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Relative Efficiency of Sequestering Carbon in Agricultural Soils Through Second Best Market-Based Instruments

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1. Introduction

The Kyoto Protocol to the United Nations Framework Convention on Climatic Change, [UNFCCC, 1998], proposes to limit future aggregate anthropogenic carbon dioxide equivalent greenhouse gas emissions (Article 3.1). The Kyoto Protocol also establishes the concept of credits for carbon sinks. These credits can be used to meet a country's emission limitation and reduction commitment. Currently, carbon sinks are limited to recent efforts in afforestation, reforestation, and deforestation and do not include agricultural soils (Article 3.3). However, Article 3.4 leaves the future inclusion of agricultural soils a distinct possibility by stating "…Parties to this Protocol shall…decide upon…guidelines as to how, and which, additional human-induced activities related to…removals by sinks in agricultural soils and land use change…shall be added to or subtracted from the assigned amounts…"

Tillage practices are important human-induced activities that deal with carbon sequestration and greenhouse gas emissions from agricultural soils [Lal et al, 1998]. Conservation tillage reduces soil and water erosion when compared to conventional plow-based tillage systems. Conventional tillage systems churn up the soil and leave it unprotected, so that soil organic carbon levels decrease from wind and water erosion. Increasing the adoption of conservation tillage practices will increase carbon sequestration rates in agricultural soils and decrease greenhouse gas emissions.

The purpose of this research is to discuss the relative efficiency of various government-based and market-based instruments available to policymakers that reduce the amount of carbon emissions from agricultural soils through the increased adoption of conservation tillage. First, various government-based subsidy schemes that encourage the adoption of conservation tillage are examined. Next, various market-based policy instruments of granting producers a carbon credit [Sandor and Skees, 1999] are examined. The total expected cost of reducing agricultural carbon emissions is estimated for both the government and market-based programs. The relative efficiency of these different programs are then determined.

2. Theoretical Model

Producers will adopt either a conventional or conservation tillage system when growing their crops. Let $E\pi^{cv}$ and $E\pi^{cs}$ denote the expected returns from conventional and conservation tillage practices. Producers are assumed to be risk neutral and adopt the tillage system that maximizes expected returns. The expected returns from conventional and conservation tillage, however, are not observable. The choice between conventional and conservation tillage is observable as well as production and geographical characteristics such as soil, weather, land, and cropping patterns.

The expected returns from each tillage system is assumed to be linearly related to the vector of observable production and geographical characteristics (x),

$$E\pi^t = \beta^t x + \varepsilon^t \qquad t = \{cv, cs\}$$

Let $Y = 1$ denote the adoption of conservation tillage and $Y = 0$ denote the use of conventional tillage. The probability of a producer adopting conservation tillage is,

$$\Pr[Y = 1 \mid x] = \Pr[E\pi^{cs} > E\pi^{cv} \mid x] = \Pr[(\beta^{cs} - \beta^{cv})x + \varepsilon^{cs} - \varepsilon^{cv} > 0 \mid x] = \Pr\left[\varepsilon > -\beta x \mid x\right]$$

The error term ε is assumed to be logistically distributed. So then,

$$\Pr[Y = 1 \mid x] = G(\beta x) = \frac{e^{\beta x}}{1 + e^{\beta x}}$$

Suppose a green payment, k, is offered to further entice the adoption of conservation tillage practices. The adoption of conservation tillage will occur if the expected returns from conservation tillage plus the green payment exceed the expected returns from conventional tillage, i.e., $E\pi^{cs} + k > E\pi^{cv}$. With green payments, the probability of a producer adopting conservation tillage practices becomes,

$$\Pr[Y=1 \mid x] = \Pr[E\pi^{cs} + k > E\pi^{cv} \mid x] = G(\beta x + k) = \frac{e^{\beta x + k}}{1 + e^{\beta x + k}}$$

