SUPPLY AND DEMAND FOR ECOSYSTEM SERVICES FROM CROPLAND IN MICHIGAN

By

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ABSTRACT

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Payment-for-Environmental-Services (PES) programs that translate external ecosystem values into direct financial incentives for local providers are gaining appeal globally as flexible approaches to inducing the voluntary provision of ecosystem services (ES). Working land PES programs that promote conservation in the agricultural production process have great potential to address the challenge of feeding growing global population while maintaining environmental sustainability. The importance of working land PES programs calls for efficient and effective design of public policies that facilitate the voluntary provision of ES. However, the design of current PES programs is rarely based upon a comprehensive understanding of the underlying supply and demand for ecosystem services. This dissertation thus aims to provide empirical insights for PES design by combining a supply-side cost function of farmers' willingness to adopt practices that provide enhanced ES with a demand-side social benefit function of residents' willingness to pay (WTP) for these ES.

This dissertation is comprised of three essays. Essay 1 investigates the farmer supply of ecosystem services via four hypothetical PES programs using a stated preference survey of 3000 Michigan corn and soybean farmers. This essay complements existing literature by dividing the decision on whether to enroll in PES programs into two stages: whether even to consider enrolling in the program and, if yes, whether to participate. Analyzed using a double-hurdle econometric model, results suggest the first-stage willingness to consider decision chiefly

depends on farm and farmer characteristics, while the second-stage decisions on whether and how much land to enroll in the program depend more on payment offer and benefit-cost criteria.

Essay 2 examines public demand for environmental improvements measured by willingness to pay (WTP) for reductions in the number of eutrophic lakes and greenhouse gas (GHG) emissions using a stated preference survey of 6000 Michigan residents. This essay evaluates alternative methods of modeling WTP that incorporate respondent preference uncertainty. Using two different functional forms, it tests the sensitivity of WTP estimates to different functions. Results suggest that the conventional dichotomous choice model without uncertainty provides a reliable median WTP estimate that reflects the influence of key variables, although incorporation of self-reported uncertainty may to improve our understanding of the ES demand and the estimation efficiency of WTP.

Essay 3 combines the farmer cost for providing ecosystem services with the public benefit from environmental improvements derived in first two essays in simulations to explore the empirical welfare-maximizing conditions for effective PES design. This essay uses non-parametric aggregation of benefit and cost, as well as biophysical linkages between farming practices and ES outcomes. Results show that the simplest cropping system with the least ES improvement is dominated by the other three systems, which offer similar economic welfare gains with varying trade-offs in cost and environmental performance. The choice of system largely depends on the goal of the PES program and evolving demand for specific ES by consumers. Allowing farms to choose different cropping systems that lower their individual costs or targeting farms that provide additional environmental services beyond their current practices would improve the cost-effectiveness of PES programs.

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LIST OF ABBREVIATIONS

ARMS	Agricultural Resource Management Survey
ASUM	Asymmetric Uncertainty Model
CDL	Cropland Data Layer
CRP	Conservation Reserve Program
CSP	Conservation Stewardship Program
CV	Contingent Valuation
CWTP	Conditional Willingness to Pay
EQIP	Environmental Quality Incentives Program
ES	Ecosystem Services
FSGGEC	Farming Systems Greenhouse Gas Emissions Calculator
GEE	Generalized Estimating Equations
GHG	Greenhouse Gas
GW	Global Warming
KBS	Kellogg Biological Station
LR	Likelihood ratio
LTER	Long Term Ecological Research
MLE	Maximum Likelihood Estimation
MWTA	Marginal Willingness to Accept
MWTP	Marginal Willingness to Pay
NASS	National Agricultural Statistics Service
NCS	Numerical Certainty Scale

NRCS	Natural Resource Conservation Service
PC	Polychotomous Choice
PES	Payment for Environmental Services
PSNT	Pre-Sidedress Nitrate Test
RUSLE	Revised Universal Soil Loss Equation
SOCRATES	Soil Organic Carbon Reserves and Transformations in EcoSystems
SPC	Stochastic Payment Card
STATSGO	United States General Soil Map (original title: State Soil Geographic)
SUM	Symmetric Uncertainty Model
TP	Total Phosphorus
USDA	United States Department of Agriculture
WTA	Willingness to Accept
WTO	World Trade Organization
WTP	Willingness to Pay

INTRODUCTION

Agriculture is an ecosystem transformed by humans for establishing production of crops and livestock. In addition to supplying market farm products, such as food, fiber and fuel, agriculture can also jointly provide nonmarket benefits to people by farmers' choice of production inputs and management practices (Wossink and Swinton, 2007). These benefits people obtained from ecosystems are defined as Ecosystem services (ES) (Millennium Ecosystem Assessment, 2003). Examples of nonmarket ecosystem services from agriculture include soil erosion control from conservation tillage, water quality improvement from reduced fertilizer input, and greenhouse gas (GHG) mitigation from adoption of winter cover crops. However, farmers typically gain little private reward from those nonmarket services, as many of them accrue to people beyond the farm gate. In the absence of policy incentives, the supply of nonmarket ecosystem services is mostly determined by the price incentives to supply market products (Antle and Valdivia, 2006). Payment-for-Environmental-Services (PES) programs that translate external ecosystem values into direct financial incentives for local providers are gaining appeal globally as flexible approaches to inducing the voluntary provision of ES (Engel, et al., 2008). In the United States and Europe, the PES programs are also viewed as a trade-neutral alternative to direct commodity subsidies to support farmer income under the World Trade Organization (WTO) rules (Swinton, et al., 2006).

The worldwide population boost and environmental degradation have posed enormous challenges to agriculture to support the sustainability for both livelihood and the environment. Working land PES programs that promote conservation activities during the agricultural production process have a great potential to address these challenges. The importance of working land PES programs calls for public policies that facilitate the voluntary provision of ecosystem services in an efficient and effective fashion. The design of PES programs should be based upon a comprehensive understanding of the underlying supply and demand for ecosystem services, which is rarely addressed in previous studies. To provide empirical insights for designing efficient and effective PES program, this dissertation thus combines farmers' willingness to adopt improved environmental stewardship in exchange for payments on the *supply side,* with the public's willingness to pay for resulting ecosystem services on the *demand side*. Specifically, this study focuses on the ecosystem services from changing cropland management practices in Michigan.

Essay 1 investigates the farmer supply of ecosystem services via four hypothetical PES programs using a stated preference survey of 3000 Michigan corn and soybean farmers. This essay is built on an earlier study by Jolejole (2009), but complements existing literature by dividing the decision on whether to enroll in PES programs into two stages: whether even to consider enrolling in the program given incentive payments that presumably are politically feasible, if yes, whether to participate. The decision process is analyzed using a double hurdle model. Results suggest the first-stage willingness to consider decision chiefly depends on farm and farmer characteristics, while the second-stage decisions on whether and how much to enroll depend more on payment offer and benefit-cost criteria. The results also show that the price elasticity of enrollment decreases with the number of cropping practices required. These two-stage decisions are integrated to predict the state-level ES-providing land enrollment in response to PES payment.

Essay 2 examines public demand for environmental improvements measured by willingness to pay (WTP) for reductions in the number of eutrophic lakes and greenhouse gas

(GHG) emissions using a stated preference survey of 6000 Michigan residents. This essay is built on an earlier study by Chen (2010), but particularly evaluates alternative methods of modeling WTP that incorporate respondent uncertainty. The hypothetical markets for contingent valuation and respondents' unfamiliarity with certain ecosystem services may enhance their preference uncertainty, which may increase variance and even cause bias in WTP estimates. Two functional forms, semi-log and mixed log-log, are adopted to test the sensitivity of conditional WTP estimates to different functions. Results suggest that the incorporation of self-reported uncertainty into binary choice models appears to improve our understanding of the demand for ecosystem services and provide more efficient estimates of WTP. Both functional forms lead to a common finding that is consistent with the analytical expectations: the symmetrically calibrated certainty-adjusted models yield indifferent WTP estimates compared to the conventional model, whereas the asymmetrically calibrated certainty-adjusted models lead to significantly lower WTP. The unbiased conventional dichotomous choice model still provides a reliable median WTP estimate that reflects the influence of key variables.

Essay 3 combines the farmer cost for providing ecosystem services with the public benefit from environmental improvements derived in first two essays to explore the welfare-maximizing conditions for PES design. This essay especially contributes to the literature by proposing agricultural PES policies based on the underlying supply-demand mechanism embedded in empirical stated preference estimates. Individual values are aggregated for the State of Michigan by linking ecological processes to benefit and cost functions. Results reveal the economic optimal levels of PES payment, land enrollment and environmental outcomes for five hypothetical PES programs, and how these outcome change under different policy scenarios. Comparing across programs, results suggest that the simplest cropping system with the least ES improvement dominated by other three systems, which offer similar economic welfare gains with varying trade-offs in cost and environmental performance. The choice of system largely depends on the goal of PES program and evolving demand for specific ES by consumers. Allowing farms to choose different cropping systems that lower their individual costs or targeting at farms that provide additional environmental services beyond their current scenario would improve the cost-effectiveness of PES programs.

REFERENCES

REFERENCES

Antle, J., and R. Valdivia. 2006. "Modelling the supply of ecosystem services from agriculture: A minimum-data approach." *Australian Journal of Agricultural and Resource Economics* 50(1):1-15.

Chen, H. 2010. "Ecosystem services from low input cropping systems and public's willingness to pay for them." M.S. Thesis, Michigan State University, Department of Agricultural, Food and Resource Economics. http://www.aec.msu.edu/theses/fulltext/chen_ms.pdf

Engel, S., S. Pagiola, and S. Wunder. 2008. "Designing payments for environmental services in theory and practice: An overview of the issues." *Ecological Economics* 65(4):663-674.

Jolejole, M.C.B. 2009. "Trade-offs, incentives and the supply of ecosystem services from cropland." M.S. Thesis, Michigan State University, Department of Agricultural, Food and Resource Economics. http://aec3.aec.msu.edu/theses/fulltext/jolejole1_ms.pdf

Millennium Ecosystem Assessment. 2003. *Ecosystems and human well-being: A framework for assessment*. Washington, DC: Island Press.

Swinton, S.M., F. Lupi, G.P. Robertson, and D.A. Landis. 2006. "Ecosystem services from agriculture: Looking beyond the usual suspects." *American Journal of Agricultural Economics* 88(5):1160-1166.

Wossink, A., and S. Swinton. 2007. "Jointness in production and farmers' willingness to supply non-marketed ecosystem services." *Ecological Economics* 64(2):297-304.

ESSAY 1: FARMERS' WILLINGNESS TO PARTICIPATE IN PAYMENT-FOR-ENVIRONMENTAL SERVICES PROGRAMS

1.1 Introduction

Agriculture is an ecosystem transformed by humans for establishing agricultural production. It supplies market goods, such as food, fiber and fuel. In addition, agriculture also provides non-market environmental services (ES) that depend on farmers' choices of production inputs and management practices (Wossink and Swinton, 2007). However, because only a small portion of the benefits from non-market ES accrue to farmers, they have little incentive to produce these services.

Various agri-environmental policies have been implemented to motivate the supply of environmental services. One prominent example is payment-for-environmental-services (PES)[1], which attracts increasing attention globally as a policy innovation that translates external ecosystem values into real financial incentives for local providers (Engel, et al., 2008). In the United States, land retirement programs, such as the Conservation Reserve Program (CRP) have played an important role in providing environmental services since 1985. Recently, as exemplified by the Environmental Quality Incentives Program (EQIP) initiated in 1996 and the Conservation Security Program (CSP) initiated in 2002[2], the policy focus has shifted to conservation on working lands—land used primarily for crop production and grazing (Cattaneo,

[1] An earlier version of this essay was submitted for publication as S. Ma , S.M. Swinton, F. Lupi, and M.C. Jolejole-Foreman, "Farmers' Willingness to Participate in Payment-for-Environmental Services Programs" (July 2011). PES is formally defined as a voluntary transaction where a well-defined environmental service or a land use likely to secure that service is being 'bought' by a service buyer from a service provider if and only if the service provider secures service provision. (Wunder, 2005)

[2] The EQIP and CSP programs are classified as PES programs by Wunder, et al. (2008).

et al., 2005). The 850 million acres of working lands, which is equivalent to 45% of land area of the 48 contiguous U.S. states, have a great potential to cost-effectively provide environmental services, such as reduced nutrient runoff, from changes in production practices. Government spending in the four largest working land programs is projected to grow to $11.7 billion during 2008-2012, an 85% increase over the period 2002-2009[3]. Most of this spending is allocated to the EQIP and CSP[4]. The focus of these programs has evolved from restricting local negative externalities, such as soil erosion and nitrate run-off, to providing public goods, such as greenhouse gas mitigation and biodiversity. Similar PES programs that pay land owners for effective agricultural land management are also launched in other developed countries. Examples include the Environmental Stewardship Scheme (ESS) for environment and wildlife protection in the United Kingdom, the user-financed Vittel (Nestlé Waters) watershed protection program in Eastern France, the Northeim Model Project for agrobiodiversity in Germany, and the Wimmera Catchment pilot program for salinity control in Australia.

An essential precondition for the success of an agricultural PES program is that farmers be willing to participate. If they are, then the next question becomes how much they will participate. Both decisions involve weighing the potential benefits and costs in PES programs. This study thus aims to investigate the determinants of farmers' willingness to participate and the degree of participation in hypothetical PES programs.

Prior to the majority of research on PES programs, many economic studies examined farmers' choices about adoption of conservation practices without incentive payments. Some of

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[3] Source: Briefing Rooms for Conservation Policy, Economic Research Service, United States Department of Agriculture (USDA). http://www.ers.usda.gov/Briefing/ConservationPolicy/background.htm

[4] The Conservation Security Program was replaced by Conservation Stewardship Program (CSP) in the 2008 Farm Act.

these adoption studies focused on single practices, such as conservation tillage (Davey and Furtan, 2008, Epplin and Tice, 1986, Rahm and Huffman, 1984, Sheikh, et al., 2003), reduced fertilizer and pesticide use (Bosch, et al., 1995, Lasley, et al., 1990), and cover crops (Neill and Lee, 2001). Other studies focused on adoption combinations of multiple practices (Ervin and Ervin, 1982, Lynne, et al., 1988, Negatu and Parikh, 1999, Nowak, 1992, Roberts, et al., 2006, Soule, et al., 2000, Wu and Babcock, 1998). Yet other adoption studies examined the number of farm-level practices adopted (Lynne and Rola, 1988, Wei, et al., 2009), land area allocated for certain practices (Gould, et al., 1989) and expenditure on permanent conservation structures (Norris and Batie, 1987). This earlier literature provides a solid empirical foundation for PES studies by attributing farmers' adoption decisions to various natural, social and economic factors. However, apart from partial cost-sharing in several cases, these articles involve no incentive payment. Hence, decisions were chiefly based on the net benefits from adopting farming practices.

Farmer participation in early paid conservation programs was studied by Purvis et al. (1989), who examined farmers' willingness to accept payment in a hypothetical program to adopt filter strips. They found that farmer decisions were determined by the size of the payment offer, perceptions of environmental change, and farmers' opportunity costs. For observed enrollment choices, Zbinden and Lee (2005) investigated participation in a PES program in Costa Rica by farmers and forest owners. They found that farm size, household farm income, and familiarity with the program significantly influence participation. The 2001 United States Department of Agriculture (USDA) Agricultural Resource Management Survey reported that the farms most likely to participate in working land PES programs were larger, operated by younger farmers, and more reliant on income from farming (Lambert, et al., 2006). Compared with the research on unpaid adoption of farming practices, these PES studies have further investigated the influence of payment on farmer decisions.

Although the decision on whether to adopt conservation farming practices with or without incentive payment is well examined, all previous studies overlook an implicit prior decision on whether seriously to consider participating in the proposed program. This willingness-to-consider decision addresses whether a proposed program is sufficiently acceptable to merit closer evaluation of the financial assistance offered. Some farmers are very unlikely to consider providing ES through payment programs, because those programs do not pass certain prior screening criteria due to unfavorable physical settings or substantial cost for adoption. These farmers' decision is not likely to change with the increased payment levels that are perceived to be in a politically feasible range. Other farmers may be willing to consider the program, and would choose to participate given a suitable payment that is high enough to make the operation rewarding. Only a proportion of farmers who consider participating will elect to enroll, as the rest are unsatisfied with the program payment offered. Explicitly modeling this additional consideration decision may improve the understanding of farmers' participation and amount of environmental services supplied under payment schemes. Using the same stated preference survey data as Jolejole (2009), but with additional information permitting separation of the consideration and participation decisions, this essay analyzes Michigan corn and soybean farmers' decisions in four hypothetical PES programs, in order to:

1) Reveal determinants of farmers' consideration and participation decisions;

2) Derive the supply of land that provides environmental services in response to payment based on aggregate decisions;

1.2 Conceptual model

1.2.1 Utility function

Following Dupraz et al. (2003), farmers are assumed to maximize utility that is based upon consumption of market goods (*Z*) and non-market environmental services (*E*), which are co-produced by farming activities. They face a budget constraint that the cost of consumption cannot exceed the sum of profit from farm production and nonfarm income (*NFI*). Farm profit (π) is earned from selling agricultural products (*Y*) at price r_y minus variable cost ($r_x X$) and fixed cost (*FC*). Output *Y* is a function of inputs *X* and *FC*. The variable cost refers to material and hired labor associated with the level of production, while fixed cost in this study refers to predetermined resources, including family labor (*L*), capital (*K*), land area (*A*), biophysical conditions (*B*) and information (*I*) available to farmers. Environmental services (*E*), which are produced jointly with market goods (*Y*) using variable and fixed inputs, may also affect the magnitude and timing of variable input (*X*) employment in turn (Zhang, et al., 2007). *F* represents farmer traits that condition the production function and hence condition the effects of PES offers.

$$\max_{Z,E} \quad U\left(Z,E \mid F\right) \tag{1.1}$$

$$s.t. \qquad Z \leq \pi + NFI \tag{1.2}$$

$$\pi = r_y Y(X,FC) - r_x X\left(E\right) - FC\left(L,K,A,B,I\right) \tag{1.3}$$

$$E = f\left(X,FC\right) \tag{1.4}$$

The maximized utility given optimal choices of consumption level (Z*) and environmental services (E*) can be represent by the indirect utility function V.

$$V\left(\pi + NFI \mid F\right) = U\left(Z^*, E^* \mid F\right) \tag{1.5}$$

1.2.2 Willingness to accept

Enrollment in a PES program could change farmers' maximized utility by requiring a higher level of environmental services or by receipt of a payment. Farmers' willingness to participate in a PES program depends on the magnitudes of the change in utility. This change can be measured monetarily by *willingness to accept (WTA)* payment, which is the minimum amount of payments that the farm household would require to provide specified environmental services in the program (Jolejole, 2009). The farmer is assumed to increase the environmental service supply, E, by a fixed quantity such that: $\Delta E = E_1 - E_0 > 0$. Their total spending on production is likely to increase with adoption of new practices. The expenditure function $e(r, E, U_0)$, represents the minimum amount of income that is needed to produce a fixed quantity of environmental services ΔE while maintaining constant utility (Equation 1.6). The input and output prices are represented by r for simplicity.

$$e(r, E, U_0) = Min[Z - \pi(r, E) \mid U(Z, E) \geq U_0] \tag{1.6}$$

WTA can be represented as the change in expenditure levels of the farm household in response to change in the level of environmental services produced, given that utility is kept the same (Equation 1.7)

$$WTA = e(r, E_1, U_0) - e(r, E_0, U_0) \tag{1.7}$$

Letting $Z^*(r, E, U_0)$ denote the solution of the cost minimization problem in Equation 1.5, the expression in Equation 1.8 becomes:

$$WTA = [\pi(r, E_0) - \pi(r, E_1)] - [Z^*(r, E_0, U_0) - Z^*(r, E_1, U_0)] \tag{1.8}$$

The first term in brackets in Equation 1.6 is the farm's foregone profit. The second term is the amount that the household is willing to pay for an increase in environmental service. In other words, the WTA equals the foregone profit offset by the monetary value of change in the farmer's utility from producing more environmental services. Based on Equation 1.8, WTA can be zero or even negative if the foregone profit from farm production is completely offset or outweighed by the benefits from higher level of ES.

Combining Equations 1.5 and 1.8, the influence of the PES program payment *P* on the change of farmer's utility can be represented by Equation 1.9. Under common assumptions that farmers prefer more payment than less but have a decreasing marginal rate of substitution between payment and other goods, the change of utility is an increasing and concave function of payment.

$$\Delta U\left(P\right)=V\left(\pi_1+NFI_1+P,E_1\mid F\right)-V\left(\pi_0+NFI_0,E_0\mid F\right) \tag{1.9}$$

Farmers' WTA is a payment level that would make the utility change equal to zero:

$$\Delta U\left(WTA\right)=V\left(\pi_1+NFI_1+WTA,E_1\mid F\right)-V\left(\pi_0+NFI_0,E_0\mid F\right)=0 \tag{1.10}$$

1.2.3 Decision rule

The farmer decision on participating in PES programs involves two steps. The first step for farmers to *consider* a PES program implies that the program is acceptable and utility-increasing if a sufficiently high payment is offered. Although in theory the payment offer could be massive, in practice the "sufficiently high payment" would be filtered by what farmers believe to be politically feasible. This politically feasible payment level varies across farmers and largely depends on their previous experience with government programs. Thus, farmers would consider a PES program only if the perceived maximum politically feasible payment P^{high} is greater than their WTA (i.e., $P^{high} > WTA$), which makes the change of utility equals zero ($\Delta U\ (WTA) = 0$).

The second step, for farmers willing to consider the program, is how much land to *enroll*. Farmers are assumed to enroll in a specific program only if the real program payment P^* is greater than their WTA (i.e., $P^* > WTA$). When the utility gain is increasing and concave, farmers' decision rule can be represented as follows.

$$Decision = \begin{cases} Consider\ \Delta U\left(P^{high}\right) > \Delta U\left(WTA\right) = 0 & \begin{cases} Enroll & \Delta U\left(P^{high}\right) > \Delta U\left(P^*\right) > \Delta U\left(WTA\right) \\ Not\ enroll & \Delta U\left(P^{high}\right) > \Delta U\left(WTA\right) > \Delta U\left(P^*\right) \end{cases} \\ Not\ consider \quad \Delta U\left(P^{high}\right) \leq \Delta U\left(WTA\right) = 0 & \end{cases}$$

The levels of utility change in response to adoption of paid conservation farming practices are unique to individual decision makers under specific settings. Figure 1-1 illustrates four indicative utility gain (ΔU) curves from a given set of production practices in response to PES payment level (P). At the maximum politically feasible payment level P^{high}, representative farmers 1, 2, 3 would consider enrolling in the PES program as the payment is greater than their WTA (i.e., $\Delta U^{1,2,3}(P^{high}) > \Delta U^{1,2,3}\ (WTA) = 0$). However, fundamental incompatibility may deter some others who have unfavorable physical settings, unacceptably high adjustment cost, negative attitudes toward the proposed practices, or unsuitable management skills. Those farmers are unlikely to consider the program at any payment that is politically feasible, represented by farmer 4 in the figure ($\Delta U^4\ (P^{high}) << \Delta U^4\ (WTA) = 0$). The payment level that would motivate farmer 4 to enroll is far beyond the feasible range, so any variation in the actual payment will not have a significant effect on his/her decision. Among those who would consider enrolling, farmer 1 and 2 would elect to enroll in a PES program with specific program payment P^*, which is greater than their WTA (i.e., $\Delta U^{1,2}$ $(P^*) > \Delta U^{1,2}$ $(WTA) = 0$). Notably, farmer 1 has positive utility gain from the proposed production practices and would adopt the practices without any payment ($WTA < 0$; ΔU^{1} $(0) > 0$). Farmer 2 is only willing to adopt the practices with incentive payment P^*. In contrast, farmer 3 who face higher costs of adoption is deterred from enrolling in the program by insufficient payment, but would consider doing so with a higher but feasible payment (ΔU^{3} $(P^*) < \Delta U^{3}$ $(WTA) < \Delta U^{3}$ (P^{high})). Each farmer perceives a uniquely different change in utility for a given combination of changed production practices. Likewise, each farmer will have a different perception of the maximum feasible payment that determines whether they believe that conditions exist for a higher payment that they might be willing to accept. This study aims to expand our understanding of farmers' participation in PES in a manner that distinguishes the above four cases.

1.3 Data and questionnaire design

Data for this study come from a 2008 mail survey of Michigan corn and soybean farmers that yielded 1688 responses (56% response rate) (Jolejole, 2009). The survey used a four contact version of the tailored design method (Dillman, 2007) consisting of 1) a pre-notice letter, 2) a questionnaire and one dollar incentive, 3) a postcard reminder, and 4) a replacement questionnaire. The survey design and questionnaire development were preceded by a series of farmer focus groups and pre-tests to ensure validity and clarity of the questions as well as an appropriate range of payment offers for those cropping practices. Six farmer focus groups were conducted during February and March of 2007, while in-person questionnaire pre-tests were conducted in January of 2008. A stratified random sample of 3,000 corn and soybean farmers was provided by the National Agricultural Statistics Service (NASS) from the 2007 agricultural census mailing list. The farms were stratified into four groups by farmland area. Different sampling percentages of farms were drawn from the four strata with 0 to 100, 101 to 500, 501 to 1000 and 1000 or more acres, respectively. Larger farms were oversampled in order to capture how most land is managed, and also because of lower expected response rates among operators of large farms. Sample weights are incorporated in the empirical analysis to appropriately correct for the stratification.

The survey questionnaire presented each respondent with four hypothetical cropping systems that provided sequence of cropping practices linked to environmental service levels. System A, the base system, was a corn-soybean rotation with chisel tillage, pre-sidedress nitrate test (PSNT) in corn, all agrochemicals broadcast in the field according to Michigan State University recommendations or pesticide label instructions. System B added a winter cover crop, System C added wheat to the crop rotation, and System D added a requirement to band fertilizer and pesticides application over the crop row and therefore reduce rates by one third below university recommendations or label rates (Table 1-1). Based on agro-ecological research, five major environmental improvements would be generated from the four hypothetical programs compared to a conventional corn-soybean system (Table 1-2). Soil erosion would be lessened by switching to chisel plow tillage from intensive tillage tools like the moldboard plow (Reganold, et al., 1987), planting cover crops over winter (Delgado, et al., 1999, Joyce, et al., 2002, Oades, 1984), and adding wheat into the corn-soybean rotation (Peel, 1998). Reduced erosion not only improves soil fertility and crop productivity (Pimentel and Kounang, 1998), but is also likely to mitigate the eutrophication problem of lakes by carrying less phosphorus-rich topsoil into surface water (Correll, 1998, Poudel, et al., 2001). Greenhouse gas emission in the form of carbon dioxide (CO_2) and nitrous oxide (N_2O) can be reduced by adding cover crops (Lal, et al., 2004, McSwiney, et al., 2010), switching to chisel tillage (Reicosky and Lindstrom, 1993), PSNT (Musser, et al., 1995), and reduced fertilizer application (Hoben, et al., 2011, McSwiney and Robertson, 2005). Farming practices related to nitrogen fertilizer application, such as cover crops, reduced fertilizer rate and PSNT, would also improve the groundwater quality due to less nitrogen leaching (Borin, et al., 1997, Poudel, et al., 2001). Reduced pesticide rate would also mitigate on-site and off-site air pollution and possible health risks for human (Glotfelty, et al., 1987, van den Berg, et al., 1999).

