) / \mathrm{Pr}_0}{1/p_0} / 100$$

where Pr_1 is the probability estimated with the carbon price being 1 plus its sample mean and all other variables at their sample means; and Pr_0 is the probability estimated with all variables at their sample means.

Table 4. Estimated production cost function for per unit farmland for ND

Independent variable	Coefficient estimate	Standard error
Intercept	11.0934***	3.5023
Natural gas price	21.9175***	3.2773
Natural gas price square	-1.2955***	0.3323
Crude oil price	-1.3347***	0.4405
Crude oil price square	0.0191***	0.0042
Adjusted R square	0.91	

Table 5. Summary of 2007 ND agricultural census data used in policy simulation

Agricultural attributes	Number of farms	Total acreage
Farms	31,970	37,830,203[a]
Land use and management		
Harvested cropland	20,408	22,035,717
Cropland only used for pasture or grazing	4,025	812,553
Cropland failed or abandoned	2,855	530,496
Cropland in cultivated summer fallow	3,443	598,516
Permanent pasture and rangeland	14,964	10,418,885
Land in conservation	15,253	3,434,036
Land tenure		
Own land	29,099	19,977,605
Rent land	15,667	19,696,981
Principle operator age group		
Less than 45 years	6,376	NA
45 to 59 years	12,707	NA
60 years and over	12,887	NA

Data source: USDA (2010)

a. Only include the land listed by land use and management, which accounts for 95% of the total farmland in ND.

Table 6. Mapping of farmland and carbon credit programs to enroll by land use and management

Farmland type by use and management	Carbon credit program to enroll
Harvested cropland	Conservation tillage
Cropland used only for pasture or grazing	Rangeland management
Cropland failed or abandoned	Cropland conversion to grass
Cropland in cultivated summer fallow	Cropland conversion to grass
Permanent pasture or rangeland	Rangeland management
Land in Conservation	Tree planting

Table 7. Simulated acreages of farmland enrolled in carbon credit programs and amounts of carbon sequestered in ND for different carbon prices