The choice of a tillage system affects the environment in many different ways, but only carbon supply curves will be derived in this section. Suppose, there are M states, each state has r_m production regions, and each region grows N crops. Let x_{imn} denote the production and geographical characteristics at the ith production site in the mth state growing the nth crop. The carbon emissions from conventional and conservation tillage are denoted as $Y0(x_{imn})$ and $Y1(x_{imn})$. The expected amount of carbon emitted into the atmosphere is equal to the amount of carbon released when using conservation tillage multiplied by the probability of using conservation tillage plus the amount of carbon released when using conventional tillage multiplied by the probability of using conventional tillage. With green payments, the expected amount of carbon emitted into the atmosphere on a per acre basis is, $LOSS(k_{imn}|x_{imn})$, and equal to,

$$LOSS(k_{imn}|x_{imn}) = Y0(x_{imn}) + G(\beta x_{imn} + k_{imn})(Y1(x_{imn}) - Y0(x_{imn}))$$

The total expected amount of carbon sequestered, $Q_{imn}(k_{imn}|x_{imn})$, is defined as the difference between the amount of carbon released if conventional tillage is used with certainty minus the expected amount of carbon emitted under the green payment,

$$Q_{imn}(k_{imn}|x_{imn}) = [Y0(x_{imn}) - LOSS(0|x_{imn})]NA_{imn} + [LOSS(0|x_{imn}) - LOSS(k_{imn}|x_{imn})]NA_{imn}.$$

Various government-based subsidy programs that encourage the adoption of conservation tillage could be under the auspices of the Environmental Quality Incentives Program (EQIP). EQIP offers assistance where significant natural resource problems, such as soil erosion, exist. A by-product of reducing soil erosion is increased carbon sequestration in agricultural soils. Under an EQIP subsidy program, a green payment in the form of a per acre subsidy is offered to producers in order to encourage the adoption of conservation tillage. Once a green payment is presented, producers can either accept or refuse the offer. Producers adopting conservation tillage practices receive their subsidy and producers using conventional tillage practices receive nothing.

An EQIP subsidy scheme could take many different forms. A single EQIP subsidy program is defined as when all producers are offered the same subsidy. A minimum cost EQIP subsidy program is defined as the subsidy scheme that minimizes the expected cost of sequestering an expected level of carbon. This paper examines the relative efficiency of a single subsidy EQIP program by comparing it the minimum expected cost EQIP subsidy program.

Market-based solutions are also investigated in the form of a carbon credit program. In a carbon credit program, producers receive a carbon credit from the government that is redeemable in an organized carbon market outside of the agricultural sector. Given the market price of carbon, producers can either sell their carbon credit and use conservation tillage practices or keep their carbon credit and use conventional tillage practices. Carbon credit programs are differentiated by the amount of carbon credit given to each producer. It will be shown that by varying the distribution of carbon credits, a market-based carbon credit program can become equivalent to any type of government-based EQIP subsidy program.

An EQIP subsidy program is a collection of subsidies, denoted by $k = (k_{imn})$, where k_{imn} is the per acre subsidy offered to the producer in the i[th] region of the m[th] state growing the n[th] crop. The expected number of acres using conservation tillage practices under an EQIP subsidy program is denoted as $NA(k)$ and equal to,

$$NA(k) = \sum_{m=1}^{M}\sum_{i=1}^{r_m}\sum_{n=1}^{N}\left[G(\beta x_{imn} + k_{imn})\, NA_{imn}\right]$$

The total expected level of carbon sequestration, $Q(k)$, is equal to,

$$Q(k) = \sum_{m=1}^{M}\sum_{i=1}^{r_m}\sum_{n=1}^{N} Q_{imn}(x_{imn}, k_{imn}).$$

The total expected cost of an EQIP subsidy program, $TC(Q(k))$, is equal to,

$$TC(Q(k)) = \sum_{m=1}^{M}\sum_{i=1}^{r_m}\sum_{n=1}^{N} k_{imn}\left[G(\beta x_{imn} + k_{imn})\, NA_{imn}\right]$$

Many EQIP subsidy schemes will produce the same expected overall level of carbon sequestration but at different expected costs. The subsidy scheme that minimizes the total expected cost of acquiring a given level of expected carbon, $\overline{Q}$, is found by,

$$\underset{k_{imn}}{Min}\ \mathrm{L} = \sum_{m=1}^{M}\sum_{i=1}^{r_m}\sum_{n=1}^{N}\left[k_{imn} G(\beta x_{imn} + k_{imn})\, NA_{imn}\right] + \lambda\left[\overline{Q} - \sum_{m=1}^{M}\sum_{i=1}^{r_m}\sum_{n=1}^{N} Q_{imn}(x_{imn}, k_{imn})\right]$$