A main effect orthogonal design framework was constructed for the 16 questionnaire versions. The versions varied by payment levels offered (4), payment provider (federal government or non-governmental organization) and sequence of cropping practices (increasing or decreasing in complexity and expected environmental benefits). For each cropping system, respondents were first offered a specific payment if they would adopt the system for a period of five years, and they were asked how many acres they would enroll in such a program. Respondents who chose not to enroll any land were asked whether they would consider enrolling in that system if the payment were higher. Thus, the "consider" group and "not consider" group are distinguished based upon this question and assuming that all farmers who chose to enroll would also consider the program with a higher payment. The "enroll" and "consider but not enroll" group are further identified by the first acreage enrollment question. Unlike the conceptual model, the willingness-to-enroll question is presented ahead of the willingness-to-consider question in order to facilitate the flow of thinking for respondents. It is easier for them to make a decision about a real payment than to think about the system abstractly at first. The follow-up question on considering enrollment with a higher payment comes out naturally if they decide not to enroll. See Figure 1-2 for conceptual differentiation of those groups, and Figure 1-3 for the number of farms falling into different groups in our data set.

Besides farmer choices associated with each cropping system, other information collected includes current crop management practice, farmers' perception of benefits from changed farming practice, attitudes on the importance of enhanced environmental services, past adoption of beneficial farming practices, participation in four hypothetical cropping systems containing those practices, as well as the demographic background. Detailed information about data collection and questionnaire design can be found in Jolejole (2009).

1.4 Empirical model and variables

1.4.1 Choice of models

To model the participation in conservation programs, several functional forms have been used in the literature. Since the basic participation or adoption decision is a dichotomous choice, binary response models, such as ***probit*** (Bosch, et al., 1995, Davey and Furtan, 2008, Rahm and Huffman, 1984, Sidibe, 2005) and ***logit*** (Lee and Stewart, 1983, Pautsch, et al., 2001, Sheikh, et al., 2003, Soule, et al., 2000, Upadhyay, et al., 2003) are widely applied. Ordered probit (Negatu and Parikh, 1999) and multinomial logit (Wu and Babcock, 1998, Zbinden and Lee, 2005) have sometimes been used to model choices among more than two alternatives.

When the choice concerns the level of participation, commonly the land acreage promised for certain practices, a continuous variable needs to be selected in addition to the binary participation choice. In certain circumstances, a corner solution may arise. This occurs when some acreage enrollment responses pile up at zero while others take strictly positive values. The simplest way to model a corner solution is the ***tobit*** model (Tobin, 1958), which assumes all zeroes are generated due to the same mechanisms underlying the positive values. The tobit model has been used for adoption of farming practices in the literature (Lynne, et al., 1988, Mazvimavi and Twomlow, 2009, Norris and Batie, 1987, Wei, et al., 2009).

One extension to the tobit model is a ***hurdle model*** (Cragg, 1971), in which different mechanisms are allowed for the participation and level decisions. A probit model is used for the binary participation decision and a truncated normal regression or log-normal regression is used for the positive amount choice. Both regression variables and estimated coefficients can differ in the two decisions. A likelihood ratio test (Greene, 2000) or Lagrange multiplier test (Lin and Schmidt, 1984) can be used to choose between the tobit and hurdle alternatives. Studies that applied both tobit and hurdle models to WTP for natural amenities (del Saz-Salazar and Rausell-Koster, 2008, Goodwin, et al., 1993) and WTA for wildlife habitat preservation (Shrestha, et al., 2007) suggested the hurdle model was preferred. A further extension to the tobit model and hurdle model is a ***P-tobit model*** (Deaton and Irish, 1984), which assumes that the proportion of potential participants is p and the proportion of respondents who would never participate is $1-p$. Both the proportion p for non-participants and the tobit model for the potential participants need to be estimated. A more flexible form of the p-tobit model that replaces the proportion p by a probit model was the ***double hurdle model*** (Blundell and Meghir, 1987). In this case, two types of zeros are implied, namely zeros due to non-participation and zeroes chosen by potential participants conditional on unsatisfied economic circumstances. The double hurdle model has been adopted in studies of food the consumption, such as meat (Burton, et al., 1996, Su and Yen, 1996), cheese (Yen and Jones, 1997), alcohol (Yen and Jensen, 1996) and prepared meals (Jensen and Yen, 1996, Newman, et al., 2003).

In this study, there are two types of zero responses by farmers that enrolled zero acres to the program. As mentioned in the conceptual model section, one type of zero response refers to those who are unwilling to consider the program, while the other refers to potential participants who are limited by the payment offer, namely those who will consider it but choose not to enroll. The second type of zero determined by the payment offer is likely to be underlain by the same choice mechanism as the affirmative enrollment responses. Thus, a standard double hurdle specification seems to be suitable for our data set. Probit regression is used in the first stage to distinguish between potential participants and those who would not consider the program. For the second stage, I test both a tobit specification as in the standard *double hurdle model* and a two-part hurdle (Cragg) model as in the *extended double hurdle model*. Although the extended double hurdle model is preferred to the double hurdle model based on statistical tests for two of the four cropping systems (Appendix 1-2), the double hurdle model performs better in terms of theoretical consistency (Lau, 1986) and ease of interpretation (Fuss and McFadden, 1978). Based on the conceptual model, once the zero-enrollment responses deterred by fundamental incompatibilities are picked up by the first-stage probit, the driving forces that distinguish positive acreage enrollment from zero enrollment in the second stage should only pertain to the benefit-cost criteria. The second stage tobit model adequately captures those influential factors, while also providing more easily interpreted results than the extended double hurdle model. Hence, the standard two-stage double hurdle (probit plus tobit) is adopted for the rest of the essay.[5] The complete econometric derivation of the double hurdle model is shown in the next section.

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[5] Fuller discussion of econometric foundations, statistical choice of model test results, and empirical results from the four models tested--the standard double hurdle model, the one-stage tobit model, the one-stage hurdle model (probit plus truncated regression), and the extended

1.4.2 Econometric model

Participation in agricultural PES program may involve two corner solutions before the real positive acreage enrollment can be observed. The farmland area that respondents choose to enroll in the program is represented by *y*, which is a compound function of the binary consideration decision *c*, and the continuous choice of acreage enrollment, *a*, which can be zero or positive.

$$y = c \cdot a \tag{1.11}$$

Probit estimation is used for the binary choices of consideration is The latent variable indicating farmers' utility gain by considering enrolling in the program with a suitable payment is c^* , x_1 is a vector of attributes determining utility, and the random term *e* is assumed to follow a normal distribution with standard deviation σ_e (Equation 1.12). Farmers would consider the program (c=1) only if their utility increases (Equation 1.13). The probability of willingness-to consider is estimated by a cumulative normal density function as in Equation 1.14.

$$c^* = x_1\gamma + e \qquad e \sim N\left(0, \sigma_e\right) \tag{1.12}$$

$$c = \begin{cases} 1 & c^* > 0 \\ 0 & c^* \leq 0 \end{cases} \tag{1.13}$$

$$\mathrm{P}\left(c = 1 \mid x_1\right) = E\left(c \mid x_1\right) = \Phi\left(x_1\gamma/\sigma_e\right) \tag{1.14}$$

The acreage enrollment variable *a* is indicated by a latent variable *a** and cornered at zero (Equation 1.15). Latent variable a^* depends on farm and farmers characteristics x_2 that influence their amount choice for enrollment (equation 1.1.16). The random term *u* has a zero

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double hurdle model (first-stage probit plus second-stage probit and truncated regression)—can be found in Appendices 1-4.

mean and variance σ^2. The positive enrolled acreage can be observed only if farmers consider the program and choose to participate given a specific payment (Equation 1.16).

$$a = max\left[a^*, 0\right] \tag{1.15}$$

$$a^* = x_2\beta + u > 0 \quad u \sim N\left(0, \sigma_u{}^2\right) \tag{1.16}$$

$$y = \begin{cases} a^* & if \quad c = 1, \quad a > 0 \\ 0 & \quad otherwise \end{cases} \tag{1.17}$$

The conditional expected enrollment acres, conditional on *c=1* is:

$$E\left(y \mid x_2, c = 1\right) = \Phi\left(x_2\beta / \sigma_u\right) x_2\beta + \sigma\phi\left(x_2\beta / \sigma_u\right) \tag{1.18}$$

The probability density functions for the consideration and enrollment decisions are shown in Equations 1.19 and 1.20.

$$f\left(c \mid x_1\right) = \left[1 - \Phi\left(x_1\gamma/\sigma_e\right)\right]^{1[c=0]} \Phi\left(x_1\gamma/\sigma_e\right)^{1[c=1]} \tag{1.19}$$

$$f\left(a \mid x_2, c = 1\right) = \left[1 - \Phi\left(x_2\beta / \sigma_u\right)\right]^{1[a=0]} \left[\sigma_u{}^{-1}\phi\left(y - x_2\beta / \sigma_u\right)\right]^{1[a>0]} \tag{1.20}$$

The unconditional density of y is derived by taking into account all decisions:

$$\begin{aligned} f\left(y \mid x_1, x_2\right) = & \left[1 - \Phi\left(x_2\beta / \sigma_u\right)\Phi\left(x_1\gamma/\sigma_e\right)\right]^{1[y=0]} \\ & + \left\{\left[\Phi\left(x_1\gamma/\sigma_e\right)\right]\phi\left[\left((y_i - x_i\beta) / \sigma_u\right)\right]/\sigma_u\right\}^{1[y>0]} \end{aligned} \tag{1.21}$$

The associated log-likelihood function used for ML estimation is:

$$\begin{aligned} l_i\left(\gamma, \beta\right) = & 1\left[y = 0\right]\log\left[1 - \Phi\left(x_{2i}\beta/\sigma_u\right)\Phi\left(x_{1i}\gamma/\sigma_e\right)\right] \\ & + 1\left[y > 0\right]\left\{\log\left[\Phi\left(x_{1i}\gamma/\sigma_e\right)\right] + \log\left\{\phi\left[\left((y_i - x_{2i}\beta)/\sigma_u\right)\right]/\sigma_u\right\}\right\} \end{aligned} \tag{1.22}$$

The results from the double hurdle model are important in predicting the supply curve, i.e., estimating the potential enrollment of land providing enhanced environmental services in response to per-acre payment variation. Intuitively, the predicted acreage is the conditional predicted enrollment acreage multiplied by the probabilities of consideration. It can be computed from the unconditional expected value of acres choice *y* (equation 1.23), which is derived from two conditional expected value functions (equations 1.19 and 1.20). The predicted supply of land contributing ES is depicted by systematically increasing the payment variable upward from zero while holding other variables at their mean values for each farm (equation 1.24).

$$\begin{aligned} E\left(y \mid x_1, x_2\right) &= \mathrm{P}\left(c=1 \mid x_1\right) \cdot E(a \mid x_2, c=1) \\ &= \Phi\left(x_{1i}\gamma/\sigma_e\right)\left[\Phi\left(x_2\beta/\sigma_u\right)x_2\beta + \sigma\phi\left(x_2\beta/\sigma_u\right)\right] \end{aligned} \tag{1.23}$$

$$\begin{aligned} \hat{y} = \Phi\left(\bar{x}_{i(pay)}\hat{\gamma} + \hat{\gamma}_{pay}x_{pay}/\hat{\sigma}_e\right)&\left[\Phi\left(\left(\bar{x}_{i(pay)}\hat{\beta} + \hat{\beta}_{pay}x_{pay}\right)/\hat{\sigma}_u\right)\right. \\ &\left.\cdot\left(\bar{x}_{i(pay)}\hat{\beta} + \hat{\beta}_{pay}x_{pay}\right) + \hat{\sigma}_u\phi\left(\left(\bar{x}_{i(pay)}\hat{\beta} + \hat{\beta}_{pay}x_{pay}\right)/\hat{\sigma}_u\right)\right] \end{aligned} \tag{1.24}$$

In estimating the supply curves, only variables that are significant with 90% probability are included. An F-test is used to ensure the joint significance of remaining variables. The coefficients are re-estimated with these variables and substituted into the above function.

1.4.3 Specification issues

There are several specification issues associated with the double hurdle model (Smith, 2002). Dependence of errors, non-normality and heterogeneity in error terms have received the most attention in empirical studies.

The dependence of errors emerges when error terms in the probit regression and truncated regression are correlated (Smith, 2003). With dependence, multivariate maximum log-likelihood estimation needs to be conducted rather than two or three independent estimations. Independence of errors is a common assumption adopted by studies using a double hurdle model. Studies that compare the results with and without independence assumptions found little improvement from assuming dependence (Jones, 1992, Uri, 1997). This assumption is also maintained in our study, namely *e* and *u* in the probit and tobit models are assumed to be independent.

Normality and homogenous errors are assumptions underlying both two regressions in our econometric models. Violation of either of these assumptions will lead to inconsistent estimates. To account for the heteroskedasticity problem, some studies have specified the standard deviation σ as an exponential function of exogenous variables that varies across observations (Jensen and Yen, 1996, Newman, et al., 2003). The normality problem can be remedied by Box-Cox transformation (Burton, et al., 1996, Martínez-Espiñeira, 2006) or Inverse Hyperbolic Sine transformation (Jensen and Yen, 1996, Newman, et al., 2003, Yen, et al., 1997). However, as pointed out by Woodridge (2008), the inconsistent coefficient estimates that result from conventional estimation methods in the absence of normal and homoskedastic distributions still yield reasonably close partial effects, and the signs of estimates should be consistent. Since the major focus of this study is to understand the signs and marginal effects of farmers' participation determinants, no adjustment is made for possible non-normality and heteroskedasticity problems.

1.4.4 Variables

There is one probit regression for consideration and one tobit regression for acreage enrollment in the double hurdle model. The dependent variable for the *consideration model* is farmers' dichotomous choice of considering enrollment in the program, which is contingent on belief that the payment is politically feasible. The dependent variable for the *acreage enrollment* *model* is the acres that farmers would enroll in the program, including both zero and positive acreages. See Table 1-3 for descriptive statistics of dependent variables.

The same set of independent variables is employed in both probit and tobit regressions for comparison. Six broad categories of explanatory variables linked to the conceptual model are defined as follows (Table 1-4): First, the *design attributes* category, corresponding to the attributes of the programs that were a part of our experimental design. These include the per-acre program payment, *P**, for each cropping system, the sequence in which the four cropping systems were presented to respondents, and whether the payment is provided by government. With the adoption of different cropping practices, farmers are assumed to incur additional direct costs (e.g., for labor and/or material inputs) and opportunity costs (e.g., for growing a less profitable crop). Following exploratory results from farmer focus group interviews in 2007[6], the payment offer ranges for the four cropping systems were: A: $4 to $17; B: $10 to $36; C: $15 to $55; and D: $20 to $75. The payment offer is hypothesized to have more effect for acreage enrollment than for the willing-to-consider decision, for which a larger but politically feasible payment is assumed to be provided. The descending sequence dummy variable denotes respondents who received questionnaires with the sequence of cropping systems decreasing in stringency and associated payment offers.

Second, the *perception and attributes* category of variables corresponds to environmental services *E*. These variables depict farmer perceptions of ES benefits from certain cropping systems, and their attitudes on whether nature provides services that could benefit their crop

[6] See Lupi, et al. (2007) for detailed focus group experiments on the performance of conservation auctions.

production. These variables are measured with 5 point Likert scale questions (1 for strongly disagree, 2 for disagree, 3 for neutral, 4 for agree and 5 for strongly agree).

The third category describes the *biophysical attributes* of farms corresponding to biophysical conditions *B*, which includes farm size and soil types. Larger farms are expected to be more likely to enroll in a PES program because they have a higher capacity to invest and to withstand risks from changed practices (Knowler and Bradshaw, 2007, Prokopy, et al., 2008). Soil type refers to dummy variables for soil texture. Clay soils may be more fertile but less well-drained than the loam soil baseline, whereas sandy soils are less fertile but better drained due to looser particles. Soil attributes exhibited mixed effects in different studies depending on the specific practices. In this study, enrollment in the reduced chemical system is expected to be positively related to clay soil, which tends to be more fertile than sandy soil and silty soil. Cropping systems with soil conservation practices, such as cover crops and corn-soybean-wheat rotation are expected to be positively related to sandy soil, which is more erodible. The fourth category measures *farm management attributes,* corresponding to variable inputs *X*, labor *L* and capital *K*. The current practices of tillage, wheat acreage, cover crops, irrigation, organic crops[7], fertilizer and pesticides[8] are expected to have positive effects if they are similar to the new cropping system. The influence of irrigation on the adoption of new practices is ambiguous. Intensive irrigated agriculture tends to facilitate adoption of nitrate testing, but deters reduced tillage and crop rotation (Bosch, et al., 1995, Wu and Babcock, 1998). These results depend on the payoff of irrigation associated with different practices.

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[7] Data treatment for organic farms can be found in Appendix 5.

[8] Reduced fertilizer and pesticides are dummy variables with one indicating currently band apply fertilizer/pesticide at 2/3 of full field rate.

The fifth category of *operator attributes* includes age, level of formal education of farm operators, and whether farm income is the major source of household income. This category may influence farmers' information *I* and choice of practice *X, L and K*. Farmers who are younger and have higher education are expected to be more likely to participate. . Farms deriving most of their income from agricultural production are hypothesized to be more likely to work on farming practices improvement and possible benefits from it.

The last category includes *market prices*, which are represented by the output price vector r_y in the conceptual model. Prices are represented by ratios of farmers' expected prices for wheat compared to corn and soybean. Both price ratio variables are expected to be positively related to adoption of cropping systems that require wheat, namely systems C and D.

1.5 Results

Although the willingness-to-consider and acreage enrollment decisions are modeled using the same set of variables, results of the double hurdle model suggest that the first-round willingness-to-consider decision depends chiefly on non-price farm and farmer characteristics. By contrast, the second-round enrollment decision depends more on payment-driven benefit-cost criteria.

Both consideration and enrollment decisions are influenced by two common factors. First, the perceived environmental performance of each system significantly contributes to both enrollment and willingness to consider each of the four cropping systems. This finding is consistent with previous studies (D'Emden, et al., 2008, Gould, et al., 1989, Purvis, et al., 1989, Sidibe, 2005, Traore, et al., 1998, Wei, et al., 2009), as the perceived ES benefits both individual farmers and the society. A new finding from this study is that the marginal effects of perceived environmental performance increase from System A to D for the willingness-to-consider decision, but they decrease for enrollment decision. This suggests that farmers would be more willing to consider a system with larger environmental benefits, but would be reluctant to enroll proportionally more land, perhaps due to higher costs associated with realizing these benefits. The second common factor for two decisions is the sequence of presenting cropping systems to farmers. Farmers who were presented with the higher-complexity and higher-payment cropping system first were less likely to consider or enroll in the other three cropping systems.

1.5.1 Willingness-to-consider decision

The double hurdle model complements previous PES studies by revealing several differences between the attributes that motivate the consideration decision and those that motivate the subsequent enrollment choice. These differences cannot be detected by a single hurdle model or a simple tobit model that lacks information on what farmers would respond to a higher payment offer. Three categories of variables drive the consideration decision (Table 1-5).

First, farmers who believe their production can benefit from nature are 5% more likely to consider enrolling in the program. Previous studies also found that positive attitudes tended to promote enrollment in conservation programs (Lynne, et al., 1988, Sheikh, et al., 2003). Their attitudes further enhance participation when combined with perceived positive environmental services.

Second, the similarity of current farm management practices to the proposed cropping system also increases willingness to consider the PES program. This effect is likely motivated by lower perceived risk and less extra cost. Prior practice of conservation tillage, wheat planting, and reduced fertilizer input are illustrative examples. Farmers with an additional 10% of land under no-till are 3% more likely to consider adopting the program that requires conservation tillage. Farmers with an additional 10% more of their land planted to wheat are 4% more likely to adopt two cropping systems that add wheat into the crop rotation. Those who currently own equipment to band apply fertilizer at a reduced rate are 10% more likely to consider System D, which requires this.

Third, information variables such as education and past experience with a governmental PES program generally promote willingness to consider. One more year of education increases the probability of considering the PES program by about 3%. Prior research has also shown positive effects of education on adoption of farming practices as education largely links to knowledge (Bosch, et al., 1995, Ervin and Ervin, 1982, Rahm and Huffman, 1984, Warriner and Moul, 1992, Wu and Babcock, 1998). Past program experience with EQIP, which is a governmental PES-type program, facilitates consideration of systems C and D by an additional 10%. However, experience with the Michigan Agriculture Environmental Assurance Program (MAEAP) reduces the probability of considering enrollment by 20%. This may due to differences in program goals between MAEAP and our hypothetical program. TMAEAP does not involve adoption of changed practices to benefit the environment; instead, it certifies compliance with "generally accepted agricultural practices". Previous studies have also found that farmers currently or previously involved in conservation programs were more likely to participate in a new program since they had more information and assistance (Bosch, et al., 1995, Ervin and Ervin, 1982, Wei, et al., 2009, Wu and Babcock, 1998).

1.5.2 Acreage enrollment decision

While the consideration decision is driven by feasibility and awareness factors, the acreage enrollment decision by the tobit regression is driven chiefly by benefit-cost criteria (Table 1-6). First and foremost, the per-acre payment offer has prominent effects on area dedicated to all four cropping systems. As expected, the price-elasticity of land supplied is declining with increasing system complexity. An increase in the annual payment of $1/acre would raise the land area enrolled in systems A, B, C and D by 18, 10, 7 and 4 acres, respectively. Compared with the other three systems, System A, which requires the smallest change from a conventional cropping system, has the greatest potential to be expanded.

Second, larger farms enroll more land in the program. A typical farm with 100 more acres in total cropland area would enroll 20-30 more acres, presumably because more land is available for production and any fixed costs of adoption can be spread over more output. This is a common finding in previous studies on conservation practice adoption (Gould, et al., 1989, Lambert, et al., 2006, Lee and Stewart, 1983, Norris and Batie, 1987, Rahm and Huffman, 1984, Wu and Babcock, 1998, Zbinden and Lee, 2005).

Third, the percentage of moldboard-tilled land has a substantial negative effect on enrollment but no effect on the consideration decision in any system. One more percentage point of land under moldboard tillage would decrease land enrollment by 8.8 acres for System A and 7.6 acres for System B. This is presumably due to the fixed cost of converting from a moldboard plow to a chisel plow, which is required by all four proposed cropping systems.

Fourth, farms with a higher proportion of irrigated land, more income from farming or older decision makers are also likely to enroll more acreage in some of the four systems. Irrigated land tends to use more fertilizer and would need soil test to reasonably reduce the nitrogen application. Consistent with Bosch (1995), farms with higher irrigation ratio are more likely to enroll in systems A and B, which include PSNT for reducing fertilizer application properly but do not strictly cut fertilizer use by one third. Similar to Lambert et al. (2006), this study suggests farms that rely chiefly on income from agricultural production devote more time and effort to farming and thus may enroll more land in the proposed programs. Older farmers tend to enroll more acreage enrollment if they consider enrolling, though the consideration probit model indicates that they are less likely to consider enrollment in the program. The age variable has shown both positive (Okoye, 1998, Warriner and Moul, 1992) and negative (Gould, et al., 1989, Lambert, et al., 2006, Neill and Lee, 2001) effects in previous studies.

In sum, these empirical results suggest different underlying determinants for the two participation decisions. The first-stage willingness-to-consider decision depends chiefly on farm and farmer characteristics, such as environmental attitudes, experience in conservation programs, education, and ownership of large equipment. In contrast, the second-stage enrollment decisions depend more on payment-driven benefit-cost factors, such as the per-acre payment offer, total cropland area, irrigated land proportion, moldboard tillage and whether main income is from farming.

1.5.3 Supply curves

The acreage supply curve predicts farmers' potential provision of environmental benefits in response to increasing levels of payment. As shown in Equation 1.20, the predicted supply of cropland reflects composite effects from the consideration and acreage enrollment decisions. The farm-level supply curves for double hurdle model are calculated from the predicted probability of consideration times the acreage enrollment conditional on consideration. State-level supply curves are calculated by proportionally magnifying individual farm-level supply given each farm's cropland area and the total number of farms in each sample acreage stratum (Figure 1-4). The payment range for each system is extrapolated upwards and downwards at the same proportion to the payment range offered in the survey, namely A: $0 to $21; B: $0 to $46; C: $0 to $65; and D: $0 to $95.

Supply curves aggregating all participation decisions for the state of Michigan suggest two general effects. First, the price elasticity of land enrollment decreases with cropping system complexity. The basic cropping system that requires the fewest management practices has the greatest potential to be expanded. Farmers would voluntarily enroll more land in this system than any other at any payment level above $35/acre. Second, without payment, more Michigan farmers prefer an integrated, low-input conservation-till corn-soybean-wheat system (System D) than a conventional conservation-till corn-soybean rotation (System A). These two systems are both preferred over intermediate variants that add individual reduced input practices to the conventional conservation-till system (Systems B and C). The surprising zero-payment enrollment for System D may be because a proportion of farms are already in a low-input conservation cropping system that is closer to or even more advanced than System D. The summary statistics in Table 1-4 suggest that about 20% cropland in the sample is not tilled and over 30% is using other conservation tillage methods than chisel plow. In addition, over 20% farms are band applying fertilizer and pesticides at a reduced rate as proposed in cropping system D.

1.6 Conclusion

This study deepens our understanding of farmers' willingness to participate in payment-for-environmental-services programs by separating the initial decision on whether even to *consider* the program from the final decision on how many acres to *enroll* at a given payment level. Comparison of different econometric models for estimating and predicting PES enrollment leads to selection of a double hurdle model, comprised of a probit for willingness to consider and a tobit for acreage enrollment.

Empirical results suggest that the first-stage willingness-to-consider decision depends more on farm and farmer characteristics, while the second-stage enrollment decisions depend more on payment-driven benefit-cost criteria. According to the first-stage probit for *willingness to consider*, farmers who would participate in a PES program at a payment level that they perceive to be politically feasible are motivated by feasibility variables, such as environmental attitudes, experience in conservation programs, education, and ownership of large equipment. The second-stage tobit for *land enrollment* reveals influential economic factors, such as the per-acre payment offer, total cropland area, irrigated land proportion, moldboard tillage and whether main income is from farming. The two stages are underpinned by two common factors: perceived environmental performance of the proposed systems and sequence of presenting the systems to respondents.

The supply curves aggregating all participation decisions for the state of Michigan illustrate both the price elasticity effect and the start-up effect for enrollment without payment. As expected, the system with least requirements—a conventional conservation-till corn-soybean rotation—is most payment responsive. However, the most stringent system— an integrated, low-input conservation-till corn-soybean-wheat system— surprisingly attracts more participants without any incentive payments, probably due to the number of respondent farms that had already adopted comparable conservation practices.

Understanding farmers' decision processes is an essential precondition for designing effective and efficient agricultural PES programs. As revealed by the consideration model, PES programs with proposed practices that significantly conflict with farm operations or farmer characteristics are unlikely to be adopted given any payment that is feasible within the context of current conservation programs. Thus, PES programs can enhance adoption by targeting more educated, experienced and properly equipped farmers who are favorably disposed toward environmental stewardship. Research and outreach that build farmer understanding of environmental services from agriculture also contribute to the appeal of agricultural PES programs. For those farmers willing to consider the program, the enrollment model finds that higher payment rates induce greater area to be enrolled in the PES program. By modeling the first-stage "consideration" decision, this essay identifies important non-monetary preconditions for farmer willingness to consider participating in a payment for environmental services program.

The hypothetical PES programs in this study focus on total environmental services generated, rather than additional ones. This approach has the advantage of treating equitably both initial and additional providers of environmental services. However, for the design of cost-effective PES policies, it is desirable not to pay for environmental services that would be provided for free. Future research should measure the cost difference between paying for all environmental services and paying only for *additional* environmental services generated by farms enrolling in new practices. By combining such supply-side information with estimates of demand for environmental service improvements, it should be possible to assess the potential for a PES market in agriculturally generated environmental services.