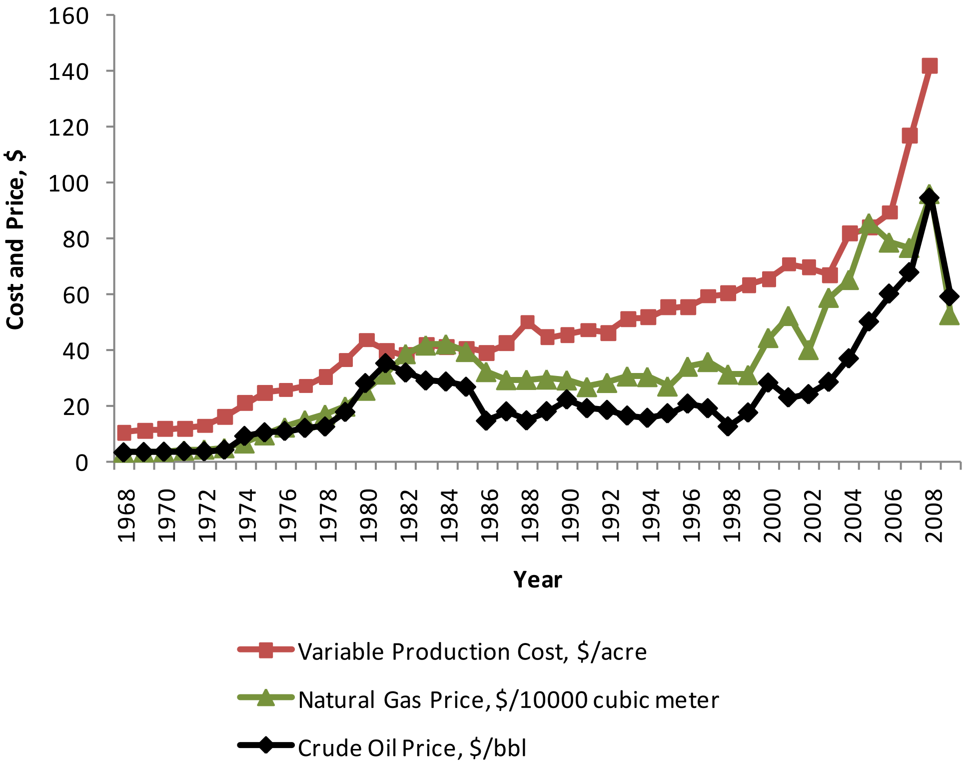
Carbon Price, $/metric ton	Conservation tillage	Cropland to grass	Rangeland manage.	Tree planting	Total acreage
		Acreages of farmland enrolled, acres (%)			
5	3,838,603 (45.16)	219,064 (2.58)	3,541,668 (41.67)	900,610 (10.60)	8,499,944 (100)
10	4,278,357 (45.65)	243,825 (2.60)	3,857,951 (41.17)	990,954 (10.57)	9,371,086 (100)
15	4,750,463 (46.15)	270,359 (2.63)	4,185,504 (40.67)	1,086,089 (10.55)	10,292,416 (100)
20	5,254,599 (46.66)	298,642 (2.65)	4,522,346 (40.16)	1,185,650 (10.53)	11,261,237 (100)
30	6,355,359 (47.69)	360,221 (2.70)	5,214,578 (39.13)	1,396,067 (10.48)	13,326,225 (100)
50	8,871,016 (49.80)	500,112 (2.81)	6,598,593 (37.04)	1,842,960 (10.35)	17,812,681 (100)
70	11,614,935 (51.87)	651,478 (2.91)	7,843,993 (35.03)	2,279,955 (10.18)	22,390,362 (100)
		Amounts of carbon sequestered, metric ton/year (%)			
5	1,535,441 (46.45)	219,064 (6.63)	425,000 (12.86)	1,125,762 (34.06)	3,305,267 (100)
10	1,711,343 (46.80)	243,825 (6.67)	462,954 (12.66)	1,238,692 (33.87)	3,656,814 (100)
15	1,900,185 (47.15)	270,359 (6.71)	502,260 (12.46)	1,357,612 (33.68)	4,030,417 (100)
20	2,101,840 (47.50)	298,642 (6.75)	542,682 (12.26)	1,482,062 (33.49)	4,425,225 (100)
30	2,542,144 (48.21)	360,221 (6.83)	625,749 (11.87)	1,745,083 (33.09)	5,273,197 (100)
50	3,548,406 (49.67)	500,112 (7.00)	791,831 (11.08)	2,303,700 (32.25)	7,144,049 (100)
70	4,645,974 (51.12)	651,478 (7.17)	941,279 (10.36)	2,849,944 (31.36)	9,088,675 (100)

Table 8. Marginal production costs for ND for different carbon prices

Carbon price, $/metric ton	Energy price increase[a]		Production cost increase, $/acre (%)[b]	
	Natural gas	Crude oil	Fert. industry exempted	Fert. industry capped
5	1%	1%	0.54 (0.69)	1.14 (1.45)
10	3%	2%	1.09 (1.38)	2.28 (2.91)
15	4%	3%	1.63 (2.08)	3.43 (4.36)
20	5%	4%	2.18 (2.77)	4.57 (5.81)
30	8%	6%	3.26 (4.15)	6.85 (8.72)
50	14%	10%	5.44 (6.92)	11.42 (14.53)
70	19%	14%	7.62 (9.69)	15.99 (20.34)

a. Energy price increases are relative to the 2009 price levels. The estimates are based on the carbon content of energy sources as if a carbon tax was posed on energy prices without considering the market equilibrium effect of carbon pricing.

b. The percentage in parenthesis is relative to the 2009 annual average of variable production cost for per unit land in ND.



Data Source: energy prices from EIA (2010), production costs from USDA ERS (2010)

Figure 1. Historical observations of annual averages of energy prices and variable production cost for per unit land in ND.