The first order condition states that at the minimum, the expected marginal cost of acquiring carbon is equal across all producers,

$$\lambda^* = \frac{\partial TC_{imn}}{\partial Q_{imn}} = \frac{\partial TC_{imn}/\partial k_{imn}}{\partial Q_{imn}/\partial k_{imn}} = \left(\frac{k^*_{imn} + 1 + e^{\beta x_{imn} + k^*_{imn}}}{Y0(x_{imn}) - Y1(x_{imn})}\right) \quad for\ all\ \ (i,m,n)$$

The Lagrange multiplier, λ^*, represents the optimal expected marginal cost of acquiring carbon, TC_{imn} is the total expected cost of acquiring carbon from the ith producer in the mth state growing the nth crop, and k^*_{imn} represents its optimal subsidy. If the expected marginal costs of acquiring carbon from a source exceeds the expected marginal costs from another source, then total expected costs of carbon sequestration can be lowered by altering the subsidy scheme. The first order condition is re-written as,

$$\lambda^* = \left[\frac{k^*_{imn}}{Y0(x_{imn}) - Y1(x_{imn})}\right]\left[1 + \frac{1}{\omega_{imn}}\right] \quad \text{for all } (i, m, n)$$

where;

$$\omega_{imn} = \left[\frac{\partial G(\cdot)}{\partial k_{imn}}\right]\left[\frac{k_{imn}}{G(\cdot)}\right] \quad = \quad \text{elasticity of adoption.}$$

The elasticity of adoption (ω_{imn}) represents a producer's willingness to adopt conservation practices. The greater the elasticity of adoption, the greater the response in the conservation tillage adoption rate given a marginal increase in the subsidy. The acre difference in the amount of carbon emissions between conventional and conservation tillage $(Y0(x_{imn}) - Y1(x_{imn}))$ represents the producer's ability to sequester carbon. Under the cost minimizing EQIP subsidy program, producers with a greater willingness to adopt conservation tillage and ability to sequester carbon will receive the greater subsidies.

The second order condition for a minimum is not met, since the adoption function may be either concave or convex. A grid search was conducted to find the λ^* that minimized the total expected costs of sequestering an expected level of carbon.

Offering a different subsidy to each producer, will create very high administrative costs and may also be politically infeasible. To reduce these barriers, a single subsidy

EQIP program is examined, so that $k_{imn} = \bar{k}$ for all (i,m,n). A single subsidy EQIP program, however, will have higher carbon acqusition costs.

Figure 1 presents for the two-producer case the relative inefficiency of the single EQIP subsidy program. The iso-carbon curves, Q, represent the combination of subsidies (k_1, k_2) that leave the overall expected level of carbon sequestration unchanged. The iso-cost curves, TC, represent the combination of subsidies that leave the overall expected cost of carbon sequestration unchanged. The slopes of the iso-carbon and iso-cost curves are shown to be convex and concave, but this may not necessarily be the case. As stated previously, the adoption function may either be concave or convex.

The 45^{o} ray $\vec{S}$ represents the solution set for the single EQIP subsidy program. At point B, the single EQIP subsidy program is expected to sequester Q_0 amount of carbon at an expected cost of TC_1. Points A and C represent the minimum cost EQIP subsidy schemes that are expected to sequester Q_0 and Q_1 amounts of carbon, respectively. The relative inefficiency of the single EQIP subsidy scheme can be expressed as the increase in total expected costs, TC_1-TC_0, for the given level of carbon sequestration Q_0 as well as in terms of the decreased level of carbon sequestration Q_1 - Q_0 for a given level of expected cost TC_1.

A carbon credit program is denoted by the distribution of carbon credits to producers, $z = (z_{imn})$, where z_{imn} is the per acre carbon credit given to the producer in the ith region of the mth state growing the nth crop. The agricultural sector is assumed to be a price-taker in an external carbon market and producers are able to sell their carbon credit at an exogenous carbon price p. Hence, the per acre incentive to adopt conservation tillage under the carbon credit program is equal to pz_{imn}.