Figures and Tables

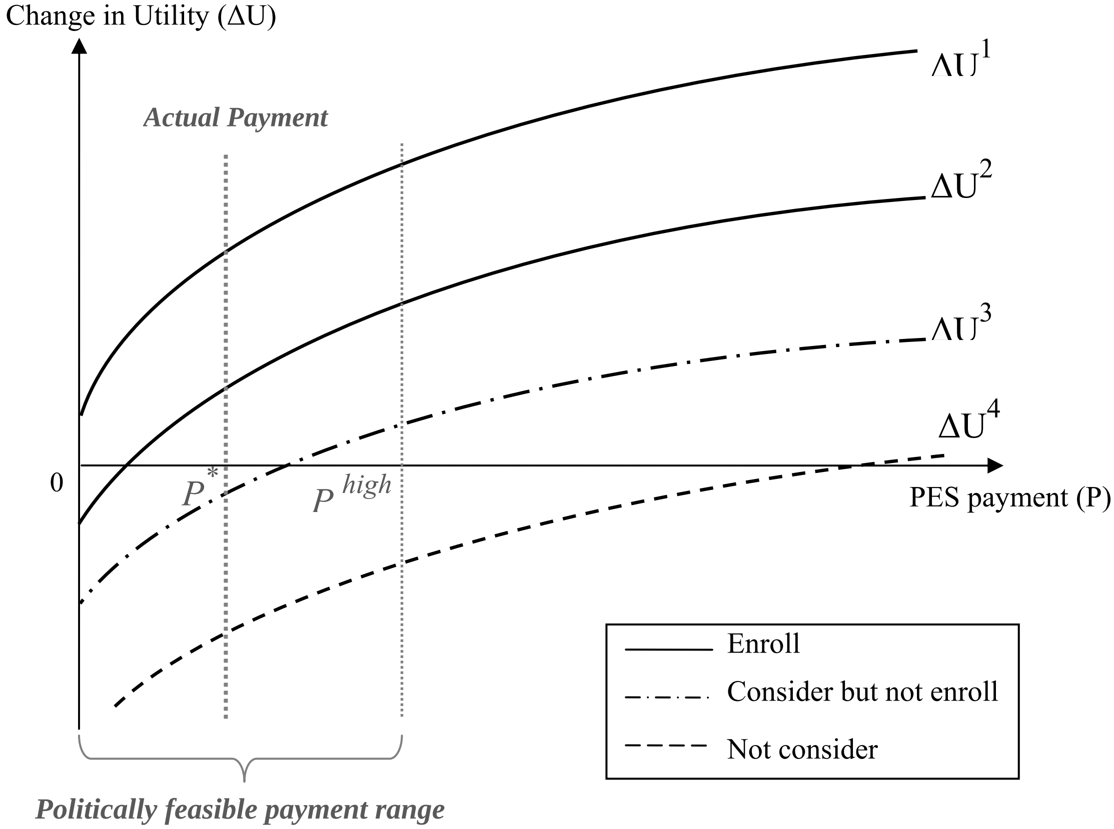

Figure 1-1 Illustration of changes in utility by four hypothetical farmers from adopting specified production practices as a function of the associated PES payment

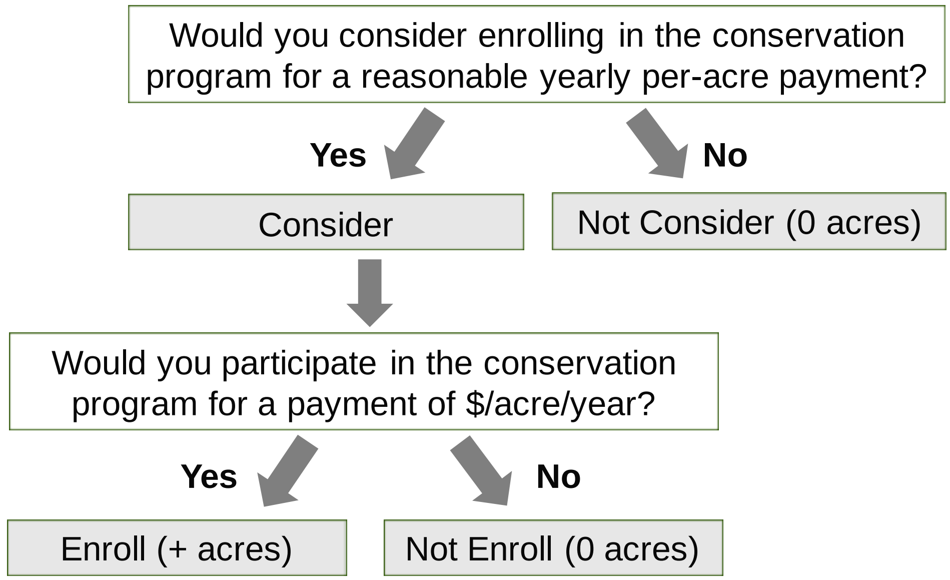

Figure 1-2 Conceptual diagram of farmers' participation decisions in a PES program

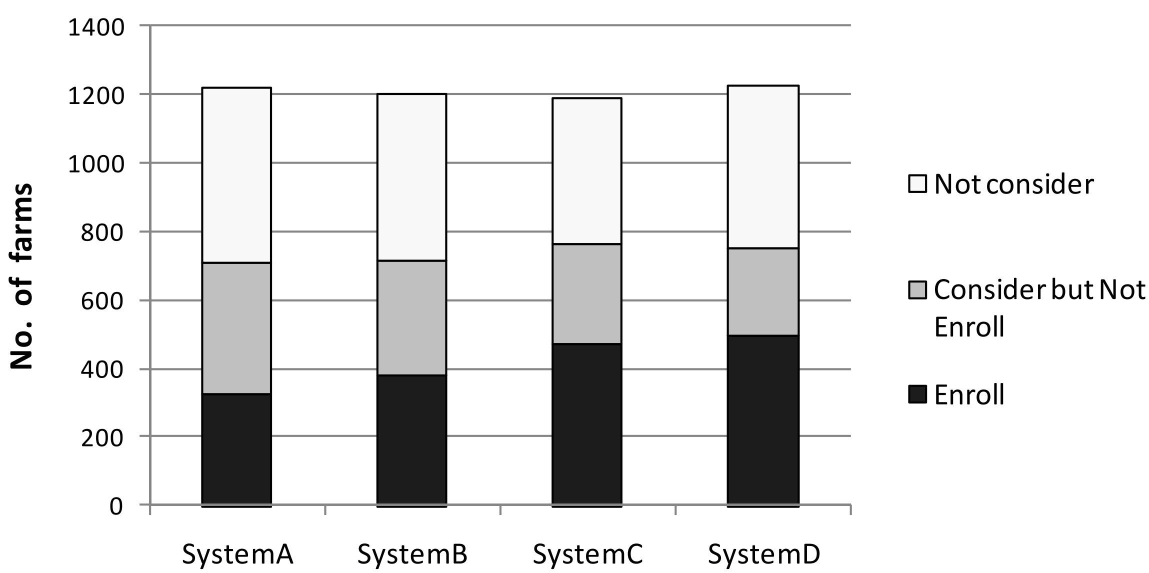

Figure 1-3 Number of farms that fell into the three participation categories for each of the four cropping systems (N=1688 Michigan corn and soybean farms, year=2008)

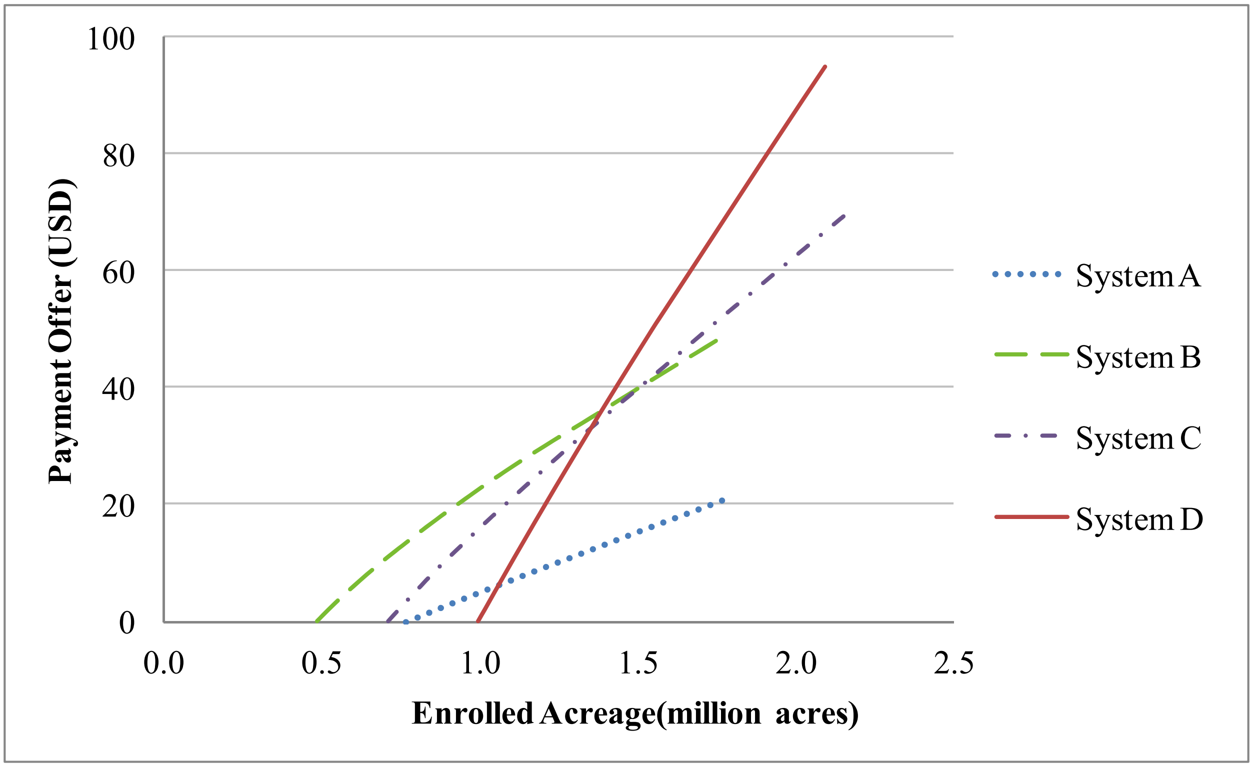

Figure 1-4 Predicted State-level Supply Curves of Enrolled Acres by Cropping System from Double Hurdle Estimation, 1688 Michigan Corn or Soybean Farms, 2008
(For interpretation of the references to color in this and all other figures, the reader is referred to the electronic version of this dissertation.)

Table 1-1 Four cropping systems offered to farmers

Practice	**Description**	**Cropping System**			
		A	B	C	D
Tillage	Chisel plow with cultivation as needed	×	×	×	×
Soil Test	Pre-sidedress Nitrate Test (PSNT)	×	×	×	×
Cover Crop	None	×			
	Any type present over winter		×	×	×
Rotation	Corn-Soybean	×	×		
	Corn-Soybean-Wheat			×	×
Fertilization	Broadcast fertilizers at full MSU rates and split Nitrogen based on PSNT	×	×	×	
	Band apply over row at MSU rates and split Nitrogen based on PSNT				×
Pesticide Rate	Broadcast pesticides at a label rate	×	×	×	
	Band apply pesticides over row at a label amount				×

Table 1-2 Environmental services and outcomes from proposed farming practices in cropping systems

Practice	Change from conventional system	Cropping systems	Environmental services	Environmental outcomes
Tillage	Moldboard Plow → **Chisel Plow**	A,B,C,D	Soil erosion ↓ (Phosphorus surface runoff ↓) CO_2 emission ↓	Soil fertility ↑ Surface water quality ↑ Global warming ↓
Soil Test	Adopting Pre-sidedress Nitrate Test (**PSNT**)	A,B,C,D	Nitrogen leaching ↓ N_2O emission ↓	Groundwater quality ↑ Global warming ↓
Cover Crops	Adopting **Winter Cover Crops**	B,C,D	Soil erosion ↓ (Phosphorus surface runoff ↓) Nitrogen leaching ↓ CO_2 and N_2O emission ↓	Soil fertility ↑ Surface water quality ↑ Groundwater quality ↑ Global warming ↓
Rotation	Adding **Wheat** in Corn-Soybean Rotation	C,D	Soil erosion ↓ (Phosphorus surface runoff ↓)	Soil fertility ↑ Surface water quality ↑
Fertilizer	Broadcast N&P Fertilizer at Full Rate **→ Band Application at 2/3 Rate**	D	Nitrogen leaching ↓ N_2O emission ↓	Groundwater quality ↑ Global warming ↓
Pesticide	Broadcast Pesticides at Full Rate **→ Band Application at 2/3 Rate**	D	Pesticide into air ↓	Health risk ↓ Air pollution↓

Table 1-3 Summary statistics for dependent variables

Dependent Variable	system	unit	Obs	Mean	Std. Dev.	Min	Max
Probit model: consideration							
Consider VS Not consider	A	dummy	1146	0.57	0.49	0	1
Consider VS Not consider	B	dummy	1124	0.59	0.49	0	1
Consider VS Not consider	C	dummy	1112	0.64	0.48	0	1
Consider VS Not consider	D	dummy	1149	0.61	0.49	0	1
Tobit model: acreage enrollment							
Acreage enrollment	A	acres	658	331	840	0	15000
Acreage enrollment	B	acres	666	278	608	0	10000
Acreage enrollment	C	acres	717	361	608	0	7000
Acreage enrollment	D	acres	701	416	690	0	7000

Table 1-4 Summary statistics of independent variables

Independent Variables	Units	Obs	Mean	Std. Dev.	Min	Max
Questionnaire Version						
Government	dummy	1796	0.497	0.500	0	1
Descending sequence	dummy	1796	0.503	0.500	0	1
Payment offer (System A)	dollars	1796	10.2	4.78	4	17
Payment offer (System B)	dollars	1796	23.2	9.05	10	36
Payment offer (System C)	dollars	1796	36.7	12.5	15	55
Payment offer (System D)	dollars	1796	51.0	16.7	20	75
Perception and attitudes						
Perceived env performance (A)	Likert 1-5	1245	2.97	0.808	1	5
Perceived env performance (B)	Likert 1-5	1189	3.24	0.776	1	5
Perceived env performance (C)	Likert 1-5	1200	3.37	0.784	1	5
Perceived env performance (D)	Likert 1-5	1245	3.46	0.794	1	5
General attitudes of ES	Likert 1-5	1475	3.12	1.11	1	5
Farm biophysical attributes						
Total land	acres	1521	1151	1408	2	21500
Sandy soil	dummy	1796	0.274	0.446	0	1
Silty soil	dummy	1796	0.028	0.165	0	1
Clay soil	dummy	1796	0.434	0.496	0	1
Farm management attributes						
Moldboard tillage land percent	ratio	1486	0.067	0.178	0	1
No till tillage land percent	ratio	1486	0.185	0.244	0	1
Conservation land percent	ratio	1486	0.342	0.286	0	1
Wheat land percent	ratio	1486	0.083	0.103	0	0.714
Cover crops land percent	ratio	1489	0.047	0.149	0	1
PSNT land percent	ratio	1489	0.050	0.170	0	1
Organic land percent	ratio	1477	0.002	0.025	0	.63
Irrigation land percent	ratio	1796	0.048	0.165	0	1
Reduced Fertilizer use	dummy	1444	0.218	0.413	0	1
Reduced Pesticide use	dummy	1442	0.209	0.407	0	1
MAEAP	dummy	1371	0.142	0.349	0	1
EQIP	dummy	1379	0.298	0.458	0	1
CRP	dummy	1421	0.349	0.477	0	1
CSP	dummy	1324	0.120	0.325	0	1
Operator attributes						
Age	years	1501	54.8	11.6	21	94
Education	years	1488	13.4	2.56	6	20
Main income source from farm	dummy	1488	0.718	0.450	0	1
Market prices						
Wheat/corn price	ratio	1059	1.682	0.323	0.15	3.33
Wheat/soybean price	ratio	1049	0.732	0.358	0.2	7

Table 1-5 Marginal effects from Probit estimation of farmers' consideration (double hurdle), weighted by stratum, by Cropping Systems, 1688 Michigan corn or soybean farmers, 2008

	System A		System B		System C		System D	
	Coef.	P>z	Coef.	P>z	Coef.	P>z	Coef.	P>z
Government	0.009	0.886	0.017	0.790	0.023	0.698	-0.038	0.489
Descending sequence	-0.178 ***	0.003	-0.127 *	0.051	-0.042	0.446	0.072	0.186
Payment offer	0.016 **	0.015	-0.002	0.432	0.001	0.758	-0.001	0.467
Perceived env perf	0.082 **	0.039	0.127 ***	0.002	0.181 ***	0.000	0.193 ***	0.000
General ES attitudes	0.069 **	0.012	0.046 *	0.098	0.051 **	0.041	0.038 *	0.082
Total land	0.000	0.130	0.000	0.427	0.000	0.467	0.000	0.277
Sandy soil	-0.109	0.267	-0.084	0.397	0.027	0.739	0.000	0.997
Clay soil	-0.045	0.605	-0.051	0.553	0.064	0.407	0.107	0.258
Moldboard tillage	-0.194	0.269	-0.264	0.122	-0.073	0.621	-0.197	0.134
No till tillage	0.366 **	0.036	0.384 **	0.032	0.411 **	0.018	0.246	0.108
Conservation tillage	0.019	0.872	-0.016	0.905	0.021	0.862	0.118	0.258
Wheat ratio	0.179	0.492	0.246	0.308	0.436 *	0.070	0.412 *	0.066
Cover crops ratio	-0.209	0.146	-0.161	0.294	-0.246	0.138	-0.081	0.576
Organic ratio	-0.023	0.971	0.592	0.575	0.567	0.595	0.841	0.530
Irrigation ratio	0.035	0.829	0.029	0.867	0.132	0.401	0.074	0.588
Reduced fertilizer	0.101	0.151	0.145 **	0.011	0.117 **	0.026	0.110 **	0.036
Reduced pesticide	0.082	0.235	0.134 **	0.041	0.013	0.842	0.075	0.217
MAEAP	-0.237 ***	0.007	-0.186 **	0.028	-0.144	0.104	-0.186 **	0.020
EQIP	0.088	0.172	0.066	0.273	0.114 *	0.068	0.137 **	0.012
CRP	0.002	0.971	0.107	0.154	0.052	0.532	0.153 **	0.021
CSP	-0.117	0.240	-0.175 *	0.066	-0.088	0.382	-0.165 *	0.057
Age	-0.004	0.137	0.000	0.858	-0.001	0.691	-0.004	0.103
Education	0.024 *	0.067	0.011	0.445	0.033 ***	0.002	0.027 **	0.013
Wheat/corn price	0.155	0.278	0.251 **	0.037	0.047	0.694	0.115	0.267
Wheat/soybean price	0.059	0.850	-0.280	0.280	-0.121	0.617	-0.196	0.392
farm income	-0.039	0.548	-0.046	0.494	-0.013	0.836	0.041	0.528
Intercept	-3.034 **	0.017	-2.623 *	0.056	-4.496 ***	0.000	-3.963 ***	0.006
Number of obs	600		594		604		613	
Wald chi2(26)	77.57		66.03		71		92.48	
Prob>chi2	0		0		0		0	
Pseudo R2	0.226		0.2192		0.2404		0.2713	
Log likelihood	-321.5		-319.2		-306.2		-303.5	

Note: ***significant at 1% level, **significant at 5% level, *significant at 10% level

Table 1-6 Marginal effects from Tobit estimation of farmers' acreage enrollment (double hurdle), weighted by stratum, by Cropping Systems, 1688 Michigan corn or soybean farmers, 2008

	System A			System B			System C			System D		
	Coef.		P>z	Coef.		P>z	Coef.		P>z	Coef.		P>z
Government	-133		0.115	-2.07		0.975	34.2		0.445	-5.20		0.900
Descending sequence	-363	***	0.000	-57.5		0.364	-163	***	0.000	-65.2		0.135
Payment offer	18.9	**	0.020	11.0	***	0.009	6.61	***	0.000	3.64	**	0.013
Perceived env perf	187	***	0.004	146	***	0.005	118	***	0.001	139	***	0.000
General ES attitudes	-8.24		0.815	-19.8		0.535	-35.9	**	0.037	-39.5	**	0.044
Total land	0.26	***	0.000	0.28	***	0.004	0.24	***	0.000	0.33	***	0.000
Sandy soil	240	*	0.071	24.5		0.815	17.0		0.797	74.6		0.322
Clay soil	391	***	0.003	33.7		0.734	22.6		0.708	84.5		0.197
Moldboard tillage	-884	***	0.004	-761	**	0.018	-193		0.159	-108		0.425
No till tillage	-121		0.617	238		0.138	88.3		0.448	305	***	0.007
Conservation tillage	115		0.537	121		0.296	14.2		0.865	153	**	0.049
Wheat ratio	-457		0.106	315	*	0.098	207		0.191	-4.24		0.975
Cover crops ratio	-495		0.112	-112		0.675	-58.8		0.772	83.4		0.323
Organic ratio	-347		0.657	-437		0.701	324		0.690	-173		0.797
Irrigation ratio	624	**	0.011	574	**	0.040	-73.4		0.661	51.5		0.725
Reduced fertilizer	-105		0.322	-37.8		0.689	14.3		0.791	-20.3		0.703
Reduced pesticide	-65.2		0.527	-127		0.190	-117	**	0.026	-125	**	0.017
MAEAP	69.8		0.565	-110		0.282	40.5		0.546	14.0		0.825
EQIP	60.4		0.544	44.7		0.577	15.2		0.802	125	**	0.040
CRP	79.6		0.401	-36.7		0.629	2.47		0.963	-38.6		0.516
CSP	365	***	0.004	171		0.152	104		0.205	-45.3		0.629
Age	3.64		0.238	4.62		0.218	1.33		0.408	4.51	***	0.010
Education	19.9		0.233	2.43		0.862	-4.96		0.577	-3.36		0.722
Wheat/corn price	443		0.106	-30.8		0.850	-140		0.176	-360	***	0.000
Wheat/soybean price	-462		0.424	50.8		0.883	140		0.515	708	***	0.000
farm income	81.6		0.381	-54.7		0.574	94.6	*	0.058	9.36		0.872
Intercept	-2126	***	0.000	-1269	**	0.013	-512	*	0.064	-880	***	0.002
/sigma	528			448			362			366		
Number of obs	364			372			430			406		
Wald chi2(26)	2.91			1.56			4.96			5.66		
Prob>chi2	0.00			0.04			0.00			0.00		
Pseudo R2	0.06			0.05			0.04			0.05		
Log likelihood	-733			-897			-1302			-1318		

Note: ***significant at 1% level, **significant at 5% level, *significant at 10% level

APPENDICES

APPENDIX 1-1: ECONOMETRIC MODELS

Tobit model

It is common in conservation program participation surveys that some responses pile up at zero while some others take strictly positive values. The tobit model is a straightforward method to deal with those zero responses (Tobin, 1958). It allows for one type of zero observations based on the implicit assumption that negative values are underpinned by the same mechanism as positive responses but can only be observed as zero.

The acreage enrollment *a* is indicated by a latent variable *a**, which depends on farm and farmer characteristics *x* that influence the amount they choice to enroll. The random term *u* has a zero mean and variance σ^2. Zero responses are observed when *a** is less than or equal to zero.

$$a = max[a^*, 0] \quad a^* = x\beta + u > 0 \quad u \sim N(0, \sigma^2) \tag{1. A1}$$

The probability density function for estimation is:

$$f(a \mid x, c=1) = [1 - \Phi(x\beta/\sigma)]^{1[a=0]} [\sigma^{-1}\phi(y - x\beta/\sigma)]^{1[a>0]} \tag{1. A2}$$

The unconditional expectation of acreage enrollment for supply curve derivation is:

$$E(a \mid x) = \Phi(x\beta/\sigma) x\beta + \sigma\phi(x\beta/\sigma) \tag{1. A3}$$

Single hurdle model (Cragg model):

The single hurdle model (Cragg, 1971) extends the tobit model by allowing different mechanisms to drive 1) the dichotomous decision of whether to enroll, and 2) the level decision on how many acres to enroll. The cropland acres that respondents choose to enroll in the program are represented by y, which is a compound function of binary participation decision p and choice of positive acreage enrollment a^*.

$$y = p \cdot a^* \tag{1. A4}$$

Probit estimation is used for binary choice of participation. p* is the latent variable indicating farmers' utility gain by enrolling in the program given a specific level of payment, where x_1 is a vector of attributes determining this utility. Farmers would consider the program (p=1) only if their utility increases.

$$p^* = x_1\alpha + \varepsilon \quad \varepsilon \sim N(0, \sigma_\varepsilon) \quad p = \begin{cases} 1 & p^* > 0 \\ 0 & p^* \le 0 \end{cases} \tag{1. A5}$$

$$\mathrm{P}(p = 1 \mid x_1) = E(p \mid x_1) = \Phi(x_1\alpha/\sigma_\varepsilon) \tag{1. A6}$$

The continuous acreage variable a* depends on farm and farmers characteristics x_2 that influence their amount choice for enrollment. The random term u has a zero mean and variance σ_u^2. Thus, a truncated normal regression model is adopted based on the fact that all zero enrollment acreages are truncated at this stage. The enrolled acreage is positive and equal to a* only if the farmers choose to participate in the program, and is zero otherwise.

$$a^* = x_2\beta + u > 0 \quad u \sim N\left(0, \sigma_u{}^2\right) \tag{1. A7}$$

$$y = \begin{cases} a^* & if \quad p = 1 \\ 0 & otherwise \end{cases} \tag{1. A8}$$

The probability density function for estimation is:

$$f(y \mid x_1, x_2) = \left[1 - \Phi(x_1\alpha/\sigma_\varepsilon)\right]^{1[y=0]} \cdot \left\{\Phi(x_1\alpha/\sigma_\varepsilon)\left[\Phi(x_2\beta/\sigma_u)\right]^{-1} \phi\left[(y - x_2\beta/\sigma_u)\right]\Big/\sigma_u\right\}^{1[y>0]} \tag{1. A6}$$

The unconditional expectation of acreage enrollment for supply curve derivation is:

$$E(y \mid x_1, x_2) = \text{P}(p=1 \mid x_1) \cdot E(y \mid x_2, c=1, p=1)$$
$$= \Phi(x_1\alpha/\sigma_\varepsilon)\left[x_2\beta + \sigma\lambda(x_2\beta/\sigma_u)\right] \quad (1.\ \text{A7})$$

Extended double hurdle model:

The extended double hurdle model is built on both single hurdle model and double hurdle model. It is similar to the double model in the sense that a prior willing-to-consider decision is explicitly modeled by probit. It is similar to the single hurdle model because the decision on whether to enroll and the decision on how much to enroll are modeled separately by probit and truncated regression. Generally, the acreage response *y* is a compound function of binary consideration decision *c*, binary participation decision *p*, and choice of positive enrollment acreage, *a**.

$$y = c \cdot p \cdot a^* \quad (1.\ \text{A8})$$

Probit estimation is used for binary choices of consideration *c*. *c** is the latent variable indicating farmers' utility gain by enrolling in the program with the maximum politically feasible payment, where x_1 is a vector of attributes determining utility and the random term *e* follows a normal distribution. Farmers would consider the program (*c*=1) only if their utility increases. The probability of consideration is estimated by a cumulative normal density function.

$$c^* = x_1\gamma + e \qquad e \sim N(0, \sigma_e) \qquad c = \begin{cases} 1 & c^* > 0 \\ 0 & c^* \le 0 \end{cases} \quad (1.\ \text{A9})$$

$$\text{P}(c=1 \mid x_1) = E(c \mid x_1) = \Phi(x_1\gamma/\sigma_e) \quad (1.\ \text{A10})$$

The participation decision p, and choice of positive enrollment acres, a* are defined as in single hurdle model:

$$p^* = x_2\alpha + \varepsilon \quad \varepsilon \sim N(0, \sigma_\varepsilon) \quad p = \begin{cases} 1 & p^* > 0 \\ 0 & p^* \le 0 \end{cases} \tag{1. A11}$$

$$\mathrm{P}(p = 1 \mid x_2) = E(p \mid x_2) = \Phi(x_2\alpha/\sigma_\varepsilon) \tag{1. A12}$$

$$a^* = x_3\beta + u > 0 \quad u \sim N\left(0, \sigma_u{}^2\right) \tag{1. A13}$$

$$y = \begin{cases} a^* & if \quad c = 1, \quad p = 1 \\ 0 & otherwise \end{cases} \tag{1. A14}$$

The probability density function derived from all three decisions for estimation is:

$$f(y \mid x_1, x_2, x_3) = \left[1 - \Phi(x_1\gamma/\sigma_e)\Phi(x_2\alpha/\sigma_\varepsilon)\right]^{1[y=0]} \cdot \left\{\Phi(x_1\gamma/\sigma_e) \cdot \Phi(x_2\alpha/\sigma_\varepsilon)\left[\Phi(x_3\beta/\sigma_u)\right]^{-1} \phi\left[(y - x_3\beta/\sigma_u)\right]\Big/\sigma_u\right\}^{1[y>0]} \tag{1. A15}$$

The unconditional expectation derived from all three decisions for supply curve derivation is:

$$\begin{aligned} E(y \mid x_1, x_2, x_3) &= \mathrm{P}(c = 1 \mid x_1) \cdot \mathrm{P}(p = 1 \mid x_2) \cdot E(y \mid x_3, c = 1, p = 1) \\ &= \Phi(x_1\gamma/\sigma_e)\Phi(x_2\alpha/\sigma_\varepsilon)\left[x_3\beta + \sigma_u\lambda(x_3\beta/\sigma_u)\right] \end{aligned} \tag{1. A16}$$

APPENDIX 1-2: STATISTICAL TESTS FOR MODEL SELECTION

Model selection based on prediction correlation:

Prediction correlation is calculated between predicted acreage enrollment based on estimation and the actual enrollment for farms that enrolled positive land area in the hypothetical PES. The following table suggests that the correlation coefficients are close among four models, though the extended double hurdle model and single hurdle model have relatively higher correlation.