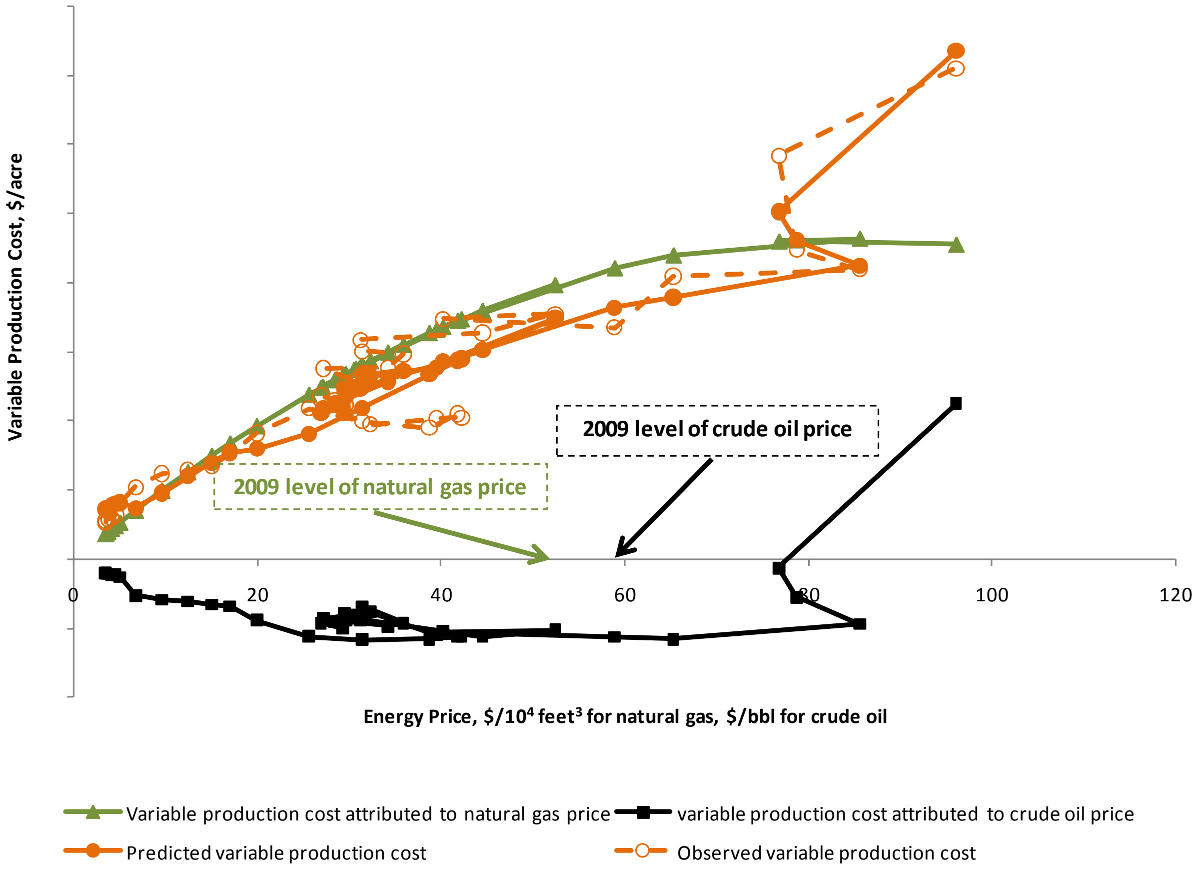


Figure 2. Relationship of ND variable production costs for per unit land with natural gas and crude oil prices