Therefore, every possible EQIP government subsidy program has an equivalent market-based solution. For example, the carbon credit program that mimics the minimum cost EQIP subsidy program is denoted as $z^* = \left(z^*_{imn}\right)$ where $z^*_{imn} = k^*_{imn}/p$ and k^*_{imn} is the minimum cost EQIP subsidy offered to the producer in the ith region of the mth state growing the nth crop. Similarly, the carbon credit program that mimics the single EQIP subsidy program, $\bar{k} = k_{imn}$ for all (i,m,n), is denoted as $\bar{z} = z_{imn}$ for all (i,m,n), where $\bar{z} = \bar{k}/p$ is the carbon credit given to all producers.

3. Empirical Analysis

The study region consists of a twelve state area in the Midwest. There are five crops and fourteen rotations in the analysis [Babcock et al, 1997]. The primary data source is the USDA National Resource Conservation Service's National Resource Inventory (NRI) conducted at 160,000 points in the study area. For each NRI point, information is collected on the natural resource characteristics of the land, the farming practices used by the producer, and weather characteristics.

The empirical analysis relies heavily on two models previously developed and used in the Center for Agricultural and Rural Development's (CARD) publication Resource and Agricultural Policy System's (RAPS) 1997 Agricultural and Environmental Outlook [Babcock et al, 1997]. First, the Site-Specific Pollution Production modeling system which estimates the difference in carbons emissions from conventional and conservation tillage [Mitchell et al. (1997)]. Second, is the Acreage Response Modeling System (ARMS) which projects crop choices and crop rotation given the climatic conditions and market conditions. Given the predictions of crop choices and crop rotations, we then use variables such as land, soil, and weather charateristics as well as cropping history to estimate the probability of adopting conservation tillage practices.

The percentage of acreage adopting conservation tillage practices has changed significantly from 1992 to 1997. The conservation tillage adoption model is estimated using 1992 data, so a calibrating factor, α, is introduced to accurately reflect the current tillage environment from the 1992 base year. The model estimates are adjusted by selecting an α such that the proportion of land using conservation tillage practices in the current year equals the expected proportion of land predicted by the adoption model.

Furthermore, the error term is assumed to be logistically distributed with a fixed variance of $\pi^2/3$ when estimating the conservation tillage adoption model. This variance determines the size of payment needed to increase the probability of adoption to a certain level. In 1997, 39.8% of the total study area acreage was in conservation tillage. This implies an "overall study area average" βx value of -0.4138. The payment, k, needed to ensure a 95% percent adoption rate is then \$3.36 per acre. This payment is the same whether the choice is between tillage systems, investment choices, or business decisions.

For the logit model to be meaningful in each separate application, an additional "identifying" restriction is needed to reflect the resistance of adopting conservation tillage. The payments necessary to entice 95% of current non-adopters of other environmentally beneficial management practices have been estimated in the range of \$65 to \$75 per acre [Cooper and Keim, 1996]. The current adoption rates for these practices are, however, much lower than for conservation tillage. Hence it is assumed that a 95% adoption rate occurs with a \$20 per acre subsidy. As a result, the subsidies are multiplied by the factor 5.96, which is found by dividing the assumed $20 payment by the payment found with the unidentified logit model ($3.36).

4. Results

The study area sequestered approximately 11.45 million metric tons (mmt) of carbon from the current use of conservation tillage. The overall rate of conservation tillage adoption is currently 39.8%. If all producers adopted conservation tillage, an additional 14 million metric tons of carbon would be sequestered or 25.87 mmt of carbon.

Figure 2 compares the total expected costs of acquiring carbon from the single subsidy and minimum cost EQIP programs. The expected total cost curves are convex and become vertical near the capacity of 25.87 mmt of carbon. The expected cost under the single subsidy EQIP program is $172 million and $3.4 billion when sequestering 13.18 mmt and 23.90 mmt of expected carbon respectively. However, the expected cost under the minimum cost EQIP subsidy program is $53 million and $2.6 billion. Hence, the inefficiency of the single subsidy EQIP program relative to the minimum cost EQIP subsidy program is $119 million when sequestering 13.18 mmt of expected carbon and $800 million when sequestering 23.90 mmt of expected carbon.