Table 1-A1 Correlation between predicted and actual acreage enrollment

Model	Regression	Correlation
Extended double hurdle model	probit + probit + truncated normal	0.6172
Single hurdle model	probit + truncated normal	0.6147
Double hurdle model	probit + tobit	0.5696
Tobit model	tobit	0.5499

Model preference based on goodness-of-fit (LR test and Vuong test):

The likelihood ratio (LR) test is commonly used for selection between nested models. However, the test is not valid after estimating weighted or clustered Maximum Log-likelihood Estimations (MLE). The "likelihood" for weighted or clustered MLEs is not a true likelihood for sample distribution because individual observations are no longer independent, and the "likelihood" does not fully account for the "randomness" of the weighted sampling[9]. Thus, Vuong test that is based on individual likelihood is applied for model selection (Vuong, 1989). The likelihood is calculated for each observation and each model. The difference is taken

[9] http://www.stata.com/support/faqs/stat/lrtest.html

between two alternative models and is tested for which model fit better statistically. The test results suggest that the order of models in terms of likelihood maximization is: extended double hurdle model, single hurdle model, double hurdle model and tobit model.

Table 1-A2 Vuong test results for model selection

Vuong test	**System A**		**System B**		**System C**		**System D**	
	coef	**p-value**	**coef**	**p-value**	**coef**	**p-value**	**coef**	**p-value**
Extended double hurdle - Single hurdle	0.911	0.000	0.423	0.000	-0.070	0.156	0.048	0.358
preferred model	extended double hurdle		extended double hurdle		indifferent		indifferent	
Double hurdle - Extended double hurdle	-0.177	0.041	-0.335	0.207	-0.166	0.108	-0.397	0.001
preferred model	extended double hurdle		indifferent		indifferent		extended double hurdle	
Double hurdle - Single hurdle	-0.083	0.102	-0.204	0.217	-0.181	0.007	-0.147	0.037
preferred model	single hurdle		indifferent		single hurdle		single hurdle	
Tobit - Single hurdle	-0.100	0.045	-0.222	0.159	-0.207	0.003	-0.250	0.004
preferred model	single hurdle		indifferent		single hurdle		single hurdle	
Tobit -Double hurdle	-0.017	0.333	-0.019	0.466	-0.025	0.342	-0.103	0.025
preferred model	indifferent		indifferent		indifferent		double hurdle	

APPENDIX 1-3: REGRESSION RESULTS (MARGINAL EFFECTS) FOR DIFFERENT MODELS

Table 1-A3 Marginal effects from Probit estimation of farmers' dichotomous enrollment decision (extended double hurdle model), weighted by stratum, by Cropping Systems, 1688 Michigan corn or soybean farmers, 2008

	System A			System B			System C			System D		
	Coef.		P>z	Coef.		P>z	Coef.		P>z	Coef.		P>z
Government	-0.090		0.198	0.085		0.245	0.084		0.208	0.013		0.813
Descending sequence	-0.224	***	0.000	-0.238	***	0.001	-0.178	**	0.013	-0.103	*	0.075
Payment offer	0.011	*	0.072	0.005		0.168	0.003		0.328	0.002		0.253
Perceived env perf	0.160	***	0.000	0.196	***	0.000	0.083	*	0.074	0.176	***	0.000
General ES attitudes	0.005		0.861	-0.043		0.147	-0.027		0.373	-0.001		0.967
Total land	0.000		0.168	0.000		0.773	0.000		0.326	0.000		0.424
Sandy soil	0.153	*	0.097	0.142		0.170	-0.091		0.354	-0.018		0.844
Clay soil	0.192	**	0.019	0.046		0.633	-0.044		0.644	0.106		0.186
Moldboard tillage	-0.238		0.210	-0.128		0.595	-0.596	**	0.017	-0.061		0.742
No till tillage	0.093		0.570	0.067		0.651	0.382	**	0.023	0.386	**	0.013
Conservation tillage	0.325	**	0.025	-0.120		0.385	0.325	**	0.023	0.342	**	0.014
Wheat ratio	-0.257		0.307	0.028		0.910	0.323		0.324	-0.047		0.839
Cover crops ratio	-0.334		0.119	-0.342		0.118	-0.350	*	0.100	0.377	**	0.036
Organic ratio	0.097		0.867	0.045		0.939	-1.051		0.490	-0.330		0.585
Irrigation ratio	0.293		0.117	-0.071		0.729	0.018		0.931	0.238		0.136
Reduced fertilizer	-0.116	*	0.096	0.043		0.525	-0.064		0.542	-0.053		0.482
Reduced pesticide	-0.071		0.336	0.013		0.864	-0.116		0.234	-0.125	*	0.091
MAEAP	0.027		0.713	0.010		0.913	-0.178	**	0.028	-0.022		0.781
EQIP	0.156	**	0.021	0.087		0.200	0.142	**	0.030	0.193	***	0.000
CRP	0.057		0.418	-0.004		0.960	-0.071		0.398	-0.077		0.295
CSP	0.285	***	0.001	0.097		0.381	-0.037		0.741	-0.011		0.912
Age	0.006	**	0.017	0.007	*	0.063	0.005		0.124	0.005	**	0.038
Education	0.017		0.260	-0.007		0.584	0.005		0.750	0.003		0.796
Wheat/corn price	0.499	***	0.005	-0.166		0.458	0.166		0.323	-0.270	*	0.052
Wheat/soybean price	-0.608		0.111	0.168		0.719	-0.433		0.204	0.588	*	0.079
farm income	0.037		0.624	-0.044		0.587	-0.046		0.569	-0.086		0.210
Intercept	-6.564	***	0.000	-2.029		0.191	-2.212		0.120	-3.836	***	0.005
Number of obs	364			372			430			406		
Wald chi2(26)	104.71			64.48			52.91			75.08		
Prob>chi2	0			0			0.0014			0		
Pseudo R2	0.3106			0.2181			0.2036			0.257		
Log likelihood	-169.64			-191.22			-235.01			-179.87		

Table 1-A3 (cont'd)

Notes: 1. This is the probit regression for the decision on whether to enroll (second hurdle) in the extended double hurdle model. The first hurdle probit result is shown in Table 1-4. The second hurdle truncated regression is shown in Table 1-A5

2. The estimated coefficient for intercept is reported.

3. ***significant at 1% level, **significant at 5% level, *significant at 10% level

Table 1-A4 Marginal effects from Probit estimation of farmers' dichotomous participation decision (single hurdle model), weighted by stratum, by Cropping Systems, 1688 Michigan corn or soybean farmers, 2008

	System A		System B		System C		System D	
	Coef.	P>z	Coef.	P>z	Coef.	P>z	Coef.	P>z
Government	-0.043	0.341	0.015	0.761	0.079	0.156	-0.019	0.715
Descending sequence	-0.225 ***	0.000	-0.135 **	0.011	-0.220 ***	0.000	-0.001	0.977
Payment offer	0.010 **	0.022	0.007 ***	0.006	0.007 ***	0.000	0.001	0.433
Perceived env perf	0.164 ***	0.000	0.171 ***	0.000	0.216 ***	0.000	0.241 ***	0.000
General ES attitudes	0.018	0.313	0.015	0.497	-0.008	0.732	0.030	0.193
Total land	0.000 *	0.061	0.000	0.134	0.000	0.187	0.000	0.684
Sandy soil	0.075	0.268	-0.059	0.491	0.043	0.614	-0.011	0.892
Clay soil	0.126 **	0.037	0.018	0.831	0.052	0.504	0.185 ***	0.008
Moldboard tillage	-0.405 ***	0.007	-0.584 ***	0.004	-0.183	0.239	-0.240 *	0.065
No till tillage	0.138	0.180	0.411 ***	0.001	0.341 **	0.019	0.343 ***	0.008
Conservation tillage	0.198 **	0.022	0.169 *	0.100	0.049	0.663	0.196 *	0.084
Wheat ratio	-0.147	0.454	0.438 *	0.053	0.444 **	0.044	0.309	0.142
Cover crops ratio	-0.328 **	0.035	-0.310 *	0.055	-0.399 **	0.015	0.034	0.819
Organic ratio	-0.061	0.927	-0.260	0.738	0.165	0.797	-0.052	0.945
Irrigation ratio	0.279 **	0.034	0.231 *	0.084	-0.021	0.898	0.281 **	0.043
Reduced fertilizer	-0.077	0.104	-0.005	0.940	0.087	0.124	0.061	0.331
Reduced pesticide	-0.034	0.531	-0.064	0.379	-0.040	0.530	-0.024	0.706
MAEAP	-0.079	0.127	-0.161 **	0.027	-0.089	0.253	-0.119 *	0.058
EQIP	0.163 ***	0.003	0.196 ***	0.000	0.109 *	0.065	0.226 ***	0.000
CRP	0.046	0.328	-0.011	0.857	0.038	0.499	0.060	0.380
CSP	0.104	0.156	-0.021	0.792	0.024	0.770	-0.104	0.152
Age	0.002	0.278	0.003	0.213	0.003	0.224	0.000	0.932
Education	0.017 *	0.074	0.013	0.251	0.015	0.193	0.020 *	0.059
Wheat/corn price	0.358 ***	0.001	0.180 *	0.087	0.026	0.823	0.006	0.955
Wheat/soybean price	-0.344	0.117	-0.150	0.484	0.007	0.978	0.120	0.600
farm income	0.029	0.545	-0.035	0.551	0.021	0.717	-0.026	0.646
Intercept	-7.053 ***	0.000	-5.676 ***	0.000	-5.484 ***	0.000	-5.831 ***	0.000
Number of obs	600		594		604		613	
Wald chi2(26)	149.18		119.99		133.69		128.97	
Prob>chi2	0		0		0		0	
Pseudo R2	0.3255		0.2817		0.2884		0.2753	
Log likelihood	-209.03		-251.86		-291.41		-301.93	

Notes: 1. This is the probit regression for the decision on whether to participate in the single hurdle model. The truncated regression hurdle is shown in Table 1-A5
2. The estimated coefficient for intercept is reported.
3. ***significant at 1% level, **significant at 5% level, *significant at 10% level

Table 1-A5 Marginal effects from Probit estimation of farmers' positive acreage enrollment decision (single hurdle & extended double hurdle model), weighted by stratum, by Cropping Systems, 1688 Michigan corn or soybean farmers, 2008

	System A			System B			System C			System D		
	Coef.		P>z	Coef.		P>z	Coef.		P>z	Coef.		P>z
Government	-101		0.233	14.4		0.252	-48.5		0.194	-32.6		0.785
Descending sequence	-173	*	0.077	17.2		0.76	-28.0		0.538	5.04		0.645
Payment offer	16.1		0.428	-8.65		0.814	4.46		0.284	10.2	*	0.061
Perceived env perf	10.1		0.663	-186		0.429	-33.3		0.69	-61.6		0.824
General ES attitudes	-98.0	**	0.023	-31.8	**	0.026	-34.2		0.112	-46.7	**	0.019
Total land	1.53	***	0.000	-14.3	***	0	2.34	***	0	3.64	***	0
Sandy soil	284		0.152	88.1		0.263	-44.6		0.374	47.3		0.362
Clay soil	482	***	0.003	117	*	0.067	55.1		0.32	9.24		0.663
Moldboard tillage	-2768	***	0.003	-2783		0.414	-1061	**	0.014	236	**	0.016
No till tillage	-1649	*	0.081	266		0.698	-244		0.679	452		0.661
Conservation tillage	-1869	*	0.054	355		0.7	-425		0.622	-538		0.19
Wheat ratio	-1690		0.853	316		0.402	665		0.543	3194		0.247
Cover crops ratio	-2663		0.118	-338		0.591	-198		0.735	-800		0.201
Organic ratio	-2844	**	0.033	-5054	**	0.015	700		0.441	-454		0.829
Irrigation ratio	677		0.153	2580	*	0.052	593		0.209	414		0.148
Reduced fertilizer	133		0.104	83.7	*	0.067	59.7		0.154	40.0		0.221
Reduced pesticide	210	*	0.076	78.5		0.137	-68.9		0.252	-23.2		0.578
MAEAP	51.8		0.629	-50.7		0.546	32.5		0.343	23.0		0.484
EQIP	-96.9		0.325	-89.7		0.118	-1.28		0.899	2.20		0.926
CRP	-46.0		0.559	75.7		0.18	17.2		0.652	28.9		0.408
CSP	284	*	0.068	104	*	0.1	85.8	*	0.076	16.0		0.614
Age	-23.4	**	0.022	-23.4	**	0.014	1.94	**	0.02	-0.82		0.934
Education	28.1		0.162	-9.14		0.897	-3.10		0.933	-13.6		0.218
Wheat/corn price	-1063		0.247	446	**	0.015	-306		0.338	-691		0.178
Wheat/soybean price	230	*	0.084	-808	**	0.017	432		0.612	468	**	0.012

Table 1-A5 (cont'd)

farm income	1402	**	0.045	575	*	0.069	750	***	0.008	641	**	0.017
Intercept	-2983		0.443	-339		0.919	-1074		0.621	-2651		0.164
/sigma	822		0.000	895		0.000	754		0.000	679		0.000
Number of obs	176			211			293			292		
Wald chi2(26)	81.5			79.5			63.4			108.8		
Prob>chi2	0			0			0			0		
Log likelihood	-550			-688			-1059			-1063		

Notes: 1. This is the truncated normal regression for the level decision on how many acres to enroll that common to both single hurdle and extended double hurdle model. The other regression for single hurdle model is shown in Table 1-A4. The other regressions for extended double hurdle model are shown in Table 1-4 and 1-A3.

2. The estimated coefficient for intercept is reported.

3. ***significant at 1% level, **significant at 5% level, *significant at 10% level

Table 1-A6 Marginal effects from Tobit estimation of farmers' enrollment decision, weighted by stratum, by Cropping Systems, 1688 Michigan corn or soybean farmers, 2008

	System A			System B			System C			System D		
	Coef.		P>z	Coef.		P>z	Coef.		P>z	Coef.		P>z
Government	-87.9		0.278	39.2		0.559	36.87		0.487	-29.4		0.554
Descending sequence	-492	***	0.000	-147	**	0.036	-198	***	0.000	-29.9		0.556
Payment offer	23.9	***	0.004	9.88	**	0.018	7.07	***	0.000	2.99	*	0.057
Perceived env perf	308	***	0.000	256	***	0.000	232	***	0.000	282	***	0.000
General ES attitudes	25.7		0.463	18.6		0.580	-18.4		0.421	-11.1		0.627
Total land	0.241	***	0.000	0.223	***	0.008	0.188	***	0.000	0.212	***	0.000
Sandy soil	171		0.174	-73.2		0.516	3.23		0.971	8.98		0.915
Clay soil	352	***	0.004	32.8		0.763	58.7		0.448	185	**	0.017
Moldboard tillage	-1155	***	0.001	-1044	***	0.002	-302	*	0.078	-316	**	0.034
No till tillage	90.6		0.665	465	***	0.007	275	**	0.033	431	***	0.001
Conservation tillage	164		0.340	134		0.290	5.63		0.955	195	**	0.043
Wheat ratio	-468		0.142	449	*	0.054	398	**	0.048	309	*	0.090
Cover crops ratio	-736	**	0.019	-284		0.258	-328	*	0.079	-54.1		0.668
Organic ratio	-672		0.634	-422		0.744	536		0.565	82.3		0.926
Irrigation ratio	662	***	0.010	624	**	0.018	-26.2		0.894	175		0.288
Reduced fertilizer	-143		0.189	28.4		0.772	47.6		0.420	36.0		0.549
Reduced pesticide	-30.9		0.769	-113		0.268	-128	**	0.033	-76.5		0.198
MAEAP	-91.9		0.453	-254	**	0.045	-39.2		0.635	-84.7		0.271
EQIP	207	**	0.033	192	**	0.019	122	*	0.060	243	***	0.000
CRP	73.5		0.407	23.5		0.761	19.6		0.742	39.8		0.524
CSP	217	*	0.094	-35.7		0.762	44.2		0.606	-117		0.225
Age	1.51		0.639	3.46		0.351	1.06		0.638	1.41		0.496
Education	29.5	*	0.087	14.3		0.324	11.9		0.268	18.7	*	0.077
Wheat/corn price	585	**	0.016	126		0.468	-73.1		0.543	-180	*	0.090
Wheat/soybean price	-480		0.353	5.02		0.989	100		0.692	484	**	0.031

Table 1-A6 (cont'd)

farm income	103		0.266	-42.3		0.654	107	*	0.064	64.6		0.296
Intercept	-3158	***	0.000	-2296	***	0.000	-1511	***	0.000	-2068	***	0.000
/sigma	602			514			424			458		
Number of obs	600			594			604			613		
Wald chi2(24)	3.16			1.59			4.34			3.9		
Prob>chi2	0.00			0.03			0.00			0.00		
Pseudo R2	0.08			0.06			0.05			0.05		
Log likelihood	-772			-946			-1379			-1411		

Notes: 1. This is the tobit regression for the level decision on how many acres to enroll, including zero and positive responses in the whole dataset.
2. The estimated coefficient for intercept is reported.
3. ***significant at 1% level, **significant at 5% level, *significant at 10% level

APPENDIX 1-4: SUPPLY CURVES FROM DIFFERENT MODELS

Farmers supply environmental services via the land acreage enrolled in PES programs. Thus, the acreage supply curve predicts farmers' potential provision of environmental benefits in response to payment offer variation. The predicted acreage supply for each farm is calculated based on the unconditional expectation for the extended double hurdle model, single hurdle model and tobit model respectively (Appendix 1-1). Each farm's predicted acreage supply is limited by its total land area. State-level supply curves are calculated by 1) proportionally magnifying individual farm-level supply by the ratio of total number of farms in the state to that in the sample in each of four sample stratum, and 2) summing up total acreage enrollment in four sample strata. The supply curves are computed using re-estimated regression coefficients with only variables that are significant at 90% level in the original regression. The p-values of the F-tests for joint variable removal are all greater than 0.1.

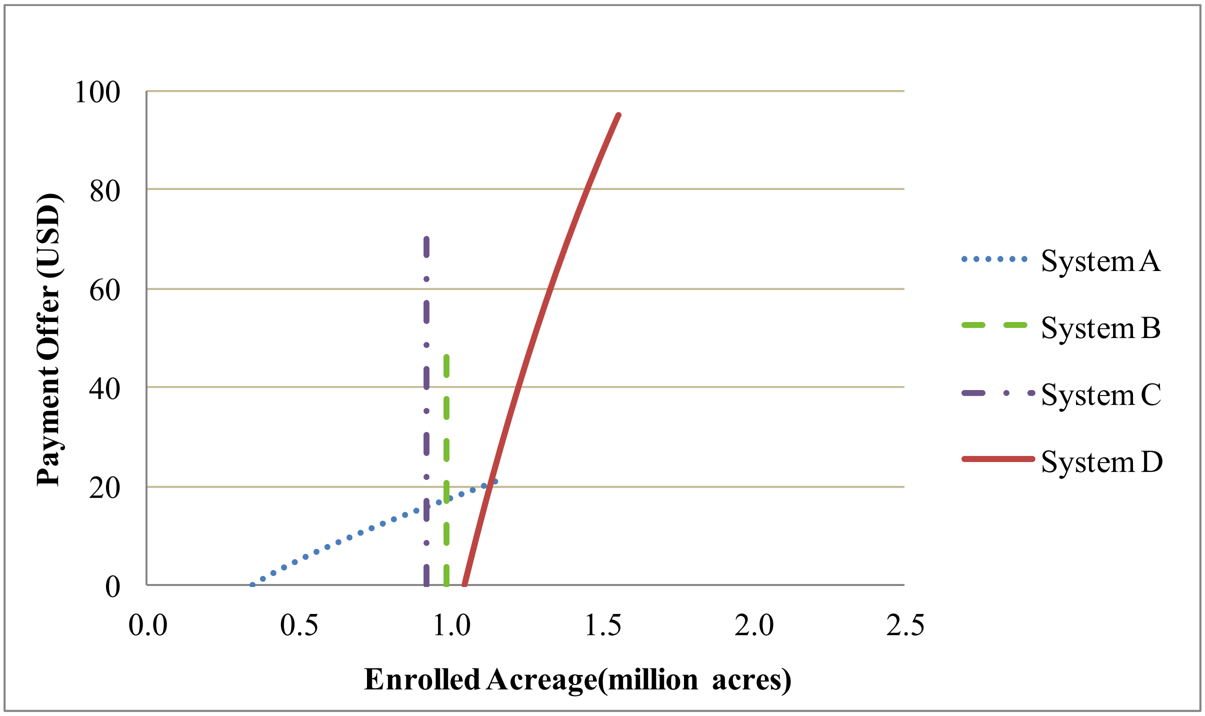

Figure 1-A1 Predicted State-level Supply Curves of Enrolled Acres by Cropping System from Extended Double Hurdle Estimation, 1688 Michigan Corn or Soybean Farms, 2008 (For interpretation of the references to color in this and all other figures, the reader is referred to the electronic version of this dissertation.)

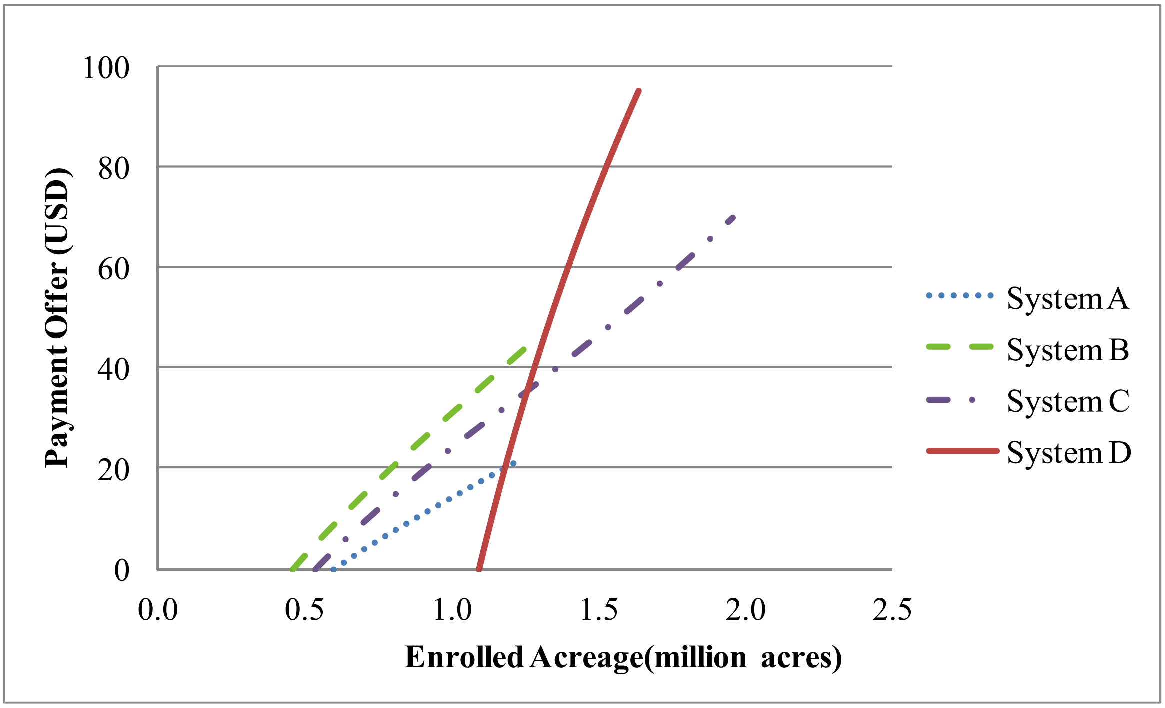

Figure 1-A2 Predicted State-level Supply Curves of Enrolled Acres by Cropping System from Single Hurdle Estimation, 1688 Michigan Corn or Soybean Farms, 2008

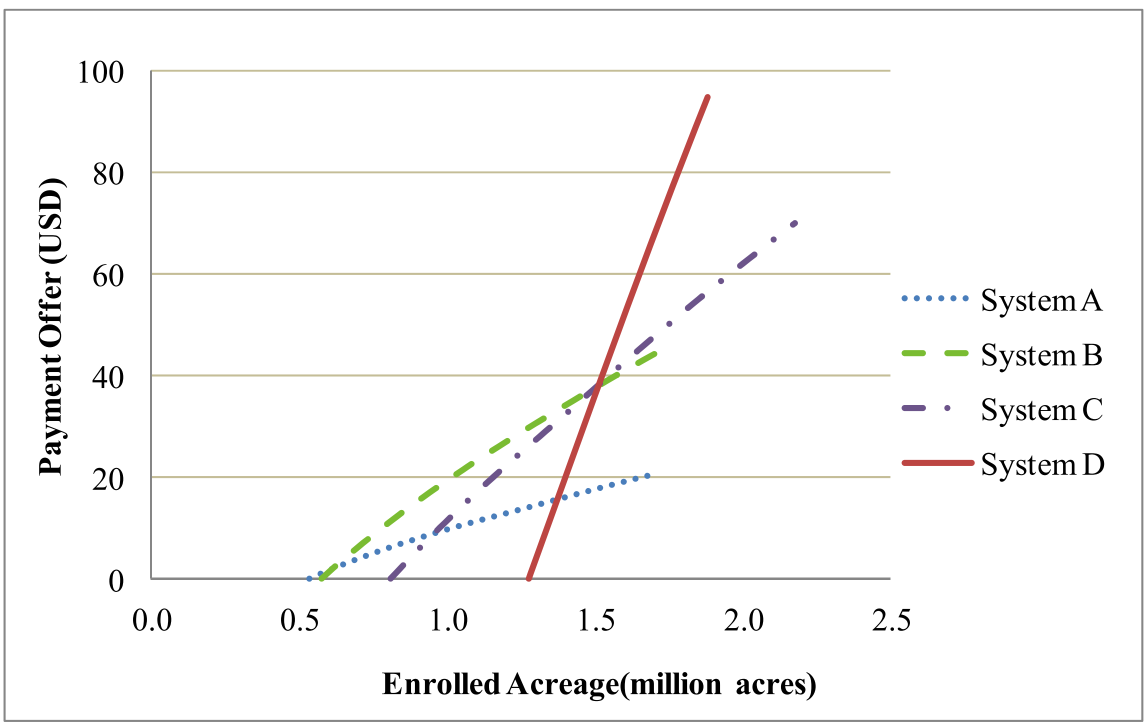

Figure 1-A3 Predicted State-level Supply Curves of Enrolled Acres by Cropping System from Tobit Estimation, 1688 Michigan Corn or Soybean Farms, 2008

APPENDIX 1-5: DATA TREATMENT FOR ORGANIC FARMS

Our hypothetical cropping systems proposed reduced use of fertilizer and pesticides, which are not compatible with organic production. The inclusion of organic farms may cause bias in the estimation. Based on our observation, there are 27 farms that have organic production on all or part of their lands. Among these farms, 15 farms have partial organic land, 9 of which enrolled positive land acreage in at least one proposed cropping system. This suggests that farms with partial organic land would still participate in our hypothetical program, and should be included in the sample. Thus, only farms with 100% organic land were removed from the regression dataset. Details of those organic farms are shown in the following table.