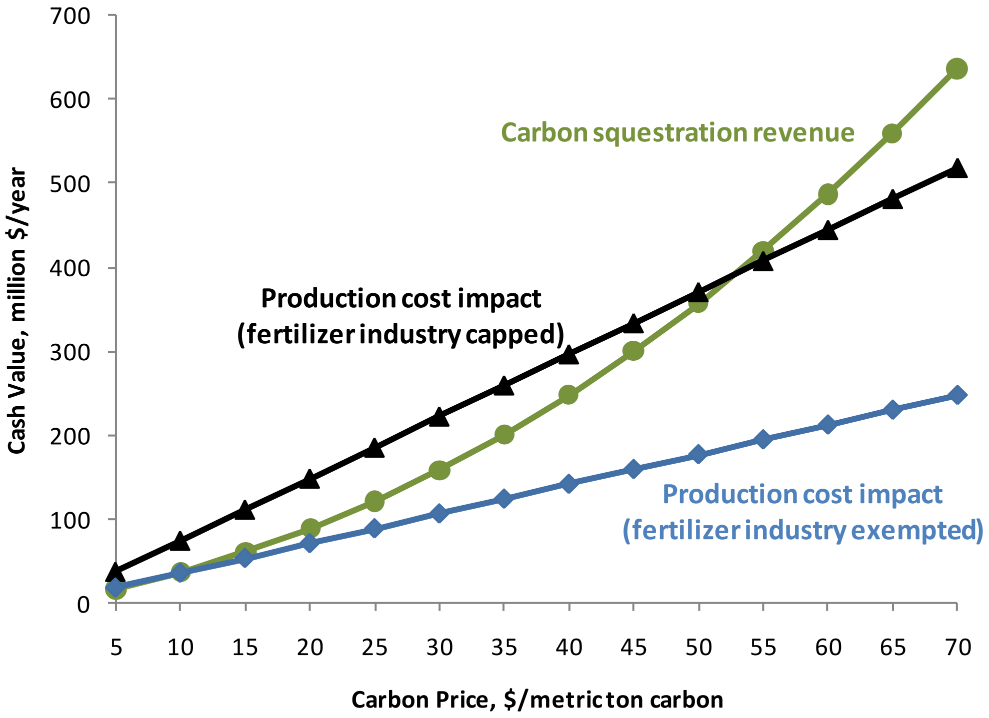
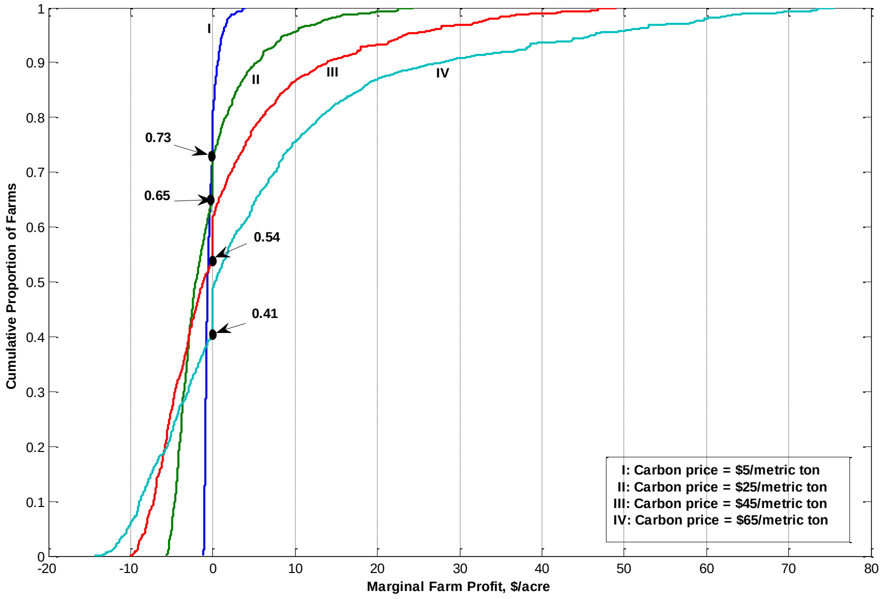
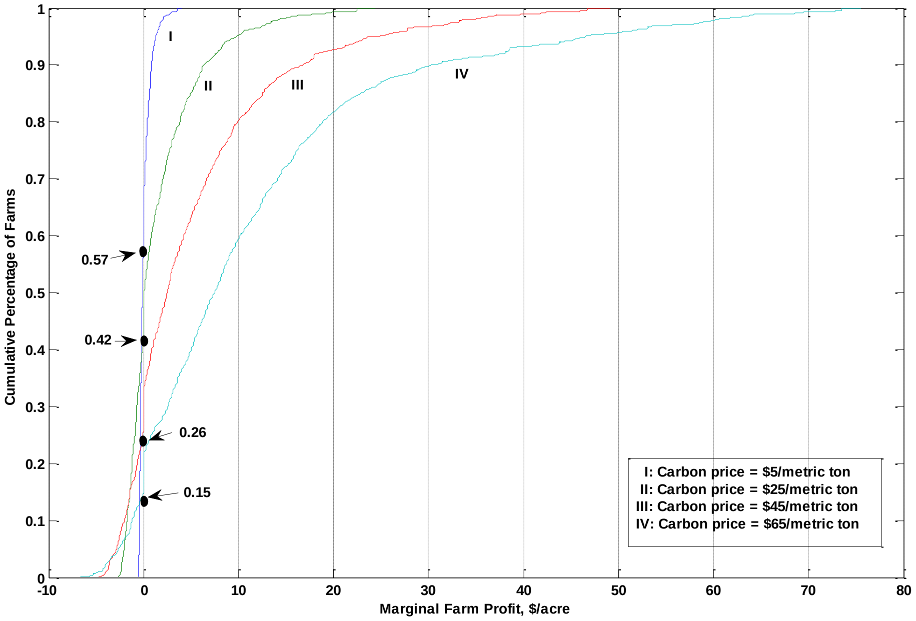


Figure 3. Aggregate revenues from carbon offset provision and marginal production costs to ND farms for different carbon prices.