5. Conclusions

The purpose of this research was to examine various policy instruments that promote carbon sequestration in agricultural soils and mitigate greenhouse gas emissions through increased adoption of conservation tillage. It was shown that that by varying the distribution of carbon credits given to producers, a market-based carbon credit program can become equivalent to any type of government-based EQIP subsidy program. Hence, the payments needed to increase the agricultural sector's adoption of conservation tillage can be switched from the public sector to the private sector.

The expected cost of carbon sequestration was estimated for the single subsidy and minimum cost EQIP programs. Identical expected costs of carbon sequestration would occur under a carbon credit program as under the EQIP subsidy program given the appropriate distribution of carbon credits. A different subsidy or size of carbon credit, however, may be prohibitively costly due to high administrative and political costs. A single subsidy or size of carbon credit program will lower these costs, but will lead to higher acquisition costs. The relative inefficiency of the single subsidy or carbon credit program was measured in terms of the increase in expected costs when sequestering an expected level of carbon. The inefficiency was estimated to be $119 million when sequestering 13.18 mmt of expected carbon and $800 million when sequestering 23.90 mmt of expected carbon. If the political and administrative costs are higher than these levels, then a single subsidy or carbon credit is more economically feasible.

Other intermediate program should also be investigated such as different subsidies or carbon credits based upon the producer's location and/or crop grown. These intermediate programs will have lower expected operational costs than the single subsidy or carbon credit programs as well as lower administrative and political costs than the minimum cost programs. Hence, overall expected costs of carbon sequestration may be lower with these other programs

Figure 1. Relative Inefficiency of the Single Subsidy EQIP Program.

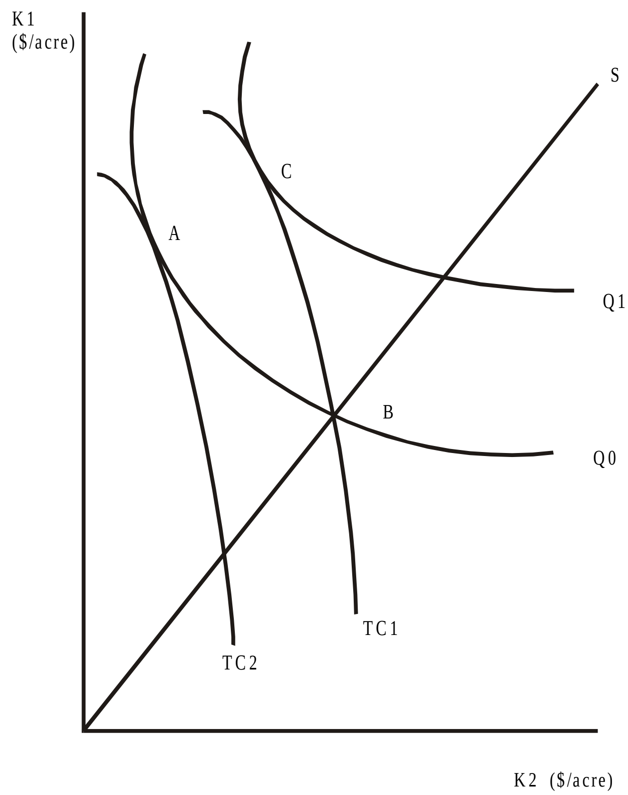
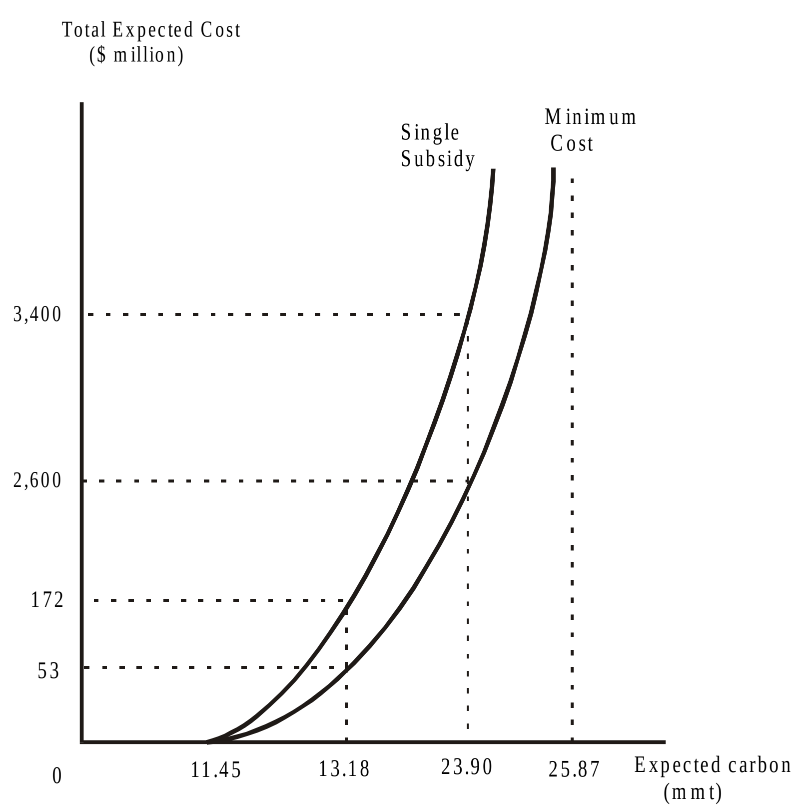