Table 1-A7 Proportional distribution and acreage enrollment for farms with partial/full organic production

Organic land ratio	Number of farms	Percent	Cumulative Percent	Average acreage enrolled			
				System A	System B	System C	System D
0.01	1	3.7	3.7	2000	0	0	0
0.02	2	7.41	11.11	200	200	650	650
0.04	1	3.7	14.81		777	0	0
0.05	2	7.41	22.22	0	0	1550	1550
0.06	1	3.7	25.93	800			800
0.07	1	3.7	29.63	0	0	600	600
0.13	1	3.7	33.33	200	100	200	100
0.14	2	7.41	40.74	0	0	655	480
0.22	1	3.7	44.44	0	0	0	0
0.32	1	3.7	48.15	0	0	0	300
0.53	1	3.7	51.85	0	370	0	0
0.63	1	3.7	55.56	0	0	0	0
1	12	44.44	100	0	0	89	94
Total	27	100					

APPENDIX 1-6: SELF-SELECTION IN RESPONSES TO QUESTIONNAIRES

Mail surveys for contingent valuation studies are often criticized for the self-selection problem, namely that questionnaire recipients choose to respond to the questionnaire based on their own characteristics or the survey attributes. Due to the lack of information for non-respondents in the survey, only the self-selection issue due to different survey versions is examined. There are 16 versions of the questionnaire based on the main effects orthogonal design with 6 variables, i.e., sequence of cropping system difficulty (ascending or descending) which correlated positively with payment level, payment vehicle (Federal government or a non-governmental organization), and the four varying payment levels for the four cropping systems.

A probit model is used to test whether each cropping system is influenced by self-selection in response. The dependent variable is whether the questionnaire recipients respond to the questionnaire. The independent variables are the six variables that determine questionnaire versions. The probit regression is applied for each cropping system separately. Regression results suggest that only responses to System D are influenced by the payment offer and its square term (Table 1-A8). Then Heckman selection models are applied to binary participation decision and positive acreage enrollment decision for cropping system D to test the significance of self-selection problem (Heckman, 1979). Both the Heckman probit regression and the two-step Heckman regression suggest that self-selection due to survey design is not significant in the sample.

Table 1-A8 Probit regression of binary survey response on survey version attributes, 3000 Michigan Corn or Soybean Farms, 2008

system	response	Coef.		Std. Err.	P>z
A	price	0.007		0.026	0.786
	price square	0.000		0.001	0.817
	constant	0.208		0.120	0.083
B	price	0.012		0.016	0.463
	price square	0.000		0.000	0.544
	constant	0.097		0.172	0.573
C	price	0.012		0.011	0.281
	price square	0.000		0.000	0.391
	constant	0.001		0.191	0.996
D	price	0.018	**	0.008	0.023
	price square	0.000	**	0.000	0.023
	constant	0.183		0.196	0.349

Table 1-A9 Heckman probit model for binary participation decision, 3000 Michigan Corn or Soybean Farms, 2008

Participation	Coef.	Std. Err.	z	P>z	[95% Conf.	Interval]
acres_d						
price	0.009***	0.002	4.250	0.000	0.005	0.014
government	0.038	0.077	0.500	0.618	0.112	0.189
sequence	0.017	0.079	0.210	0.834	0.171	0.138
constant	0.755	0.836	0.900	0.367	2.392	0.883
response						
government	0.022	0.051	0.430	0.664	0.078	0.123
sequence	0.027	0.052	0.520	0.601	0.075	0.130
price	0.020**	0.009	2.150	0.032	0.002	0.038
price square	0.000**	0.000	2.190	0.028	0.000	0.000
constant	0.446**	0.216	2.070	0.039	0.869	0.023
/athrho	0.021	1.026	0.020	0.984	2.031	1.989
rho	0.021	1.025	0.966	0.963		
LR test of indep. eqns. (rho = 0):	chi2(1) =0.00	Prob > chi2 = 0.9837				
Number of obs	2481					
Wald chi2(3)	19.1					
Prob>chi2	0.0003					
Log likelihood	-2554.75					

Table 1-A10 Heckman model for acreage enrollment decision, 3000 Michigan Corn or Soybean Farms, 2008

Acreage enroll	Coef.	Std. Err.	z	P>z	[95% Conf.	Interval]
acres						
acres_d	3.17***	1.03	3.08	0.002	1.15	5.18
price	38.7	36.1	1.07	0.284	32.1	109
government	33.1	37.3	0.890	0.375	106	34.0
sequence	269.500	387	0.700	0.487	1029	490
response						
government	0.023	0.051	0.450	0.649	0.077	0.124
sequence	0.026	0.052	0.500	0.617	0.076	0.128
price	0.020**	0.009	2.16	0.031	0.002	0.038
price square	0.000**	0.000	2.21	0.027	0.000	0.000
constant	0.448**	0.216	2.08	0.038	0.871	0.026
mills						
lambda	431	479	0.9	0.368	508	1370
rho	0.666					
sigma	647					
Number of obs	2480					
Wald chi2(3)	12.4					
Prob>chi2	0.0062					

REFERENCES

REFERENCES

Blundell, R., and C. Meghir. 1987. "Bivariate alternatives to the tobit model." *Journal of Econometrics* 34(1-2):179-200.

Borin, M., C. Giupponi, and F. Morari. 1997. "Effects of four cultivation systems for maize on nitrogen leaching 1. Field experiment." *European Journal of Agronomy* 6(1-2):101-112.

Bosch, D.J., Z.L. Cook, and K.O. Fuglie. 1995. "Voluntary versus mandatory agricultural policies to protect water quality: Adoption of nitrogen testing in Nebraska." *Review of Agricultural Economics* 17(1):13-24.

Burton, M., R. Dorsett, and T. Young. 1996. "Changing preferences for meat: Evidence from UK household data, 1973-93." *European Review of Agricultural Economics* 23(3):357-370.

Cattaneo, A., R. Claassen, R. Johansson, and M. Weinberg. 2005. "Flexible conservation measures on working land: What challenges lie ahead?". United States Department of Agriculture, Economic Research Service. http://www.ers.usda.gov/publications/err5/err5.pdf

Correll, D. 1998. "Role of phosphorus in the eutrophication of receiving waters: A review." *Journal of Environmental Quality* 27(2):261-266.

Cragg, J.G. 1971. "Some statistical models for limited dependent variables with application to thedemand for durable goods." *Econometrica* 39(5):829-844.

D'Emden, F.H., R.S. Llewellyn, and M.P. Burton. 2008. "Factors influencing adoption of conservation tillage in australian cropping regions." *Australian Journal of Agricultural and Resource Economics* 52(2):169-182.

Davey, K.A., and W.H. Furtan. 2008. "Factors that affect the adoption decision of conservation tillage in the prairie region of canada." *Canadian Journal of Agricultural Economics* 56(3):257-275.

Deaton, A., and M. Irish. 1984. "Statistical models for zero expenditures in household budgets." *Journal of Public Economics* 23(1-2):59-80.

del Saz-Salazar, S., and P. Rausell-Koster. 2008. "A double-hurdle model of urban green areas valuation: Dealing with zero responses." *Landscape and Urban Planning* 84(3-4):241-251.

Delgado, J., R. Sparks, R. Follett, J. Sharkoff, and R. Riggenbach. 1999. "Use of winter cover crops to conserve soil and water quality in the San Luis Valley of south central Colorado, soil quality and soil erosion." *Soil and Water Conservation Society*:125–142.

Dillman, D.A. 2007. *Mail and Internet Surveys: The Tailored Design Method*. 2nd ed. New York: John Wiley.

Dupraz, P., D. Vermersch, B.H. De Frahan, and L. Delvaux. 2003. "The environmental supply of farm households: A flexible willingness to accept model." *Environmental and Resource Economics* 25(2):171-189.

Engel, S., S. Pagiola, and S. Wunder. 2008. "Designing payments for environmental services in theory and practice: An overview of the issues." *Ecological Economics* 65(4):663-674.

Epplin, F.M., and T.F. Tice. 1986. "Influence of crop and farm size on adoption of conservation tillage." *Journal of Soil and Water Conservation* 41(6):424-427.

Ervin, C.A., and D.E. Ervin. 1982. "Factors affecting the use of soil conservation practices: Hypotheses, evidence, and policy implications." *Land Economics* 58(3):277-292.

Fuss, M.A., and D. McFadden (1978) Production economics: A dual approach to theory and applications, ed. M.A. Fuss, and D.L. McFadden, vol. 1. Amsterdam, North-Holland, pp. 219-268.

Glotfelty, D.E., J.N. Seiber, and A. Liljedahl. 1987. "Pesticides in fog." *Nature* 325(6105):602-605.

Goodwin, B., L. Offenbach, T. Cable, and P. Cook. 1993. "Discrete/continuous contingent valuation of private hunting access in Kansas." *Journal of Environmental Management* 39(1):1-12.

Gould, B.W., W.E. Saupe, and R.M. Klemme. 1989. "Conservation tillage - the role of farm and operator characteristics and the perception of soil-erosion." *Land Economics* 65(2):167-182.

Greene, W.H. 2000. *Econometric Analysis*. Fourth ed. Englewood Cliffs, NJ: Prentice Hall.

Heckman, J.J. 1979. "Sample selection bias as a specification error." *Econometrica: Journal of the Econometric Society*:153-161.

Hoben, J.P., R.J. Gehl, N. Millar, P.R. Grace, and G.P. Robertson. 2011. "Nonlinear nitrous oxide (N_2O) response to nitrogen fertilizer in on-farm corn crops of the us midwest." *Global Change Biology* 17(2):1140-1152.

Jensen, H.H., and S.T. Yen. 1996. "Food expenditures away from home by type of meal." *Canadian Journal of Agricultural Economics* 44(1):67-80.

Jolejole, M.C.B. 2009. "Trade-offs, incentives and the supply of ecosystem services from cropland." Michigan State University. http://aec3.aec.msu.edu/theses/fulltext/jolejole1_ms.pdf

Jolejole, M.C.B. 2009. "Trade-offs, incentives and the supply of ecosystem services from cropland." M.S. Thesis, Michigan State University, Department of Agricultural, Food and Resource Economics. http://aec3.aec.msu.edu/theses/fulltext/jolejole1_ms.pdf

Jones, A. 1992. "A note on computation of the double-hurdle model with dependence with an application to tobacco expenditure." *Bulletin of Economic Research* 44(1):67-74.

Joyce, B., W. Wallender, J. Mitchell, L. Huyck, S. Temple, P. Brostrom, and T. Hsiao. 2002. "Infiltration and soil water storage under winter cover cropping in California's Sacramento Valley." *Transactions of the ASAE* 45(2):315-326.

Knowler, D., and B. Bradshaw. 2007. "Farmers' adoption of conservation agriculture: A review and synthesis of recent research." *Food Policy* 32(1):25-48.

Lal, R., M. Griffin, J. Apt, L. Lave, and M. Morgan. 2004. "Managing soil carbon." *Science* 304(5669):393.

Lambert, D., P. Sullivan, R. Claassen, and L. Foreman. 2006. Title. Economic Research Report No. 14. Economic Research Service, U.S. Department of Agriculture.

Lasley, P., M. Duffy, K. Kettner, and C. Chase. 1990. "Factors affecting farmers' use of practices to reduce commercial fertilizers and pesticides." *Journal of Soil and Water Conservation* 45(1):132-136.

Lau, L.J. (1986) Functional forms in econometric model building, ed. Z. Griliches, and M.D. Intriligator, vol. 3. Amsterdam, North-Holland Publishing Co., pp. 1515-1566.

Lee, L.K., and W.H. Stewart. 1983. "Landownership and the adoption of minimum tillage." *American Journal of Agricultural Economics* 65(2):256-264.

Lin, T.-F., and P. Schmidt. 1984. "A test of the tobit specification against an alternative suggested by cragg." *The Review of Economics and Statistics* 66(1):174-177.

Lynne, G.D., and L.R. Rola. 1988. "Improving attitude-behavior prediction models with economic variables - farmer actions toward soil conservation." *Journal of Social Psychology* 128(1):19-28.

Lynne, G.D., J.S. Shonkwiler, and L.R. Rola. 1988. "Attitudes and farmer conservation behavior." *American Journal of Agricultural Economics* 70(1):12-19.

Martínez-Espiñeira, R. 2006. "A box-cox double-hurdle model of wildlife valuation: The citizen's perspective." *Ecological Economics* 58(1):192-208.

Mazvimavi, K., and S. Twomlow. 2009. "Socioeconomic and institutional factors influencing adoption of conservation farming by vulnerable households in Zimbabwe." *Agricultural Systems* 101(1-2):20-29.

McSwiney, C.P., and G.P. Robertson. 2005. "Nonlinear response of n2o flux to incremental fertilizer addition in a continuous maize (zea mays l.) cropping system." *Global Change Biology* 11(10):1712-1719.

McSwiney, C.P., S.S. Snapp, and L.E. Gentry. 2010. "Use of N immobilization to tighten the N cycle in conventional agroecosystems." *Ecological Applications* 20(3):648-662.

Musser, W.N., J.S. Shortle, K. Kreahling, B. Roach, W.-C. Huang, D.B. Beegle, and R.H. Fox. 1995. "An economic analysis of the pre-sidedress nitrogen test for Pennsylvania corn production." *Review of Agricultural Economics* 17(1):25-35.

Negatu, W., and A. Parikh. 1999. "The impact of perception and other factors on the adoption of agricultural technology in the Moret and Jiru Woreda (district) of Ethiopia." *Agricultural Economics* 21(2):205-216.

Neill, S.P., and D.R. Lee. 2001. "Explaining the adoption and disadoption of sustainable agriculture: The case of cover crops in northern honduras." *Economic Development and Cultural Change* 49(4):793-820.

Newman, C., M. Henchion, and A. Matthews. 2003. "A double-hurdle model of irish household expenditure on prepared meals." *Applied Economics* 35(9):1053 - 1061.

Norris, P., and S. Batie. 1987. "Virginia farmers' soil conservation decisions: An application of tobit analysis." *Southern Journal of Agricultural Economics* 19(1):79-90.

Nowak, P. 1992. "Why farmers adopt production technology." *Journal of Soil and Water Conservation* 47(1):14-16.

Oades, J. 1984. "Soil organic matter and structural stability: Mechanisms and implications for management." *Plant and Soil* 76(1):319-337.

Okoye, C.U. 1998. "Comparative analysis of factors in the adoption of traditional and recommended soil erosion control practices in Nigeria." *Soil and Tillage Research* 45(3-4):251-263.

Pautsch, G., L. Kurkalova, B. Babcock, and C. Kling. 2001. "The efficiency of sequestering carbon in agricultural soils." *Contemporary Economic Policy* 19(2):123-134.

Peel, M. 1998. "Crop rotations for increased productivity, eb-48. North Dakota State University extension service." http://www.ag.ndsu.edu/pubs/plantsci/crops/eb48-1.htm

Pimentel, D., and N. Kounang. 1998. "Ecology of soil erosion in ecosystems." *Ecosystems* 1(5):416-426.

Poudel, D., W. Horwath, J. Mitchell, and S. Temple. 2001. "Impacts of cropping systems on soil nitrogen storage and loss." *Agricultural Systems* 68(3):253-268.

Prokopy, L.S., K. Floress, D. Klotthor-Weinkauf, and A. Baumgart-Getz. 2008. "Determinants of agricultural best management practice adoption: Evidence from the literature." *Journal of Soil and Water Conservation* 63(5):300-311.

Purvis, A., J. Hoehn, V. Sorenson, and F. Pierce. 1989. "Farmers' response to a filter strip program: Results from a contingent valuation survey." *Journal of Soil and Water Conservation* 44(5):501.

Rahm, M.R., and W.E. Huffman. 1984. "The adoption of reduced tillage - the role of human-capital and other variables." *American Journal of Agricultural Economics* 66(4):405-413.

Reganold, J., L. Elliott, and Y. Unger. 1987. "Long-term effects of organic and conventional farming on soil erosion."

Reicosky, D., and M. Lindstrom. 1993. "Fall tillage methods: Effect on short-term carbon dioxide flux from soil." *Agronomy Journal* 85(6):1237-1243.

Roberts, R.K., B. English, Q. Gao, and J.A. Larson. 2006. "Simultaneous adoption of herbicide-resistant and conservation-tillage cotton technologies." *Journal of Agricultural and Applied Economics* 38(3):629.

Sheikh, A.D., T. Rehman, and C.M. Yates. 2003. "Logit models for identifying the factors that influence the uptake of new 'no-tillage' technologies by farmers in the rice-wheat and the cotton-wheat farming systems of pakistan's punjab." *Agricultural Systems* 75(1):79-95.

Shrestha, R.A.M., J. Alavalapati, A. Seidl, K. Weber, and T.R.I. Suselo. 2007. "Estimating the local cost of protecting koshi tappu wildlife reserve, nepal: A contingent valuation approach." *Environment, Development and Sustainability* 9(4):413-426.

Sidibe, A. 2005. "Farm-level adoption of soil and water conservation techniques in northern Burkina Faso." *Agricultural Water Management* 71(3):211-224.

Smith, M. 2003. "On dependency in double-hurdle models." *Statistical Papers* 44(4):581-595.

Smith, M. 2002. "On specifying double-hurdle models." *Handbook of Applied Econometrics and Statistical Inference*:535-552.

Soule, M., A. Tegene, and K. Wiebe. 2000. "Land tenure and the adoption of conservation practices." *American Journal of Agricultural Economics*:993-1005.

Su, S.-J.B., and S.T. Yen. 1996. "Microeconometric models of infrequently purchased goods: An application to household pork consumption." *Empirical Economics* 21(4):513-533.

Tobin, J. 1958. "Estimation of relationships for limited dependent variables." *Econometrica* 26(1):24-36.

Traore, N., R. Landry, and N. Amara. 1998. "On-farm adoption of conservation practices: The role of farm and farmer characteristics, perceptions, and health hazards." *Land Economics* 74(1):114-127.

Upadhyay, B.M., D.L. Young, H.H. Wang, and P. Wandschneider. 2003. "How do farmers who adopt multiple conservation practices differ from their neighbors?" *American Journal of Alternative Agriculture* 18(1):27-36.

Uri, N. 1997. "Conservation tillage and input use." *Environmental Geology* 29(3):188-201.

van den Berg, F., R. Kubiak, W.G. Benjey, M.S. Majewski, S.R. Yates, G.L. Reeves, J.H. Smelt, and A.M.A. van der Linden. 1999. "Emission of pesticides into the air." *Water, Air, & Soil Pollution* 115(1):195-218.

Vuong, Q.H. 1989. "Likelihood ratio tests for model selection and non-nested hypotheses." *Econometrica: Journal of the Econometric Society*:307-333.

Warriner, G., and T. Moul. 1992. "Kinship and personal communication network influences on the adoption of agriculture conservation technology." *Journal of Rural Studies* 8(3):279-291.

Warriner, G.K., and T.M. Moul. 1992. "Kinship and personal communication network influences on the adoption of agriculture conservation technology." *Journal of Rural Studies* 8(3):279-291.

Wei, Y.P., D. Chen, R.E. White, I.R. Willett, R. Edis, and J. Langford. 2009. "Farmers' perception of environmental degradation and their adoption of improved management practices in Alxa, China." *Land Degradation & Development* 20(3):336-346.

Woodridge, J. (2008) Econometric analysis of cross-section and panel data, 2nd Edition. Cambridge, MA, The MIT Press, pp. 453-481.

Wossink, A., and S. Swinton. 2007. "Jointness in production and farmers' willingness to supply non-marketed ecosystem services." *Ecological Economics* 64(2):297-304.

Wu, J., and B. Babcock. 1998. "The choice of tillage, rotation, and soil testing practices: Economic and environmental implications." *American Journal of Agricultural Economics* 80(3):494-511.

Yen, S., P. Boxall, and W. Adamowicz. 1997. "An econometric analysis of donations for environmental conservation in Canada." *Journal of Agricultural and Resource Economics* 22:246-263.

Yen, S., and H. Jensen. 1996. "Determinants of household expenditures on alcohol." *Journal of Consumer Affairs* 30(1).

Yen, S.T., and A.M. Jones. 1997. "Household consumption of cheese: An inverse hyperbolic sine double-hurdle model with dependent errors." *American Journal of Agricultural Economics* 79(1):246-251.

Zbinden, S., and D.R. Lee. 2005. "Paying for environmental services: An analysis of participation in Costa Rica's PSA program." *World Development* 33(2):255-272.

Zhang, W., T.H. Ricketts, C. Kremen, K. Carney, and S.M. Swinton. 2007. "Ecosystem services and dis-services to agriculture." *Ecological Economics* 64(2):253-260.

ESSAY 2: MODELING CERTAINTY-ADJUSTED WILLINGNESS TO PAY FOR ECOSYSTEM SERVICE IMPROVEMENT FROM AGRICULTURE

2.1 Introduction

The public demand for nonmarket ecosystem services (ES) stems from people's desire for a better environment for living, such as clean air and drinking water for health, abundant natural resources for recreation, and diverse landscapes for scenic views. A broad variety of environmental improvements that would affect the welfare of local communities and the general public can be generated from land management practices in agricultural ecosystems. Examples include water quality improvement from less fertilizer input, and greenhouse gas (GHG) mitigation from winter cover crops. Payment-for-Ecosystem-Service (PES) programs have been increasingly implemented around the world to facilitate the provision of these ecosystem services (ES). In order to design efficient public policies for enhancing ecosystem services from agriculture, the demand for ES needs to be addressed in addition to the supply side analysis on farmers. The public willingness to pay (WTP) from stated preference studies is an important measure of the demand for non-market ES.

However, the survey-based contingent valuation is likely to suffer from respondents' preference uncertainty, which may increase the variance and even cause bias in the estimation of WTP. The valuation of public goods like ecosystem services is likely to be subject to even larger bias than valuation of private goods (List and Gallet, 2001). Based on review of the literature, the uncertainty in preference may originate from the three sources.

First, uncertain responses can be caused by incomplete knowledge of the hypothetical markets (Li and Mattsson, 1995). The good or service to be valued may be unclear to respondents who have never experienced or used it, such as mitigation of greenhouse gas emissions. For tangible goods or services, the result of changes in quality/quantity may not be fully understood (Wang and Whittington, 2005). For example, the degree of improvement in eutrophic lakes may be unclear to some people.

Second, respondents may have different understanding of the proposed policy instrument for providing the good (Shaikh, et al., 2007), such as how an increased income tax would serve as a payment vehicle to collect public funding. The implementation of policy can influence their certainty of payment.

Third, individuals may also have specific uncertainties in their evaluation of trade-off between amenity and dollar values (Shaikh, et al., 2007), the perception of substitutes for the hypothetical goods, or their expectation of future income (Wang and Whittington, 2005).

Given the potential for preference uncertainty in willingness to pay estimation, ES demand estimates should be tested and, if necessary, adjusted accordingly. Taking advantage of a unique stated preference data set that includes a follow-up question rating the respondent's certainty level, this study evaluates alternative methods of modeling certainty-adjusted WTP for two important ecosystem services from cropland management--improvement in eutrophic lakes and mitigation of global warming.

Previous studies have used various ways to incorporate preference uncertainty into contingent valuation. In the case of binary choice format with a follow-up 10-point numerical certainty scale, "yes" and "no" responses were recoded to a grid of probability ranging from 0 to 1 (Chang, et al., 2007, Li and Mattsson, 1995, Loomis and Ekstrand, 1998, Shaikh, et al., 2007). Alternatively, "no" responses were recoded as "yes" based on a fixed cutoff level of certainty (Champ and Bishop, 2001, Champ, et al., 1997, Ethier, et al., 2000, Loomis and Ekstrand, 1998, Samnaliev, et al., 2006). In the case of a polychotomous choice format with uncertain choices such as “probably yes”, “not sure”, and “probably no”, the responses were analyzed directly (Lundhede, et al., 2009, Wang and Whittington, 2005), or re-categorized to binary responses under different assumptions (Chang, et al., 2007, Johannesson, et al., 1998, Samnaliev, et al., 2006, Vossler, et al., 2003, Whitehead, et al., 1998). There are also other unique attempts to model preference uncertainty. For example, Li and Mattsson (1995) treated respondent uncertainty as one source of measurement error and weighted the individual dichotomous-choice responses directly in the likelihood function by a numerical certainty scale. Van Kooten et al. (2001) introduced a fuzzy model that assumes two fuzzy sets for willingness to pay and unwillingness to pay. This model was then extended to a fuzzy random utility maximization framework by Sun and van Kooten (2009). Wang and Whittington (2005) developed a non-econometric approach relying on the stochastic payment card for modeling preference uncertainty. Moore et al. (2010) assumed that the certainty scale embodied a flexible mapping between the probability of payment and the integers 1-10, and applied maximum likelihood estimation (MLE) to obtain the parameters of a mapping rule for a specific dataset.

Examples of goods and services that have been valued with preference uncertainty include conservation of a lagoon (Chang, et al., 2007, Whitehead, et al., 1998), private access to public land (Samnaliev, et al., 2006, Vossler, et al., 2003), green energy (Champ and Bishop, 2001, Ethier, et al., 2000, Poe, et al., 2002), and endangered species (Loomis and Ekstrand, 1998).

Compared to previous studies, this essay complements the literature in three ways. First, I compare four calibration methods to incorporate numerical certainty using a large dataset with panel data structure. The number of observations used in previous studies typically range from

300 to1600 (Akter, et al., 2008), whereas this study has a sample of about 3000 observations including multiple choices made by the same respondent. In the process, econometric treatment for panel data is applied to models that symmetrically or asymmetrically recode binary responses into a grid of probability based on 10-point certainty scale. Second, two functional forms for WTP are compared to examine the consistency of the influence from preference uncertainty on WTP estimation. Third, the regime of preference uncertainty estimation is extended beyond single tangible goods or services in a local setting (such as green energy, lagoon conservation and endangered species) to ecosystem services from agriculture, which include both a global public good, greenhouse gas mitigation, and a regional public good, eutrophic lake abatement.