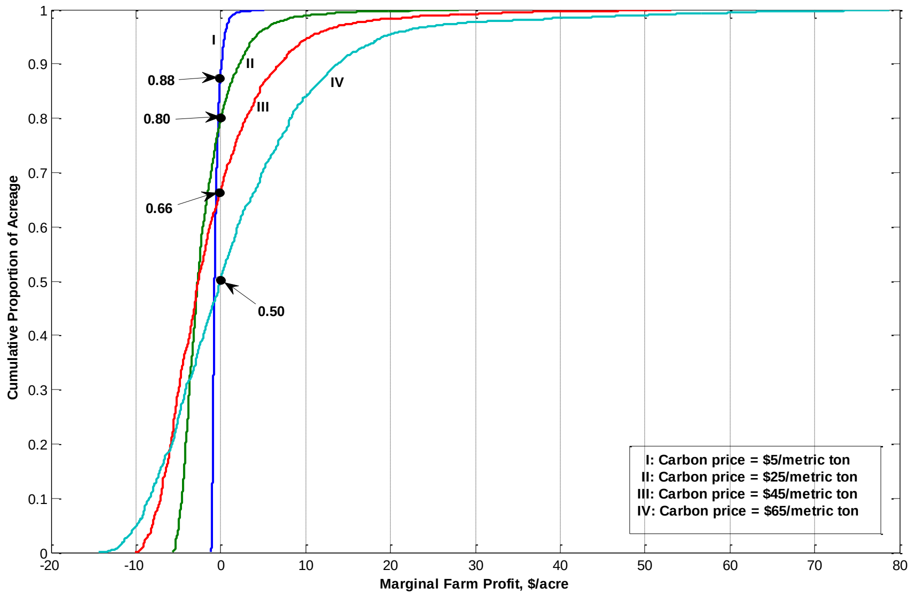


a. Fertilizer industry capped

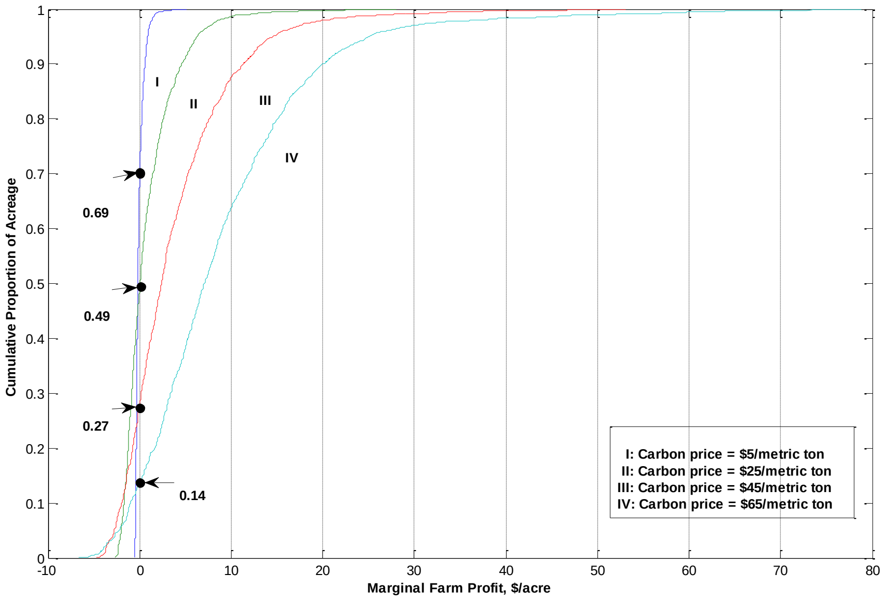


b. Fertilizer industry exempted

Figure 4. Cumulative distributions of marginal farm profits by farms for ND for different carbon prices



a. Fertilizer industry capped



b. Fertilizer industry exempted

Figure 5. Cumulative distributions of marginal farm profits by acreage for ND for different carbon prices