Figure 2. Total Expected Cost of Carbon Sequestration.



6. References

Babcock, B., T. Campbell, P. Gassman, T. Hurley, P. Mitchell, T. Otake, M. Siemers, and J. Wu. 1997. *Resource and Agricultural Policy Systems 1997: Agricultural and Environmental Outlook*. CARD, Ames, IA.

Climate Change Sectretariat (UNFCCC). 1998. Kyoto Protocol to the United Nations Framework Convention on Climate Change. http://www.cop3.de/.

Conservation Tillage Information Center (CTIC). 1993. *National Residue Management Survey*. National Association of Conservation Districts, West Layfayette, IN.

Lal, R., J.M. Kimble, R.F. Follet, and C.V. Cole. 1998. *The Potential of U.S. Cropland to Sequester Carbon and Mitigate the Greenhouse Effect*. Ann Arbor, MI: Sleeping Bear Press.

Mitchell, P.D., P.G. Lakshminarayan, T. Otake, and B.A. Babcock. 1998. "The Impact of Soil Conservation Policies on carbon Sequestration in Agricultural Soils of the Central United States", in eds Lal, Rattan, John M. Kimble, Ronald F. Follett, Bobby A. Stewart. *Management of Carbon Sequestration in Soil*. CRC Press, Boca Raton, FL., pp. 125-142.

Mullins, J.A., R.F. Carsel, J.E. Scarbough, A.M. Ivery. 1993. *PRZM-2, A Model for Predicting Pesticide Fate in the Crop Root and Unsaturated Soil Zones.* U.S. EPA Technical Report EPA/600/R-93/046. Athens, GA:USEPA.

Sandor, R.L. and J.R. Skees. 1999. "Creating a Market for Carbon Emissions", *Choices*, First Quarter: 13-17.

Sharpley, A.N. and J.R. Williams, ed. 1990. EPIC-Erosion Productivity Impact Calculator: Model Documentation. U.S. Department of Agriculture Technical Bulletin No. 1768. Washington D.C.: USDA.

United Nations. *Framework Convention on Climate Change*. 1992. United Nations Environment Programme Information Unit for Conventions. http://www.unep.ch/.

United States Department of Agriculture, Economic Research Service. 1994. *The 1992 Annual Cropping Practices Survey*. Unofficial data files. USDA/ERS, Washington D.C.

United States Department of Agriculture, Soil Conservation Service. 1994. *The 1992 National Resources Inventory Database*. USDA/SCS, Washington D.C.

Williams, J.R., C.A. Jones, and P.T. Dyke. 1988. *EPIC, The Erosion Productivity Index Calculator: Model Documentation*, Vol. 1. USDA/ARS, Temple, TX.