2.2 Theoretical model

Public demand for nonmarket ecosystem services is assumed to be rooted in the individual utility model (Flores, 2003). That model holds that utility depends on a bundle of market goods, *Z*, and the level of environmental improvements, *ES*, conditioned on resident-specific characteristics, *R*, such as age, education, gender and voter registration. People choose the level of market goods to maximize utility subject to a budget constraint that the expenditure cannot exceed income *y*, given price vector P_z.

$$\underset{Z}{Max}\, U^{R}\left(Z^{R}, ES(lake, GHG) \mid R\right) \tag{2.1}$$

$$s.t.\ \ P_Z Z^R \leq y \tag{2.2}$$

The demand function for market good is

$$Z^{R*} = Z\left(P_Z, ES, y \mid R\right) \tag{2.3}$$

The indirect utility function at the optimal level of the market good bundle is

$$U^{R*}\left(Z^{R*}, ES \mid R\right) = V\left(P_Z, ES, y \mid R\right) \tag{2.4}$$

At the status quo level of ecosystem services, the indirect utility can be written as

$$V\left(P_Z, ES^0, y \mid R\right) \tag{2.5}$$

If there is an improvement in ecosystem services from ES^0 to ES^1, such as reduction in eutrophic lakes and greenhouse gas emissions, then the individual would be willing to give up a certain amount of income, known as willingness to pay (WTP), such that:

$$V\left(P_Z, ES^0, y \mid R\right) = V\left(P_Z, ES^1, y - WTP \mid R\right) \tag{2.6}$$

The true WTP can be solved as a function of those characteristics in the indirect utility function $WTP\left(P_Z, ES^0, ES^1, y \mid R\right)$. However, for each individual, the observed WTP in stated preference surveys is comprised of the true willingness to pay, WTP_i*, and an error term ε_i, which represents stochastic disturbances that are not captured by the indirect utility function.

$$WTP_i = WTP_i^*\left(P_Z, ES^0, ES^1, y \mid R\right) + \varepsilon_i \tag{2.7}$$

In an ordinary contingent valuation study, the error term, which is typically specified as following a normal distribution with zero mean and constant variance, is assumed to reflect the observer uncertainty arising from omitted variables. However, the stochastic disturbance may also be related to the respondent due to their inherent randomness in preferences (Li and Mattsson, 1995). For the dichotomous choice question, the respondent's one-shot response is a realization of the underlying probabilistic mechanism because they may not give the same response each time when facing the same conditions. Li and Mattsson (1995) showed that the maximum likelihood estimate of the valuation distribution incorporating both observer uncertainty and respondent uncertainty would be flattened compared with the true distribution. The associated overestimation of the standard deviation may lead to value inference bias, although the parameter vector is still consistent. Different approaches to capture and model this preference uncertainty are discussed in sections 3 and 4.

In dichotomous-choice contingent valuation surveys in a referendum format, respondents are typically asked to vote "yes" or "no" for a payment level associated with an improvement in the quality of non-market goods. They would vote "yes" if WTP is greater than the given program cost *C* as shown in equation 2.8.

$$\begin{aligned} \Pr(yes_i) &= \Pr\left(V\left(ES^1, y_i - C_i\right) > V\left(ES^0, y_i\right)\right) \\ &= \Pr\left(V\left(ES^1, y_i - C_i\right) > V\left(ES^1, y_i - WTP_i\right)\right) = \Pr\left(WTP_i > C_i\right) \end{aligned} \tag{2.8}$$

As pointed out by Wang (1997), an individual's valuation of any good or service is best characterized as a random variable with an unspecified probability. Such a probability can be represented by the probability of voting "yes" in equation 2.8. An example probability distribution is illustrated in Figure 2-1. Normally, if the mean of WTP is greater than proposed tax payment (C), the respondent would vote "yes". When considering preference uncertainty, the decision rule depends on the whole distribution rather than the mean. The variance of distribution reflects both observer uncertainty and respondent uncertainty. The shaded area that is below the function and greater than the proposed tax payment represents the probability of voting "yes" in empirical estimation. Higher certainty for voting "yes" means higher probability, which is typically associated with higher mean of WTP.

Following Chen (2010), this study adopts a spike probability model to distinguish people who have zero willingness to pay for the ecosystem services and are not responsive to price change. The unconditional probability of voting “yes” to the program is a product of the probability of positive WTP and the conditional probability of “yes” vote as in equation 2.9.

$$\Pr(yes_i \mid WTP_i) = \Pr\left(WTP_i > 0\right)\Pr\left(yes_i \mid WTP_i > 0\right) \tag{2.9}$$

The probability of having positive willingness to pay is endogenously modeled with environmental quality changes and individual characteristics.

2.3 Data

Data for this study come from a 2009 mail survey of Michigan residents that yielded 2211 responses (40% response rate). The contingent valuation (CV) question was posed as a dichotomous choice referendum with income taxes as the payment vehicle. Each respondent was asked to vote on three independent land stewardship programs, which provide different greenhouse gas and eutrophic lake reductions from changes in land management practices associated with a tax payment. Respondents were informed that if more than 50% of the voters voted for the program, it would be implemented and they would have to pay the cost.

The reductions in eutrophic lake numbers and greenhouse gas emissions were selected among a series of environmental improvements from agriculture because of their significant and measurable impact on the public based on both an ES quantification study and a survey pretest (Chen, 2010). Five levels of the two environmental improvements offered were: zero change, low change, median change, high change and double of the high change[10]. The high change was maximum possible reduction calculated by Chen (2010).

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[10] In pretest interviews for this contingent valuation survey, some respondents reported that the ecosystem service changes were too small to influence their choices. To reduce the probability of scope insensitivity problem, the original maximum change is doubled as the new range of the two attributes (Chen, 2010).

The cost for each program was expressed as the respondent's own share of increased annual federal income tax, which would only be used in the state of Michigan. The costs for all three land stewardship programs were the same to each respondent but were varied across residents. Based on the questionnaire pretest, the program cost levels were set at $10, $30, $50, $100, and $200 per year. If the respondent voted "no" for the WTP question, a follow-up question asked whether she would vote for the program if it did not cost her anything. That response is used to identify respondents who have zero WTP.

To test the effect of provision mechanisms on respondents' WTP, two alternative versions of the questionnaire were provided. One specified that the land stewardship program was to pay *farmers* to adopt environmental friendly farming practices, while the other was to pay *general land owners*.

To capture the individual preference uncertainty, several formats have been used in the literature. The simplest format is to add a "not sure" or "don't know" option to the dichotomous "yes/no" choice to a given price (Balcombe and Fraser, 2009, Fenichel, et al., 2006, Haener and Adamowicz, 1998, Krosnick, et al., 2002, Wang, 1997). A similar but extended format is the polychotomous choice (PC) method, in which respondents are provided with a set of uncertainty options, for example, "definitely yes", "probably yes", "not sure", "probably no", and "definitely no" (Alberini, et al., 2003, Chang, et al., 2007, Johannesson, et al., 1998, Samnaliev, et al., 2006, Vossler, et al., 2003, Whitehead, et al., 1998). The third way is to follow the standard "yes/no" choice by a numerical certainty scale ranging from 1 to 10, with which the respondents can indicate the level of certainty about their "yes/no" voting decision (Champ and Bishop, 2001, Champ, et al., 1997, Chang, et al., 2007, Ethier, et al., 2000, Li and Mattsson, 1995, Loomis and Ekstrand, 1998, Moore, et al., 2010, Poe, et al., 2002, Samnaliev, et al., 2006, Shaikh, et al., 2007). A fourth approach that directly elicits the distribution of preference uncertainty is the stochastic payment card (SPC) format, which presents each respondent with numerical likelihood that the she would vote “yes” to a series of payment levels (Ichoku, et al., 2009, Wang and Whittington, 2005).

Among those formats for eliciting preference uncertainty, this study adopted the 10-point numerical certainty scale approach in a follow-up question, which asked how certain the respondents were with their “yes/no” answers to the WTP question. The survey question is shown in Figure 2-2.

Fourteen questionnaire versions were generated from an experimental design with three CV questions per respondent. Information was provided about eutrophication of lakes and global warming (GW), how residents would be affected and how land management practices would improve environmental qualities. Additional questions covered residents’ responses to the backgrounds, demographic status and their attitudes on various environmental issues. Variable descriptions appear in Table 2-1 with descriptive statistics in Table 2-2. Among 2211 responses, 3396 observations from 1293 respondents are used for analyzing the certainty-adjust models with panel data structure. Detailed information about data collection and questionnaire design can be found in Chen (2010).

2.4 Empirical model and variables

2.4.1 Econometric model of WTP

The model for estimating empirical WTP conforms to the theoretical structure presented in equation 2.9, which combines a spike for zero WTP with conditional positive WTP. Following Chen (2010), the spike probability of positive WTP for individual *i* is a function of the change in ecosystem services, and individual resident characteristics R_i. *Lake* and *GHG* represent the effect of the hypothetical program in terms of the number of eutrophic lakes cleaned and the percentage of greenhouse gas emission reduced from the year 2000 level.

$$\Pr\left(WTP_i > 0\right) = \Phi\left(a + b_L Lake + b_G GHG + cR_i\right) \tag{2.10}$$

As respondents who have a zero WTP have been separated by the spike model, the WTP from the rest of respondents is strictly positive, which is then ensured by the semi-log functional form in equation 2.11. In this equation, ES_L and ES_G represent the abatement in eutrophic lakes and GHG emissions. *A* is respondent's attitude towards global warming. *R* indicates individual-specific characteristics. An interaction of concern about global warming and greenhouse gas reduction is generated to test the aggregate effect.

$$WTP_i \,|_{WTP_i > 0} = \exp\left(\delta + \beta_L ES_L + \beta_G ES_G + \alpha A_i + \varphi ES_G A_i + \gamma R_i + \varepsilon_{ij}\right) \tag{2.11}$$

Two functional forms different in the expression of lake and GHG variables are compared to examine the consistency of influence from incorporating preference uncertainty on the WTP estimation. In the first semi-log function, ES_L and ES_G represents the number of cleaned eutrophic lakes and percentage of greenhouse gas emission reduced from the 2000 level as in the spike model (equation 2.12).

$$WTP_i\,|_{WTP_i>0} = \exp\left(\delta + \beta_L lake + \beta_G GHG + \alpha A_i + \varphi GHG \cdot A_i + \gamma R_i + \varepsilon_{ij}\right) \quad (2.12)$$

This assumption of linearity in environmental improvements within the semi-log function is common in the literature. However, the projected resident's WTP would be growing at an increasing rate with respect to the environmental services, while the economic theory of demand typically assumes an increasing and concave benefit (WTP) function due to diminishing marginal utility (Marshall, 2009). To maintain the assumptions of both positive conditional WTP and diminishing marginal utility, the mixed log-log functional form is proposed in equation 2.13, where the number of cleaned eutrophic lakes and percentage of greenhouse gas mitigation are transformed by taking the natural logarithm in addition to first functional form in equation 2.12[11].

$$WTP_i\,|_{WTP_i>0} = \exp\left(\delta + \beta_L \mathbf{ln} lake + \beta_G \mathbf{ln} GHG + \alpha A_i + \varphi \mathbf{ln} GHG \cdot A_i + \gamma R_i + \varepsilon_{ij}\right) \quad (2.13)$$

Assuming the error term ε is normally distributed with mean zero and constant variance σ^2, the conditional probability distribution of voting "yes" to the dichotomous-choice valuation question with cost C_i is

$$\begin{aligned}
\Pr(Y_i = 1\,|_{WTP_i>0}) &= \Pr\left(WTP_i > C_i\right) \\
&= \Pr\left(\exp\left(\delta + \beta_L ES_L + \beta_G ES_G + \alpha A_i + \varphi ES_G A_i + \gamma R_i + \varepsilon_{ij}\right) > C_i\right) \\
&= \Pr\left(\delta + \beta_L ES_L + \beta_G ES_G + \alpha A_i + \varphi ES_G A_i + \gamma R_i + \varepsilon_{ij} > \ln C_i\right) \qquad (2.14) \\
&= \Pr\left(\frac{\delta - \ln C_i + \beta_L ES_L + \beta_G ES_G + \alpha A_i + \varphi ES_G A_i + \gamma R_i}{\sigma} > -\frac{\varepsilon_{ij}}{\sigma}\right) \\
&= \Phi\left(\frac{\delta}{\sigma} - \frac{1}{\sigma}\ln C_i + \frac{\beta_L}{\sigma} ES_L + \frac{\beta_G}{\sigma} ES_G + \frac{\alpha}{\sigma} A_i + \frac{\varphi}{\sigma} ES_G A_i + \frac{\gamma}{\sigma} R_i\right)
\end{aligned}$$

---

[11] The *Lake* variable is adjusted by adding $1*10^{-12}$ to all observation to produce valid estimation as some observations have zero values for this variable. Likewise, the *GHG* variable is adjusted by adding $1*10^{-15}$ as its mean is about 300 times smaller than *Lake*.

The unconditional probability of voting "yes" is:

$$\begin{aligned}\Pr(Y_i=1) &= \Pr\left(WTP_i>0\right)\Pr\left(Y=1_i \mid WTP_i>0\right)\\ &= \left[1-\Phi\left(a+b_L ES_L+b_G ES_G+cR_i\right)\right]\cdot \\ &\Phi\left(\frac{\delta}{\sigma}-\frac{1}{\sigma}\ln C_i+\frac{\beta_L}{\sigma}ES_L+\frac{\beta_G}{\sigma}ES_G+\frac{\alpha}{\sigma}A_i+\frac{\varphi}{\sigma}ES_G A_i+\frac{\gamma}{\sigma}R_i\right)\end{aligned} \quad (2.15)$$

The first term represents the probability of having positive WTP. The second term represents the probability of WTP conditional on willingness to pay a positive amount for the environmental improvements. Since the two decisions are assumed to be independent, the probability of zero WTP and a positive amount of WTP can be estimated separately. As the response to the zero WTP question is binary and the probability is assumed to follow a normal distribution, standard probit regression can be applied to the spike model. Since each respondent was presented with three independent alternative programs, random effect probit is used to account for the correlation among the three decisions made by the same respondent.

2.4.2 Methods for incorporating preference uncertainty

For the conditional probability of positive WTP, conventional dichotomous-choice CV studies employ binary response models, such as probit or logit. In this essay, the dichotomous responses are calibrated by numerical certainty scale from a follow-up question and adopt the following econometric models to estimate the adjusted WTP.

- **Probit model with different fixed cutoff certainty levels**

With the 10-point numerical certainty scale, the dichotomous choice regarding program participation at a given price can be recoded based on an arbitrarily chosen cutoff level of certainty. The binary "yes" response (Y_i=1) is recoded as "no" (Y_i=0) if the respondent's certainty is less than a specific cutoff level. Four cutoff levels are considered, at 10, 9, 8 and 7, as shown in Table 2-3. The adjusted responses are then used in the standard random effect probit model. In this essay, the cutoff point is set at 7 when comparing results with other methods. This method translates some "yes" responses into "no", and is expected to reduce the WTP estimates.

- **Ordered probit model with polychotomous response**

The binary responses are recoded as "yes" (Y_i=1), "indifferent" (Y_i=0.5) and "no" (Y_i=0) depending on a cutoff level of certainty as shown in Table 2-4. The cutoff certainty level is set at 7, so answers of "yes" or "no" with certainty values of 7 or higher are coded as Y_i=1 or Y_i=0. Certainty levels of 6 or lower are coded Y_i=0.5 for "uncertain." As the probability is increased for "no" responses and reduced for "yes" responses, the total effect of adjustment on WTP can be either positive or negative, depending on the original binary choice and the magnitude of associated certainty.

The adjusted responses are then estimated by ordered probit with the following log-likelihood function, where δ_i and η_i are unknown cut points.

$$\begin{aligned}\log L = & \sum_{Y_i=2} \log\left[1-\Phi\left(\frac{\ln C_i + \delta_i - \beta_L ES_L - \beta_G ES_G - \alpha A_i - \varphi ES_G A_i - \gamma R_i}{\sigma}\right)\right] \\ & + \sum_{Y_i=1} \log\left[\Phi\left(\frac{\ln C_i + \delta_i - \beta_L ES_L - \beta_G ES_G - \alpha A_i - \varphi ES_G A_i - \gamma R_i}{\sigma}\right)\right. \\ & \left. -\Phi\left(\frac{\ln C_i - \eta_i - \beta_L ES_L - \beta_G ES_G - \alpha A_i - \varphi ES_G A_i - \gamma R_i}{\sigma}\right)\right] \\ & + \sum_{Y_i=0} \log\left[\Phi\left(\frac{\ln C_i - \eta_i - \beta_L ES_L - \beta_G ES_G - \alpha A_i - \varphi ES_G A_i - \gamma R_i}{\sigma}\right)\right]\end{aligned} \tag{2.16}$$

- **Symmetric/ Asymmetric uncertainty model**

The original responses are recoded as probability of "yes" by combining the certainty score with dichotomous choices. Different recoding approaches have been applied in previous studies (Chang, et al., 2007, Li and Mattsson, 1995, Loomis and Ekstrand, 1998, Shaikh, et al., 2007). Li and Mattsson (1995) coded a 60% certainty level following "yes" response as 0.6, while a 60% certainty level following "no" response was coded as 1−0.6=0.4. Loomis and Ekstrand (1998) criticized this coding scheme as it altered the original "yes" or "no" choice made by the respondent. Instead, they implemented a slightly different numerical certainty scale to separate "yes" and "no" response as shown in Figure 2-3, where 0 and 1 indicate the most certain extremes of the "no" and "yes" responses respectively, and 0.5 indicates uncertainty of either response. They and others have adopted logit models to estimate the recoded data by transforming the dependent variable as $\log\left[\Pr(Yes)/(1-\Pr(Yes))\right]$ (Chang, et al., 2007, Loomis and Ekstrand, 1998, Shaikh, et al., 2007). When both "yes" and "no" responses are recoded, the method is referred as the Symmetric Uncertainty Model (SUM). The Asymmetric Uncertainty Model (ASUM) refers to the case when only "yes" responses are recoded.

This essay also applies the SUM and ASUM methods, but with a different coding scheme and econometric models. For the Symmetric Uncertainty Model, the binary responses are recoded as continuous responses ranging from 0 to 1 depending on the level of certainty. If a respondent voted "yes", the lowest probability for her to pay is 0.5. As shown in Table 2-3, each one point increase in the certainty level adds 0.05 to 0.5, so a "yes" response with certainty of 1 gives a probability of 0.55 and whereas a "yes" with a certainty of 10 gives a probability of "1.00". Similarly, the "no" responses are recoded from a highly certain 0 to a very uncertain 0.45

in response to certainty levels 10 to 1. For the Asymmetric Uncertainty Model, only “yes” responses are recoded while “no” is left as zero probability. The details of calibration are shown in Table 2-5. Figures 2-4 and 2-5 display the percentage of binary responses and certainty-adjusted responses under SUM method in the survey sample.

The probability of these adjusted responses can be estimated using a fractional binary response models, such as fractional probit. Since $\Pr(Y_i=1|_{WTP>0})$ is normally distributed in [0,1], nonlinear least squares (NLS) can be used to consistently estimate the model. However, NLS is unlikely to be efficient because common distributions for a fractional response imply heteroskedasticity. Thus, a quasi-MLE approach can be a good alternative to consistently estimate model parameters (Wooldridge, 2010). The log-likelihood function is as follows:

$$\begin{aligned}\log L = \sum_{i}^{N} \Big\{ & \left[1-\Pr(Y_i=1|_{WTP_i>0})\right]\cdot \\ & \log\left[1-\Phi\left(\frac{\delta}{\sigma}-\frac{1}{\sigma}\ln C_i+\frac{\beta_L}{\sigma}ES_L+\frac{\beta_G}{\sigma}ES_G+\frac{\alpha}{\sigma}A_i+\frac{\varphi}{\sigma}ES_G A_i+\frac{\gamma}{\sigma}R_i\right)\right] \\ & +\Pr(Y_i=1|_{WTP_i>0})\cdot \\ & \log\left[\Phi\left(\frac{\delta}{\sigma}-\frac{1}{\sigma}\ln C_i+\frac{\beta_L}{\sigma}ES_L+\frac{\beta_G}{\sigma}ES_G+\frac{\alpha}{\sigma}A_i+\frac{\varphi}{\sigma}ES_G A_i+\frac{\gamma}{\sigma}R_i\right)\right]\Big\}\end{aligned} \quad (2.17)$$

A panel data structure should be imposed on the model due to correlation among multiple choices made by each respondent. The common random effects approach, which attempts to obtain a joint distribution and to integrate out unobserved heterogeneity, is computationally demanding and would require additional assumptions on distribution. The generalized estimating equations (GEE) method with a specified correlation matrix provides a tractable solution (Wooldridge, 2010) that is estimated using STATA 10.1. Similar to the indifference adjustment, the WTP estimates using SUM can either increase or decrease compared to the conventional model, whereas the WTP will be reduced undoubtedly with ASUM, as only downward transformation are made to the dependent variables.

2.4.3 Welfare estimation

In order to compare different econometric specifications that incorporate preference uncertainty, the mean WTP, median WTP and efficiency of WTP estimation are calculated for these certainty-adjusted models and the conventional dichotomous-choice CV model.

The mean and median willingness to pay conditional on WTP greater than zero are

$$E(WTP_i |_{WTP_i>0}) = \exp\left(\delta + \beta_L ES_L + \beta_G ES_G + \alpha A_i + \varphi ES_G A_i + \gamma R_i + \frac{\sigma^2}{2}\right) \qquad (2.18)$$

$$Median(WTP_i |_{WTP_i>0}) = \exp\left(\delta + \beta_L ES_L + \beta_G ES_G + \alpha A_i + \varphi ES_G A_i + \gamma R_i\right) \qquad (2.19)$$

Since the semi-log function of WTP typically has a fat tail and may lead to extremely large mean values, the median WTP is computed and compared across different methods.

The unconditional median willingness to pay that combines the prior probability of having a positive WTP shown in Equation 2.10 and the conditional WTP shown in Equation 2.19 is presented as:

$$\begin{aligned} Median(WTP_i) &= \Pr\left(WTP > 0\right) \cdot Median(WTP_i |_{WTP_i>0}) \\ &= \left[\Phi\left(a + b_L ES_L + b_G ES_G + cR_i\right)\right] \\ &\cdot \exp\left(\delta + \beta_L ES_L + \beta_G ES_G + \alpha A_i + \varphi ES_G A_i + \gamma R_i\right) \end{aligned} \qquad (2.20)$$

The efficiency of WTP estimation is measured by comparing the relative variability around the median WTP using equation 2.19, where CI_U and CI_L are upper and lower bounds of a 95% confidence interval (Loomis and Ekstrand, 1998).

$$EF\ (WTP) = (CI_U - CI_L)\ /\ \text{Median}\ (WTP) \quad (2.21)$$

Based on a review by Akter et al. (2008), empirical evidence indicated that various certainty measurements and calibration techniques generate inconsistent welfare estimates in terms of value and efficiency, though it is expected that the certainty-adjusted WTP estimate should be lower and more efficient than the conventional WTP.

The median spike probability and conditional WTP are calculated for each respondent using individual-specific values for attributes that are significant at 80% level. The conditional WTP, unconditional WTP and their confidence intervals in the entire sample are estimated by bootstrapping the mean from individual median WTPs with 100 replications.

2.4.4 Preference certainty model

To explore the determinants of certainty in respondents' willingness-to-pay decisions, the 10-point numerical certainty scale is regressed on a set of variables nearly identical to those in the conditional WTP model. Given the categorical nature of the certainty scale, the ordered probit model is applied to two subsets of observations with "yes" and "no" responses separately. Following Loomis and Ekstrand (1998), a variable measuring the square of proposed tax payment is added to the variable set from the WTP model to capture the nonlinear effect of certainty on cost.

2.4.5 Variables

The dependent variables have been described with the econometric model in Section 4.2. There are seven categories of independent variables corresponding to the conceptual model: 1) quantitative environmental improvements in eutrophic lakes and greenhouse gas emission; 2) cost of hypothetical programs; 3) questionnaire version for type of land management to generate the ES (farming practice or general land management); 4) resident's perception of and attitudes about eutrophic lakes and global warming; 5) resident's opinion on general environmental issues; 6) demographic characteristics, including age, gender, education, income, household size, length of residency, whether the respondent is a farmer or forester, whether the respondent is a registered voter, and whether the respondent considers himself or herself a Michigan resident; and 7) frequencies of fishing, swimming, boating and hiking in Michigan. The variable definitions and summary statistics can be found in Tables 2-4 and 2-5.

2.5 Results

With both the semi-log and the mixed log-log functional forms, the certainty-adjusted models are found to differ slightly from the conventional dichotomous choice model in several aspects, including the significant variables, the magnitude of marginal effects, as well as the value and efficiency of welfare estimation. Comparing the two functional forms, the significance of variables and their marginal effects are similar. Although the two functional forms lead to different median WTP estimates and variation of WTP in response to environmental improvements, the differences are generally not statistically significant.

2.5.1 Preference certainty model

The results from two ordered probit models on determinants of certainty following "yes" and "no" responses are shown in Table 2-7. The two models share a common set of influential demographic characteristics, such as age, whether the respondent is a Michigan resident, and whether she belongs to environmental organizations. These variables enhance the certainty of “yes” responses while decreasing the certainty of “no” responses. The certainty of “yes” responses increases with the proposed reduction in GHG for those who are very concerned about global warming. The respondents are more certain about “yes” responses if they are registered voters, or frequently hike near inland lakes. The certainty following “no” responses increases if the respondents have been living longer in Michigan, work in the forest, frequently swim or fish in inland lakes more or rarely go boating. Depending on a “yes” versus a “no,” certainty of response is influence in opposite (but economically logical) ways by the hypothetical tax payment. For “yes” responses, decision certainty declines with increasing cost, whereas for “no” responses it rises with cost. The quadratic forms of cost are not significant in either “yes” or “no” response models, suggesting a linear relationship between cost and certainty. These results are similar to previous studies that found influential variables to include the bid level, prior knowledge (Loomis and Ekstrand, 1998), and respondents' attitudes towards the hypothetical market (Champ and Bishop, 2001, Samnaliev, et al., 2006).

2.5.2 Conditional willingness to pay

Incorporating decision certainty results in more significant variables in both the semi-log and mixed log-log versions of the random effect probit models (Tables 2-8 and 2-9). The conventional random effect probit model suggests that the probability of voting “yes” to the proposed tax program significantly increases with higher reduction in eutrophic lakes, more concern about global warming, higher income, age and education levels, and if the respondent is a registered voter. The probability is negatively associated with the proposed tax payment, as expected. The certainty-adjusted voting probabilities depends on these same factors, but is also positively influenced if the respondent goes boating and hiking more often, is involved in environmental organizations, and consider himself/herself a Michigan resident. The constant term also becomes significant in all certainty-adjusted models.

The major difference between the two functional forms in coefficient estimates is represented by the interaction between GHG reduction and whether the respondent is concerned about global warming. With the semi-log function, this interaction variable is only significant at 54-82% probability levels in certainty-adjusted models, while it is significant at the 90% level in the conventional model. In contrast, with the mixed log-log function, this variable is significant in the conventional model and three out of four certainty-adjusted models with at least 95% probability and is significant in the remaining model at the 80% level. In terms of overall statistical significance and goodness-of-fit, the two functional forms perform similarly. Based on chi-square test of differences between the log-log and semi-log Wald statistics, the mixed log-log functional form leads to higher statistical significance measure by Wald test in the conventional model (p-value=0.0006), whereas the semi-log function performs better in the SUM (p-value=0.0000), ASUM (p-value=0.002) and fixed-cutoff model (p-value=0.05) with higher Wald test statistics. The two statistics are not statistically different in the certainty model with an "indifference" option (p-value=0.13). The goodness of fit measured by likelihood can only be calculated in three models. The two functional forms have similar degree of fit in the conventional model and Indifference model, while the semi-log model has better fit in the fixed-cutoff model (p-value=0.0001).

The marginal effects of significant variables are generally smaller in certainty-adjusted models than in the conventional model. This is true of both the semi-log and mixed log-log functions (Tables 2-10 and 2-11). The variations of dependent variables are smaller in the

Symmetric Uncertainty Model, the Asymmetric Uncertainty Model and the Indifferent ordered probit model due to the finer recoding of the binary responses, hence it is not surprising that the probabilities of voting "yes" are less sensitive to those significant variables. As an exception, the model with fixed cutoff point shows either larger or smaller marginal effects on different variables compared with the conventional model, because transforming a portion of "yes" responses to "no" would not change the nature of the dependent variable.

2.5.3 Spike model

The spike model that estimates the influence of various attributes on the probability of having a positive WTP is a prior estimation to the conditional willingness to pay. With all the methods for adjusting preference certainty in WTP, the spike model is used to calculate the unconditional WTP. Results from the spike probability model (Table 2-6) suggest that the probability that a respondent had a positive WTP depends endogenously on the level of environmental improvement in eutrophic lakes and greenhouse gas, as well as the resident's concern about global warming, and demographic traits such as income, whether respondents are Michigan residents and how long they have been living in Michigan.

2.5.4 Welfare effect

Both the conditional and unconditional median WTP for 140 fewer eutrophic lakes and a GHG emission reduction of 0.4% from the Year 2000 level were calculated for each respondent following the conventional CV model and the four certainty-adjusted models. The semi-log and mixed log-log functional forms are used for estimating the conditional WTP to test the consistency of preference certainty on WTP estimation. The average median WTP across residents and a bootstrapped 95% confidence interval following the two functional forms are shown in Tables 2-12 and 2-13.

With the *mixed log-log* function, the median WTP from the symmetric uncertainty model (SUM) is the highest among all methods--$164 tax payment per year conditional on having a positive WTP and a $144 unconditional WTP. The conventional random effects model and polychotomous response (Indifferent) model have the same WTP estimates, which reduce the conditional and unconditional WTP to $142 and $124 respectively. The two asymmetric models yield the lowest estimates, i.e., the conditional and unconditional WTP are $73 and $64 in the asymmetric uncertainty model (ASUM), and are $48 and $42 in the dichotomous response (Fixed Cutoff) model. The relative changes of WTP with respect to the conventional dichotomous choice model are consistent with several prior studies (Chang, et al., 2007, Loomis and Ekstrand, 1998, Shaikh, et al., 2007).

By contrast, the *semi-log* function generates a median WTP from the conventional method that is the highest among all methods--$134 per year conditional WTP and $118 unconditional WTP. The SUM reduces the conditional and unconditional WTP to $76 and $67 respectively, while the ASUM method further lowers them to $34 and $30. The polychotomous response (Indifferent) model and dichotomous response (Fixed Cutoff) model with cutoff point both generate slightly higher WTP than the SUM and ASUM methods.

Based on the 95% confident intervals for WTP estimates with both functional forms, the median WTP estimates from the two symmetrically calibrated models are no different from the conventional model. Due to the symmetric calibration, the probability of voting “yes” is increased for “no” responses and reduced for “yes” responses. Thus, the total effect of adjustment on WTP can be positive or negative depending on the magnitude of associated certainty and the original binary choice. It seems the preference certainties associated with “yes” responses are similar to those associated with “no” responses in this sample, and hence do not lead to major influence on the median WTP estimates. In addition, the two asymmetrically calibrated models give median WTP estimates that are lower than those from symmetrically calibrated models. Given the asymmetric calibration, only the probability of voting associated with “yes” responses is adjusted downwards, which leads to an under-estimated median WTP. Thus, the results of bias conform to the analytical expectation. The inconsistency of the influence from preference uncertainty on WTP estimates between the two functional forms echoes results from previous of certainty-adjusted WTP estimates, especially in symmetrically calibrated models (Akter, et al., 2008).

The variations of estimation efficiency among five models are consistent between two functional forms. The conventional model, which does not incorporate the preference uncertainty, is clearly the least efficient with a high variability measure. The indifference ordered probit model and the fixed cutoff model, which reduce variability by 60%-80%, are more efficient than the conventional model. The SUM and ASUM certainty-adjusted models result in the highest efficiency levels, which reduce the variability by about 90%. These findings reinforce the body of literature showing that certainty-adjusted models increase the efficiency (Champ, et al., 1997, Shaikh, et al., 2007), although other researchers have observed the opposite effect (Chang, et al., 2007, Loomis and Ekstrand, 1998, Samnaliev, et al., 2006).

Comparing the predicted WTP curve based on the semi-log and mixed log-log functional forms for conventional dichotomous choice models (Figures 2-6 and 2-7), the WTP shows a different pattern of responses to environmental improvements. As constrained by the functions, the WTP estimated with the semi-log function follows a steady, exponentially increasing rate, while the WTP estimated with the mixed log-log function rises sharply at low values of environmental improvements and then grows slowly at a diminishing rate with little sensitivity to environmental improvement. However, the predicted WTPs based on both functional forms share a common range of values from $15 to $45 per person, and the goodness of fit of the two models does not diff, as shown by the likelihood statistics. As the predicted values and goodness of fit offer no obvious choice between two functions, the mix log-log function that is theoretically consistent and statistically significant[12] would be a better choice.

2.6 Conclusion

Over half of the respondents to this stated-preference survey displayed uncertainty about their willingness to pay for a public program to reduce numbers of eutrophic lakes and to mitigate greenhouse gas emissions (Figure 2-5). To examine the influence of preference uncertainty on their stated willingness to pay, this essay compares four calibration methods to incorporate numerical certainty with the conventional dichotomous-choice model for estimating WTP. Two functional forms, semi-log and mixed log-log, are evaluated to test the sensitivity of conditional WTP estimates to different functions. Compared to the conventional probit, the certainty-adjusted models are more sensitive to underlying determinants of WTP related to the demographics and recreational experience of respondents. Moreover, these models largely improve the efficiency of estimation. Comparing the welfare estimates with 95% confident interval based on two functional forms, both reveal that the median WTP estimated from the conventional model is not significantly different from the two symmetrically calibrated certainty-adjusted models, although the mixed log-log functional form leads to higher WTP estimates in

[12] Wald statistic in the mixed log-log model is significantly higher than the semi-log model with p-value equal to 0.0006.

those models than the semi-log does. The two asymmetrically calibrated certainty-adjusted models generally have lower WTP than the conventional models. The biased WTP estimates are expected analytically because the probability of voting “yes” is calibrated downwards. Thus, there is no concrete evidence that one specific certainty-adjusted model should replace the conventional model for estimating WTP. The WTP responses predicted from the conventional dichotomous choice model using two functional forms show a similar range of WTP values and goodness of fit, although the shapes of the WTP curves differ due to their functional forms. The mixed log-log function, which embodies the diminishing marginal utility theory, has higher statistical significance.

In sum, incorporating self-reported certainty in the willingness to pay estimation appears to improve our understanding of the demand for ecosystem services by revealing more variables that are influential and providing a range of possible estimates. However, the unbiased conventional dichotomous choice model still provides a reliable median WTP estimate that reflects the influence of key variables. For further analysis that combines demand for ecosystem services with their supply, the mixed log-log function for conditional WTP seems to be a better choice than the traditional semi-log function due to its theoretical consistency and statistical significance.

Figures and Tables

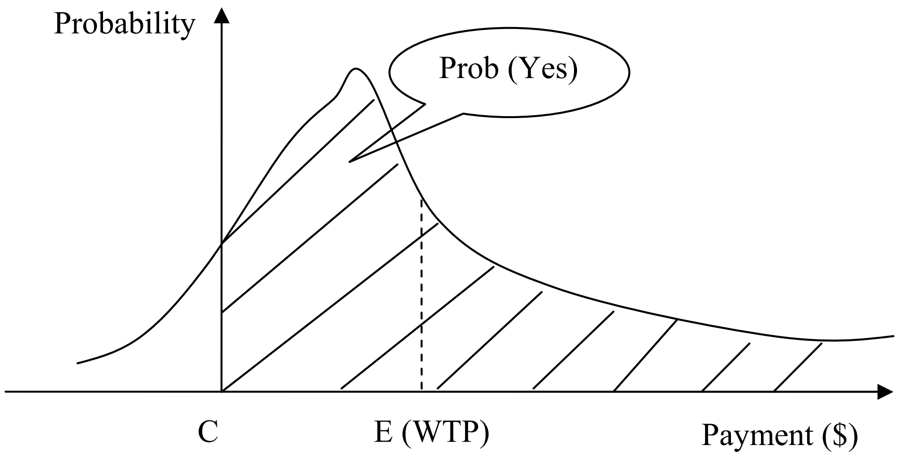

Figure 2-5 Probability of voting “yes” as a representation of underlying WTP with preference uncertainty

On a scale of 1 to 10, where 1 means “very uncertain” and 10 means “very certain”, how certain are you with your answer in Question 15?

1 2 3 4 5 6 7 8 9 10

Very uncertain Very certain

Figure 2-2 Numerical certainty scale used in survey, 2211 Michigan residents, 2009

|----------|----------|----------|--------|---------|---------|----------|-----------|----------|---------|

0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0

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increasing uncertainty of No response increasing uncertainty of Yes response

Figure 2-3 Numerical certainty scale used in Loomis and Ekstrand (1998)

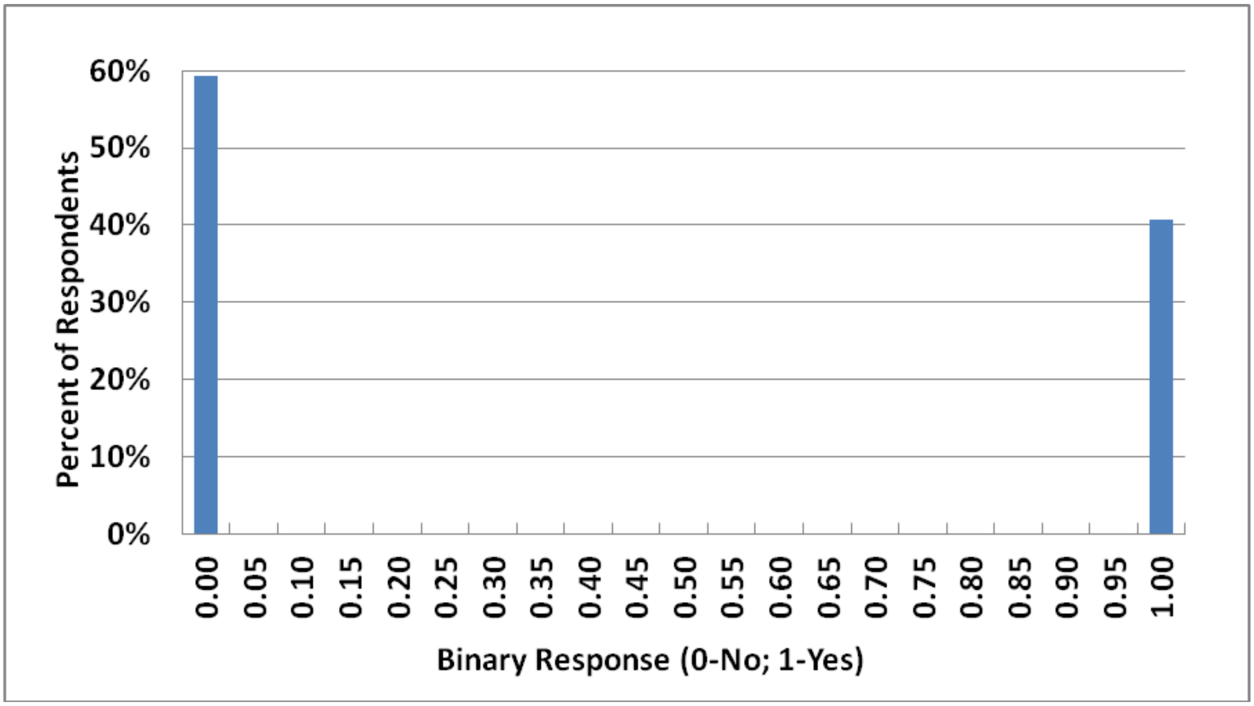

Figure 2-4 Binary response percentage in sample, 2211 Michigan residents, 2009

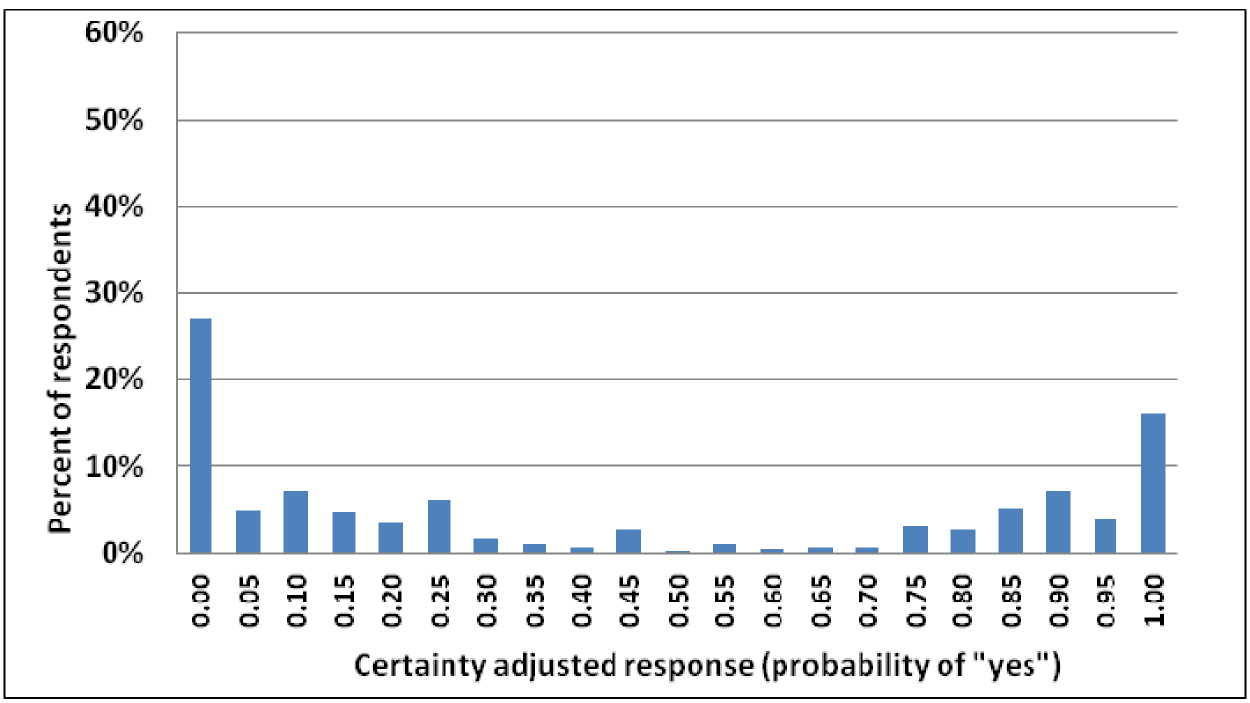

Figure 2-5 Certainty-adjusted response percentage under the Symmetric Uncertainty Model (SUM) in sample, 2211 Michigan residents, 2009

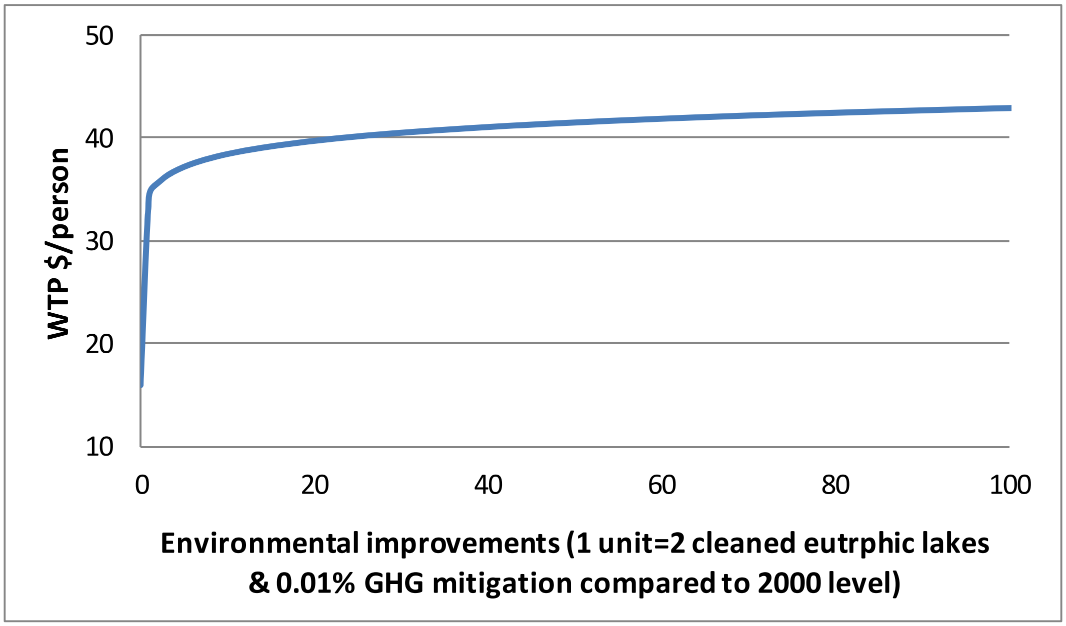

Figure 2-6 Median WTP in conventional dichotomous choice model with respect to eutrophic lake and GHG improvements [mixed log-log function]

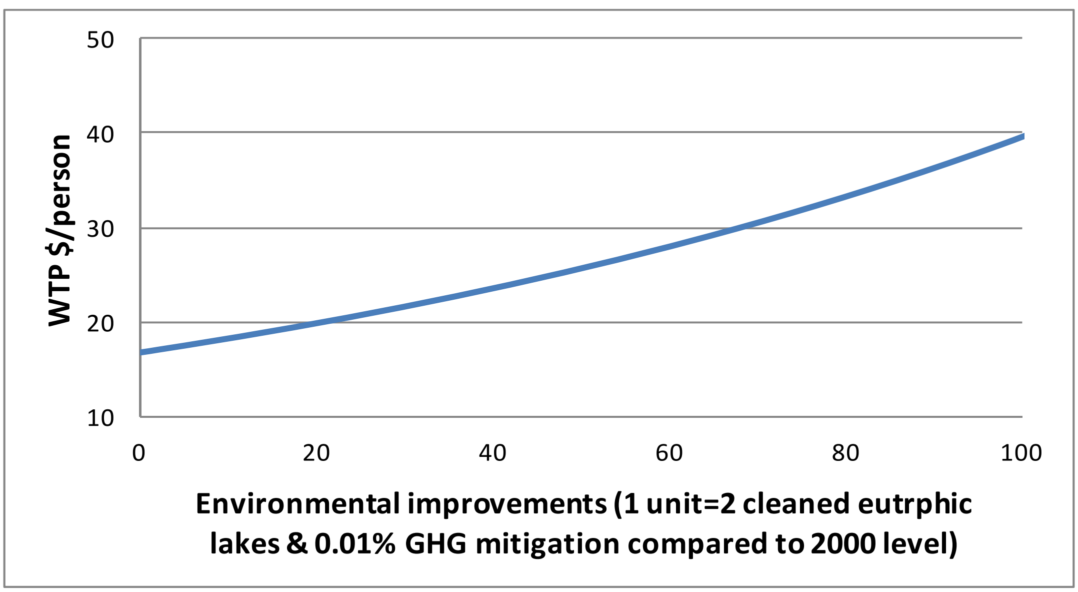

Figure 2-7 Median WTP in conventional dichotomous choice model with respect to eutrophic lake and GHG improvements [semi-log function]

Table 2-1 Variable description, 2211 Michigan residents, 2009

Variable name	**Definition**	**Unit of measure**	**Ranges and levels**
Contingent voting			
Vote yes	Vote on program A/B/C with proposed tax payment	binary	1-yes, 0-no
Certainty	How certain with vote on program A/B/C	category	1-very uncertain, …, 10-very certain
No-cost vote	Vote on program if it did not cost anything	binary	1-yes, 0-no
Ecosystem service change			
Lake	Eutrophic lakes that would be reduced if the program were to be implemented	number	0, 70, 140, 200, 400
GHG	Greenhouse gas reduction of the 2000 emission level that would be achieved if the program were to be implemented	%	0, 0.2, 0.4, 0.6, 1.2
Cost			
Cost	The amount of annual tax increase that would be used to fund the program	USD/year	10, 30, 50, 100, 200
Version			
Farm version	Whether the questionnaire version is the agricultural-farmer version or the general land management version	NA	0-Land management version, 1-Agricultural-farmer version
Perception and attitudes			
GW concern	Whether the respondent is concerned about global warming (GW)	category	0-Not concerned or somewhat concerned, 1-Very concerned
Demographics			
MI years	Length of continuing to live in MI	category	1-less than 1 year, 2- 1-5 years, 3- 5-10 years
MI resident	Michigan resident	binary	1-yes, 0-no
Male	Male respondent	binary	1-yes, 0-no
Household num	Number of people in the household	number	
Age	Age	year	
Farmer	Whether work on a farm	binary	1-yes, 0-no
Forester	Whether work in forests	binary	1-yes, 0-no
Env org	Belong to environmental organizations	binary	1-yes, 0-no

Table 2-1 (cont'd)

Income	Household annual pretax income	1000 USD	
Education	Education level	category	1-Some high school or less, 2-High school diploma, 3-Technical training beyond high school, 4-Some college, 5-College degree, 6-Some graduate work, 7-Graduate degree
Voter	Registered voter	binary	1-yes, 0-no
Recreational experiences			
Fishing freq	How often go fishing	category	1-Never, 2-In some years, 3-In most years, 4-Every year
Swimming freq	How often go swimming	category	1-Never, 2-In some years, 3-In most years, 4-Every year
Boating freq	How often go boating	category	1-Never, 2-In some years, 3-In most years, 4-Every year
Hiking freq	How often hike	category	1-Never, 2-In some years, 3-In most years, 4-Every year

Table 2-2 Descriptive statistics of variables

Variable	Definition	Obs	Mean	Std.	Min	Max
Contingent voting						
Vote yes	Vote on program A/B/C	3396	0.631	0.482	0	1
Certainty	How certain with vote on program	3396	7.889	2.25	1	10
No-cost vote	Vote on program if it did not cost anything	4125	0.832	0.374	0	1
Cost	The amount of annual tax increase that would be used to fund the program	4125	64.5	62.78	10	200
Ecosystem service change						
Lake	Eutrophic lakes that would be reduced if the program were to be implemented	4125	169	111.3	0	400
GHG	Greenhouse gas reduction of the 2000 emission level that would be achieved if the program were to be implemented	4125	0.527	0.319	0	1.20
Version						
Farm version	Whether the questionnaire version is the agricultural-farmer version or the general land management version	1429	0.482	0.500	0	1
Perception and attitudes						
GW concern	Whether the respondent is very concerned about global warming	1429	0.394	0.489	0	1
GW*GHG	The interaction of GW concern and GHG reduction level	4125	0.208	0.326	0	1.20
Demographics						
MI years	Length of continuing to live in MI	1429	3.66	0.688	1	4
MI resident	Michigan resident	1429	0.990	0.0985	0	1
Male	Gender: male	1429	0.659	0.474	0	1
Household	Number of people in the household	1429	2.54	1.37	0	9
Age	Age of respondent	1429	54.9	15.3	13	96.5
Farmer	Whether work on a farm	1429	0.0399	0.196	0	1
Forester	Whether work in forests	1429	0.0168	0.129	0	1
Env org	Belong to environmental organizations	1429	0.0777	0.268	0	1
Income	Household annual pretax income	1429	68.3	50.5	5	250
Education	Education level	1429	4.25	1.74	1	7
Voter	Registered voter	1429	0.947	0.224	0	1
Recreational experiences						
Fishing freq	How often go fishing	1429	2.20	1.17	1	4
Swimming freq	How often go swimming	1429	2.37	1.14	1	4
Boating freq	How often go boating	1429	2.43	1.11	1	4
Hiking freq	How often hike	1429	2.24	1.15	1	4

Table 2-3 Dependent variable for probit model with different cutoff certainty levels

Cutoff level	10		9		8		7	
Certainty scale	1--9	10	1--8	9--10	1--7	8--10	1--6	7--10
Y_i if answer Yes	0	1	0	1	0	1	0	1
Y_i if answer No	0		0		0		0	

Table 2-4 Dependent variables for ordered probit model

Certainty scale	1	2	3	4	5	6	7	8	9	10
Y_i if answer Yes	0.5						1			
Y_i if answer No							0			

Table 2-5 Dependent variables for fractional response models

Symmetric Uncertainty Model

Certainty scale	1	2	3	4	5	6	7	8	9	10
$Pr(Y_i=1\|_{WTP>0})$ if answer Yes	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1
$Pr(Y_i=1\|_{WTP>0})$ if answer No	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0

Asymmetric Uncertainty Model

Certainty scale	1	2	3	4	5	6	7	8	9	10
$Pr(Y_i=1\|_{WTP>0})$ if answer Yes	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1
$Pr(Y_i=1\|_{WTP>0})$ if answer No	0									

Table 2-6 Spike probability model, 1429 Michigan residents, 2009

Variable	Regression coefficient Coef.		P>z	Marginal Effect Coef.		P>z
Version						
Farm version	-0.051		0.760	-0.002		0.713
ES change and concern						
Lake	0.004	***	0.000	0.000	***	0.000
GHG	0.383	**	0.032	0.015	**	0.021
GW concern	1.271	***	0.000	0.019	***	0.000
Demographics						
MI years	-0.204		0.107	-0.008	*	0.067
MI resident	0.907		0.267	0.018	***	0.002
Male	-0.085		0.648	-0.004		0.595
Household num	-0.014		0.835	-0.001		0.793
Age	0.003		0.677	0.000		0.602
Farmer	-0.563		0.195	-0.036		0.263
Forester	-0.041		0.951	-0.002		0.940
Env org	-0.146		0.648	-0.007		0.609
Income	0.004	**	0.032	0.000	**	0.017
Education	0.005		0.933	0.000		0.915
Voter	0.339		0.351	0.010		0.124
Recreational experiences						
Fishing freq	-0.100		0.305	-0.004		0.217
Swimming freq	-0.003		0.976	0.000		0.970
Boating freq	-0.022		0.853	-0.001		0.815
Hiking freq	-0.100		0.277	-0.004		0.191
Constant	1.030		0.338			
/lnsig2u	1.77					
sigma_u	2.43					
rho	0.85					
Number of obs	4125					
Number of group	1429					
Wald chi2(22)	104.58					
Prob > chi2	0					
Log likelihood	-1350					

Table 2-7 Determinants of preference certainty for yes/no responses, 2211 Michigan residents, 2009 (Dependent variable: certainty scale [1-very uncertain; 10- very certain])

	Ordered probit for *Yes* responses			Ordered probit for *No* responses		
Certainty	Coef.		P>t	Coef.		P>t
Cost						
Cost	-0.004	**	0.030	0.003		0.114
Cost square	9.03E-06		0.230	-1.36E-05		0.158
Ecosystem service change						
Lake	0.000		0.162	0.000		0.245
GHG	-0.029		0.759	-0.065		0.565
Version						
Farm version	-0.061		0.198	0.030		0.623
Perception and attitudes						
GW concern	0.166		0.252	-0.068		0.722
GW*GHG	0.364	***	0.000	-0.037		0.760
Demographics						
MI years	-0.024		0.471	0.097	**	0.021
MI resident	0.817	**	0.050	-0.967	***	0.001
Male	0.086		0.124	0.006		0.931
Household num	0.013		0.503	-0.012		0.595
Age	0.005	***	0.005	-0.004	*	0.072
Farmer	-0.122		0.306	0.004		0.985
Forester	0.320		0.145	0.625	**	0.020
Env org	0.351	***	0.000	-0.217	**	0.039
Income	0.001		0.257	0.000		0.969
Education	-0.022		0.175	-0.005		0.807
Voter	0.194	*	0.081	-0.094		0.401
Recreational experiences						
Fishing freq	0.028		0.334	0.071	**	0.050
Swimming freq	0.012		0.724	0.082	**	0.030
Boating freq	-0.010		0.769	-0.126	***	0.001
Hiking freq	0.077	***	0.004	0.006		0.846
Number of obs	2143			1253		
Wald chi2(48)	173.07			52.1		
Prob > chi2	0			0.0003		
Pseudo R2	0.0237			0.0091		
Log pseudo likelihood	-3719.1			-2389.4		

Table 2-8 Comparison of coefficient estimates on the probability of voting "yes" to proposed tax payment with and without certainty, 1293 Michigan residents, 2009 [mixed log-log function]

	Basic model			SUM			ASUM			Indifferent			Cutoff=7		
Model	RE probit			GEE fractional probit			GEE fractional probit			Ordered probit robust error			RE probit		
variable	Coef.		P>z	Coef.		P>z	Coef.		P>z	Coef.		P>z	Coef.		P>z
Version															
Farm version	-0.0564		0.813	-0.0176		0.741	-0.0157		0.793	-0.0499		0.227	-0.246		0.304
Cost															
Ln(cost)	-1.35	***	0.000	-0.274	***	0.000	-0.307	***	0.000	-0.292	***	0.000	-1.09	***	0.000
ES change and concern															
Ln(Lake)	0.0303	***	0.000	0.00714	***	0.000	0.00801	***	0.000	0.0105	***	0.000	0.0260	***	0.000
Ln(GHG)	-0.00706		0.444	-0.0000870		0.962	-0.000879		0.680	0.000123		0.973	0.00604		0.499
GW* Ln(GHG)	0.0436	***	0.001	0.00838	**	0.011	0.0101	***	0.006	0.0124	**	0.030	0.0179		0.163
GW	1.89	***	0.000	0.447	***	0.000	0.496	***	0.000	0.490	***	0.000	2.09	***	0.000
Demographics															
MI years	-0.0813		0.649	-0.0311		0.438	-0.0181		0.692	-0.0401		0.186	-0.0695		0.695
MI resident	1.62		0.199	0.591	**	0.015	0.529	**	0.043	0.649	***	0.000	3.10	***	0.007
Male	-0.194		0.476	-0.0360		0.550	-0.0365		0.590	-0.00392		0.932	0.273		0.305
Household num	-0.0254		0.803	-0.00215		0.927	-0.00247		0.925	0.0137		0.446	0.0780		0.446
Age	0.0301	***	0.001	0.00683	***	0.001	0.00714	***	0.002	0.00906	***	0.000	0.0328	***	0.000
Farmer	-0.579		0.374	-0.122		0.368	-0.144		0.350	-0.105		0.348	-0.537		0.399
Forester	0.692		0.473	0.134		0.613	0.200		0.488	-0.098		0.603	0.439		0.619
Env org	0.512		0.252	0.184	*	0.083	0.182		0.118	0.262	***	0.004	1.076	**	0.015
Income	0.0146	***	0.000	0.00296	***	0.000	0.00337	***	0.000	0.00276	***	0.000	0.0102	***	0.000
Education	0.182	**	0.023	0.0305	*	0.095	0.0377	*	0.068	0.0449	***	0.001	0.190	**	0.018
Voter	1.71	***	0.002	0.372	***	0.005	0.416	***	0.007	0.386	***	0.000	1.49	***	0.005

Table 2-8 (cont'd)

Recreational experiences										
Fishing freq	0.211	0.132	0.028	0.379	0.041	0.245	0.029	0.232	0.133	0.337
Swimming freq	0.102	0.520	0.015	0.674	0.028	0.482	0.006	0.820	0.178	0.251
Boating freq	0.121	0.470	0.048	0.206	0.036	0.400	0.055 **	0.048	0.124	0.453
Hiking freq	0.152	0.262	0.042	0.155	0.050	0.128	0.048 **	0.036	0.247 *	0.063
Constant (cut 1)	-1.84	0.255	-0.67 *	0.052	-0.85 **	0.026	0.46		-6.23 ***	0.000
Cut point 2							1.20			
/lnsig2u	2.54								2.51	
sigma_u	3.57								3.52	
Rho	0.927								0.925	
No. of obs	3396		3396		3396		3396		3396	
No. of group	1293		1293		1293				1293	
Wald chi2(22)	242		285		268		533		270	
Prob > chi2	0.00		0		0		0		0	
Log-likelihood	-1367						-3238		-1471	

Table 2-9 Comparison of coefficient estimates on the probability of voting “yes” to proposed tax payment with and without certainty, 1293 Michigan residents, 2009 [semi-log function]

	Basic model		SUM		ASUM		Indifferent		Cutoff=7	
Model	RE probit		GEE fractional probit		GEE fractional probit		Ordered probit robust error		RE probit	
variable	Coef.	P>z	Coef.	P>z	Coef.	P>z	Coef.	P>z	Coef.	P>z
Version										
Farm version	-0.0643	0.790	-0.0240	0.654	-0.0233	0.698	-0.0481	0.241	-0.263	0.291
Cost										
Ln(cost)	-1.45***	0.000	-0.289***	0.000	-0.321***	0.000	-0.311***	0.000	-1.20***	0.000
ES change and concern										
Lake	0.00375***	0.000	0.00088***	0.000	0.00093***	0.000	0.000959***	0.000	0.00412***	0.000
GHG	-0.220	0.403	-0.0154	0.778	-0.0429	0.495	0.0294	0.723	-0.0129	0.961
GW*GHG	0.628*	0.078	0.111	0.180	0.135	0.139	0.118	0.385	0.246	0.466
GW	1.50***	0.000	0.369***	0.000	0.401***	0.000	0.397***	0.000	2.02***	0.000
Demographics										
MI years	-0.0893	0.623	-0.0317	0.434	-0.0190	0.679	-0.0418	0.169	-0.0856	0.643
MI resident	1.67	0.193	0.591**	0.016	0.531**	0.044	0.651***	0.001	3.23***	0.007
Male	-0.190	0.494	-0.0344	0.569	-0.0330	0.628	-0.00209	0.964	0.291	0.295
Household num	-0.0239	0.817	-0.00323	0.891	-0.00335	0.899	0.0131	0.468	0.0774	0.472
Age	0.0302***	0.002	0.00664***	0.001	0.00696***	0.003	0.00892***	0.000	0.0336***	0.000
Farmer	-0.657	0.317	-0.135	0.315	-0.162	0.294	-0.122	0.279	-0.614	0.346
Forester	0.788	0.403	0.167	0.523	0.233	0.410	-0.069	0.712	0.529	0.550
Env org	0.529	0.243	0.184*	0.081	0.181	0.117	0.255***	0.004	1.12**	0.014
Income	0.0148***	0.000	0.00297***	0.000	0.00336***	0.000	0.00272***	0.000	0.0107***	0.000
Education	0.185**	0.023	0.0299	0.103	0.0373*	0.073	0.0445***	0.001	0.192**	0.023
Voter	1.77***	0.002	0.372***	0.005	0.414***	0.007	0.391***	0.000	1.57***	0.005

Table 2-9 (cont'd)

Recreational experiences										
Fishing freq	0.207	0.143	0.0245	0.442	0.0372	0.295	0.0257	0.294	0.125	0.387
Swimming freq	0.0891	0.581	0.0132	0.712	0.0262	0.515	0.00234	0.930	0.170	0.295
Boating freq	0.141	0.405	0.0509	0.178	0.0389	0.365	0.0580**	0.036	0.147	0.395
Hiking freq	0.150	0.274	0.0417	0.161	0.0502	0.130	0.0506**	0.027	0.259*	0.062
Constant (cut 1)	-2.05	0.218	-0.717**	0.040	-0.885**	0.022	0.538		-6.80***	0.000
Cut point 2							1.27			
/lnsig2u	2.60								2.61	
sigma_u	3.66								3.68	
Rho	0.93								0.93	
No. of obs	3396		3396		3396		3396		3396	
No. of group	1293		1293		1293				1293	
Wald chi2(22)	234		299		274		530		273	
Prob > chi2	0		0		0		0		0	
Log-likelihood	-1367						-3239		-1461	

Table 2-10 Comparison of marginal effects on the probability of voting "yes" to proposed tax payment with and without certainty, 1237 Michigan residents, 2009 [mixed log-log function]

	Basic model		SUM		ASUM		Indifference		Cutoff7	
Model	RE probit		GEE fractional probit		GEE fractional probit		Ordered probit robust error		RE probit	
variable	Coef.	P>z	Coef.	P>z	Coef.	P>z	Coef.	P>z	Coef.	P>z
Version										
Farm version	-0.00859	0.767	-0.00623	0.677	-0.00557	0.741	0.0146	0.133	-0.0440	0.190
Cost										
Ln(cost)	-0.206 ***	0.000	-0.097 ***	0.000	-0.109 ***	0.000	0.0856 ***	0.000	-0.193 ***	0.000
ES change and concern										
Ln(Lake)	0.00461 ***	0.000	0.00252 ***	0.000	0.00284 ***	0.000	-0.00309 ***	0.000	0.00462 ***	0.000
Ln(GHG)	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000
GW* Ln(GHG)	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000
GW	0.211 ***	0.000	0.146 ***	0.000	0.165 ***	0.000	-0.122 ***	0.000	0.342 ***	0.000
Demographics										
MI years	-0.0124	0.566	-0.0110	0.328	-0.00640	0.617	0.0118 *	0.096	-0.0123	0.622
MI resident	0.191 **	0.017	0.186 ***	0.000	0.175 ***	0.004	-0.151 ***	0.000	0.446 ***	0.000
Male	-0.0301	0.378	-0.0128	0.453	-0.0130	0.498	0.00115	0.915	0.0488	0.198
Household num	-0.00388	0.753	-0.000758	0.908	-0.000874	0.906	-0.00402	0.337	0.0138	0.338
Age	0.00458 ***	0.000	0.00241 ***	0.000	0.00253 ***	0.000	-0.00266 ***	0.000	0.00583 ***	0.000
Farmer	-0.0926	0.277	-0.0435	0.261	-0.0515	0.239	0.0318	0.249	-0.0931	0.272
Forester	0.0965	0.311	0.0466	0.515	0.0696	0.371	0.0295	0.523	0.0784	0.531
Env org	0.0734	0.122	0.0634 **	0.024	0.0635 **	0.044	-0.0707 ***	0.000	0.190 ***	0.001
Income	0.00223	0.000	0.00104	0.000	0.00119	0.000	-0.000810	0.000	0.00181	0.000
Education	0.0276 ***	0.004	0.0107 **	0.035	0.0133 **	0.021	-0.0132 ***	0.000	0.0338 ***	0.003
Voter	0.198 ***	0.000	0.123 ***	0.000	0.140 ***	0.000	-0.100 ***	0.000	0.257 ***	0.000

Table 2-10 (cont'd)

Recreational experiences										
Fishing freq	0.0322 *	0.056	0.00989	0.267	0.0146	0.142	-0.00860	0.131	0.0237	0.225
Swimming freq	0.0155	0.417	0.00529	0.596	0.0100	0.375	-0.00178	0.774	0.0316	0.147
Boating freq	0.0184	0.360	0.0168	0.110	0.0127	0.288	-0.0160 **	0.013	0.0220	0.344
Hiking freq	0.0231	0.156	0.0149 *	0.073	0.0178 *	0.055	-0.0141 ***	0.008	0.0438 **	0.018

Table 2-11 Comparison of marginal effects on the probability of voting "yes" to proposed tax payment with and without certainty, 1237 Michigan residents, 2009 [semi-log function]

Model	Basic model RE probit			SUM GEE fractional probit			ASUM GEE fractional probit			Indifference Ordered probit robust error			Cutoff7 RE probit		
variable	Coef.		P>z	Coef.		P>z	Coef.		P>z	Coef.		P>z	Coef.		P>z
Version															
Farm version	-0.00939		0.740	-0.00844		0.573	-0.00823		0.626	-0.0172		0.139	-0.0449		0.180
Cost															
Ln(cost)	-0.211	***	0.000	-0.102	***	0.000	-0.114	***	0.000	-0.1113	***	0.000	-0.204	***	0.000
ES change and concern															
Lake	0.000549	***	0.000	0.000311	***	0.000	0.000327	***	0.000	0.000344	***	0.000	0.000700	***	0.000
GHG	-0.0322		0.291	-0.00542		0.722	-0.0152		0.390	0.0105		0.655	-0.00219		0.951
GW*GHG	0.0918	**	0.025	0.0391	*	0.091	0.0476	*	0.062	0.0424		0.274	0.0418		0.359
GW	0.175	***	0.000	0.122	***	0.000	0.135	***	0.000	0.140	***	0.000	0.319	***	0.000
Demographics															
MI years	-0.0131		0.535	-0.0111		0.323	-0.00672		0.602	-0.0150	*	0.082	-0.0145		0.559
MI resident	0.188	**	0.016	0.185	***	0.000	0.175	***	0.005	0.223	***	0.000	0.441	***	0.000
Male	-0.0283		0.398	-0.0122		0.474	-0.0117		0.542	-0.000748		0.954	0.0496		0.188
Household num	-0.00350		0.771	-0.00114		0.862	-0.00118		0.873	0.00471		0.360	0.0131		0.364
Age	0.00442	***	0.000	0.00234	***	0.000	0.00246	***	0.000	0.00320	***	0.000	0.00571	***	0.000
Farmer	-0.102		0.224	-0.0483		0.210	-0.0576		0.187	-0.0436		0.169	-0.102		0.220
Forester	0.104		0.229	0.0573		0.408	0.0805		0.284	-0.0247		0.641	0.0901		0.449
Env org	0.0724		0.114	0.0631	**	0.023	0.0630	**	0.044	0.0910	***	0.000	0.189	***	0.001
Income	0.00216		0.000	0.00104		0.000	0.00119		0.000	0.000974		0.000	0.00181		0.000
Education	0.0270	***	0.004	0.0105	**	0.040	0.0132	**	0.024	0.0160	***	0.000	0.0326	***	0.004
Voter	0.196	***	0.000	0.123	***	0.000	0.140	***	0.000	0.138	***	0.000	0.257	***	0.000

Table 2-11 (cont'd)

Recreational experiences										
Fishing freq	0.0303 *	0.064	0.00863	0.332	0.0131	0.186	0.00921	0.185	0.0212	0.275
Swimming freq	0.0130	0.487	0.00463	0.642	0.0092	0.412	0.000839	0.912	0.0289	0.186
Boating freq	0.0206	0.291	0.0179 *	0.089	0.0137	0.253	0.0208 ***	0.008	0.0249	0.284
Hiking freq	0.0219	0.167	0.0147 *	0.077	0.0177 *	0.056	0.0181 ***	0.005	0.0440 **	0.017

Table 2-12 Comparison of median WTP (in U.S. dollars) and estimation efficiency [mixed log-log function]

Method	Basic model	SUM	ASUM	Not sure	Cutoff7
Econometric Model	RE probit	GEE fractional probit	GEE fractional probit	Ordered probit	RE probit
Conditional WTP					
Median WTP	142	164	73	142	48
95% lower CI	-365	55.1	27.8	-91	2
95% upper CI	648	273	119	375	94
efficiency	7.15	1.33	1.24	3.29	1.93
Mean spike Prob	0.876	0.876	0.876	0.876	0.876
Unconditional WTP					
Median WTP	124	144	64	124	42
95% lower CI	-320	48	24.4	-80	1
95% upper CI	568	239	104	329	83
efficiency	7.15	1.33	1.24	3.29	1.93

*Notes:

- Median WTP is calculated instead of mean due to the fat tail in the mixed log-log functional form of WTP.
- Only variables that are significant at 90% level are included in the WTP calculation.
- 95% confidence interval is obtained by bootstrapping with 200 replications.
- Efficiency is calculated as (CI_{upper}–CI_{lower}) / Median (*WTP*). A lower value indicates higher efficiency.
- The 18.6% protest rate of nonresponse is not factored into the results

Table 2-13 Comparison of median WTP (in U.S. dollars) and estimation efficiency [semi-log function]

Method	Basic model	SUM	ASUM	Not sure	Cutoff7
Econometric Model	RE probit	GEE fractional probit	GEE fractional probit	Ordered probit	RE probit
Conditional WTP					
Median WTP	134	76	34	98	40
95% lower CI	-867	16	16	-29	1
95% upper CI	1135	136	52	225	79
efficiency	14.9	1.57	1.04	2.59	1.96
Mean spike Prob	0.876	0.876	0.876	0.876	0.876
Unconditional WTP					
Median WTP	118	67	30.1	86	35
95% lower CI	-760	14	14	-25	1
95% upper CI	995	119	46	197	70
efficiency	14.9	1.57	1.04	2.59	1.96

*Notes:

- Median WTP is calculated instead of mean due to the fat tail in the semi-log functional form of WTP .
- Only variables that are significant at 90% level are included in the WTP calculation.
- 95% confidence interval is obtained by bootstrapping with 200 replications.
- Efficiency is calculated as $(CI_{upper}–CI_{lower})$ / Median (WTP). A lower value indicates higher efficiency.
- The 18.6% protest rate of nonresponse is not factored into the results

REFERENCES

REFERENCES

Akter, S., J. Bennett, and S. Akhter. 2008. "Preference uncertainty in contingent valuation." *Ecological Economics* 67(3):345-351.

Alberini, A., K. Boyle, and M. Welsh. 2003. "Analysis of contingent valuation data with multiple bids and response options allowing respondents to express uncertainty." *Journal of Environmental Economics and Management* 45(1):40-62.

Balcombe, K., and I. Fraser. 2009. "Dichotomous-choice contingent valuation with "don't know" responses and misreporting." *Journal of Applied Econometrics* 24(7):1137-1152.

Champ, P.A., and R.C. Bishop. 2001. "Donation payment mechanisms and contingent valuation: An empirical study of hypothetical bias." *Environmental and Resource Economics* 19(4):383-402.

Champ, P.A., R.C. Bishop, T.C. Brown, and D.W. McCollum. 1997. "Using donation mechanisms to value nonuse benefits from public goods." *Journal of Environmental Economics and Management* 33(2):151-162.

Chang, J.I., S.H. Yoo, and S.J. Kwak. 2007. "An investigation of preference uncertainty in the contingent valuation study." *Applied Economics Letters* 14(9):691 - 695.

Chen, H. 2010. "Ecosystem services from low input cropping systems and public's willingness to pay for them." M.S. Thesis, Michigan State University, Department of Agricultural, Food and Resource Economics. http://www.aec.msu.edu/theses/fulltext/chen_ms.pdf

Ethier, R.G., G.L. Poe, W.D. Schulze, and J. Clark. 2000. "A comparison of hypothetical phone and mail contingent valuation responses for green-pricing electricity programs." *Land Economics* 76(1):54-67.

Fenichel, E., F. Lupi, J. Hoehn, and M. Kaplowitz (2006) Split-sample tests of" don't know" and" indifferent" responses in an attribute based choice model, American Agricultural Economics Association (New Name 2008: Agricultural and Applied Economics Association).

Flores, N.E. (2003) Conceptual framework for nonmarket valuation, ed. P. Champ,K. Boyle, and T. Brown, A primer on nonmarket valuation. Boston, MA, Kluwer Academic Publishers.

Haener, M., and W. Adamowicz. 1998. "Analysis of "don't know" response to referendum contingent valuation questions." *Agricultural and Resource Economics Review* 27(2).

Ichoku, H., W. Fonta, and A. Kedir. 2009. "Measuring individuals' valuation distributions using a stochastic payment card approach: Application to solid waste management in nigeria." *Environment, Development and Sustainability* 11(3):509-521.

Johannesson, M., B. Liljas, and P. Johansson. 1998. "An experimental comparison of dichotomous choice contingent valuation questions and real purchase decisions." *Applied Economics* 30(5):643-647.

Krosnick, J.A., A.L. Holbrook, M.K. Berent, R.T. Carson, W. Michael Hanemann, R.J. Kopp, R. Cameron Mitchell, S. Presser, P.A. Ruud, V. Kerry Smith, W.R. Moody, M.C. Green, and M. Conaway. 2002. "The impact of "no opinion" response options on data quality: Non-attitude reduction or an invitation to satisfice?" *Public Opinion Quarterly* 66(3):371-403.

Li, C.-Z., and L. Mattsson. 1995. "Discrete choice under preference uncertainty: An improved structural model for contingent valuation." *Journal of Environmental Economics and Management* 28(2):256-269.

List, J., and C. Gallet. 2001. "What experimental protocol influence disparities between actual and hypothetical stated values?" *Environmental and Resource Economics* 20(3):241-254.

Loomis, J., and E. Ekstrand. 1998. "Alternative approaches for incorporating respondent uncertainty when estimating willingness to pay: The case of the mexican spotted owl." *Ecological Economics* 27(1):29-41.

Lundhede, T., S. Olsen, J. Jacobsen, and B. Thorsen. 2009. "Handling respondent uncertainty in choice experiments: Evaluating recoding approaches against explicit modelling of uncertainty." *Journal of Choice Modelling* 2(2):118.

Marshall, A. (2009) Graduations of consumers' demands, Principles of economics, 8th Edition. New York, NY, Cosimo Classics, pp. 78-85.

Moore, R., R.C. Bishop, B. Provencher, and P.A. Champ. 2010. "Accounting for respondent uncertainty to improve willingness-to-pay estimates." *Canadian Journal of Agricultural Economics* 58(3):381-401.

Poe, G.L., J.E. Clark, D. Rondeau, and W.D. Schulze. 2002. "Provision point mechanisms and field validity tests of contingent valuation." *Environmental and Resource Economics* 23(1):105-131.

Samnaliev, M., T.H. Stevens, and T. More. 2006. "A comparison of alternative certainty calibration techniques in contingent valuation." *Ecological Economics* 57(3):507-519.

Shaikh, S.L., L. Sun, and G. Cornelis van Kooten. 2007. "Treating respondent uncertainty in contingent valuation: A comparison of empirical treatments." *Ecological Economics* 62(1):115-125.

Sun, L., and G. van Kooten. 2009. "Comparing fuzzy and probabilistic approaches to preference uncertainty in non-market valuation." *Environmental and Resource Economics* 42(4):471-489.

van Kooten, G., E. Krcmar, and E. Bulte. 2001. "Preference uncertainty in non-market valuation: A fuzzy approach." *American Journal of Agricultural Economics* 83(3):487-500.

Vossler, C.A., J. Kerkvliet, S. Polasky, and O. Gainutdinova. 2003. "Externally validating contingent valuation: An open-space survey and referendum in Corvallis, Oregon." *Journal of Economic Behavior & Organization* 51(2):261-277.

Wang, H. 1997. "Treatment of "don't-know" responses in contingent valuation surveys: A random valuation model." *Journal of Environmental Economics and Management* 32(2):219-232.

Wang, H., and D. Whittington. 2005. "Measuring individuals' valuation distributions using a stochastic payment card approach." *Ecological Economics* 55(2):143-154.

Whitehead, J.C., J.-C. Huang, G.C. Blomquist, and R.C. Ready. 1998. "Construct validity of dichotomous and polychotomous choice contingent valuation questions." *Environmental and Resource Economics* 11(1):107-116.

Wooldridge, J. 2010. *Econometric Analysis of Cross Section and Panel Data*. 2nd ed. Cambridge, MA: The MIT Press.

ESSAY 3: AGGREGATE SUPPLY AND DEMAND FOR ECOSYSTEM SERVICES FROM CROPLAND IN MICHIGAN AND POLICY SIMULATION

3.1 Introduction

The two previous essays have estimated supply and demand for ecosystem services (ES) from croplands. On one hand, farmers showed interest in providing ecosystem services if paid. On the other hand, Michigan residents cared about the environmental improvements from land management practices and were willing to pay for them. The stated-preference estimates of ES demand and supply from the previous essays can potentially be integrated to inform the design of economically efficient Payment-for-Environmental-Services (PES) programs. This essay explores two key policy questions: First, does public willingness to pay for ecosystem services exceed the required payment by service providers? Second, could one design an efficient payment system for ecosystem services from agriculture?

The market equilibrium for different commodities has been investigated in a large number of studies of marketed ecosystem services from agriculture, such as grain and livestock (Balagtas and Kim, 2007, Jayne, et al., 2008, Willett and French, 1991). These studies assumed that market prices are determined by a clearing process that equilibrates supply and demand, sometimes with quantity rationing on one or both sides due to trade and storage. A few previous studies have combined the benefit and cost estimates from contingent valuation to examine the potential demand and supply of natural habitat preservation (Amigues, et al., 2002, Thomas and Blakemore, 2007) and farmland preservation programs (Welsch, et al., 2005). However, to my knowledge, the aggregate supply and demand of nonmarket ecosystem services from working-land farming practices has not been studied. Three potential challenges might have prevented progress in this area.

First, the way that ES are supplied by producers is not equivalent to the way that they are experienced by consumers. In this case, the residents pay for the final environmental improvements in lake water quality and global warming. Although farmers produce these two ecosystem services jointly with marketed products, what they are really paid for is the land enrolled in PES programs that guarantees a set of conservation practices. Moreover, even if the quantitative relationship between a set of land management practices and subsequent environmental improvements can be established, a farmer's land enrollment in PES programs does not necessarily lead to real change in the environment, as they may have already adopted the required practices on lands enrolled. The extra environmental services that would have not been produced without the PES are commonly referred to as "additional". The establishment of a baseline and the verification of additionality is a crucial issue in PES programs and ecosystem markets for land conservation, water quality, wetland mitigation banking, and carbon credits (Wunder, 2005). Under the hypothetical PES programs analyzed in Essay 1, the proposed practices and farmers' previously adopted practices need to be compared to identify those practices that offer additional ES.

The second challenge to combining supply and demand estimates of ES from working land is the jointness of production. On the supply side, one practice may produce multiple ES while one environmental improvement may be triggered by multiple practices. For example, adding cover crops to a corn-soybean rotation leads to less soil erosion and N_2O volatilization, which then reduce eutrophic lakes and greenhouse gas (GHG) emission respectively. GHG emissions may also be mitigated by planting cover crops, adopting the Pre-Sidedress Nitrate Test

(PSNT) and applying reduced fertilizer. The weighted aggregation of multiple ecosystem services is being addressed in the U.S. Department of Agriculture's Conservation Reserve Program (CRP) using an "environmental benefits index," which is based on weights given to different environmental service components and regional population density (Antle, 2007). However, further linkage between joint production and consumption is rare.

The third potential challenge is that even if functions for the supply and demand for ES could be developed, the measurement of actual ES outcomes is prohibitively costly due to the non-point source nature of most ES. Yet measured ES outcomes are needed to derive a truly optimal payment for ES. The optimal payment levels can be derived so that they maximize economic welfare, where economic welfare is defined narrowly as the difference between resident WTP for environmental improvements due to working land conservation programs and farmer WTA to enroll in these programs. As payment is associated with farming practices instead of ecosystem service outcomes, and because PES programs typically have uncertainty and incomplete information, the payment can be characterized as second-best socially optimal condition (Lipsey and Lancaster, 1956).

Given these challenges, this essay aims to analyze the socially optimal conditions for the provision of two major ecosystem services from a set of cropland management practices by matching the (marginal) benefit from consumption and cost of production. Taking advantage of unique, coupled datasets of stated preferences, this essay combines a supply-side cost function of farmers' willingness to adopt practices that provide increased ecosystem services with a demand-side social benefit function of residents' willingness to pay (WTP) for these ES. The additionality from enrollment in PES programs and the linkage from joint farming practices to joint environmental outcomes are also examined to achieve the aggregation. Variations of the second-best optimal conditions under different policy scenarios are discussed as well.

3.2 Conceptual model

3.2.1 Input-output system for ecosystem services

In general, the hypothetical PES programs presented to farmers in the 2008 survey of Michigan corn and soybean farmers are multi-input, multi-output systems. The inputs related to ES production include seed for wheat and cover crops, mineral fertilizer, pesticides, banded spray application, pre-sidedress nitrate soil test (PSNT), labor, and chisel plowing. The outputs are the market goods corn, soybean and wheat, and non-market ecosystem services, e.g., enhancing soil fertility by adopting cover crops, improving lake water quality by reducing soil erosion and phosphorus runoff, and mitigating global warming by reducing nitrogen leaching and carbon dioxide emission. Among these, the final ES outputs consumed by residents and evaluated in this paper are lake quality reduction and GHG mitigation. The relationships between outputs and inputs are also shown in Figure 3-1.

3.2.2 Utility maximization models for ES supply and demand

Both consumers and producers are assumed to maximize their utility. Farmers as producers not only benefit from income generation but also from ecosystem services provided from their own land. Thus, the expected level of ES, which influences their production decisions, needs to be incorporated in their utility. The conceptual model of ***farmer*** behavior is a constrained utility maximization model. Farmers are assumed to maximize utility by choosing the level of market goods (Z) and non-market environmental services (ES), which are co-produced by farming activities. The budget constraint limits the cost of consumption to the sum of profit from farm production (π) and nonfarm income (*NFI*). Farm profit is earned from selling agricultural products (*Y*) at price r_y minus variable cost ($r_x X$) and fixed cost (*FC*). Output *Y* is a function of inputs *X* and *FC*. Variable cost refers to material and hired labor associated with the level of production, while fixed cost in this study refers to predetermined resources, including family labor (*L*), capital (*K*), land area (*A*), biophysical conditions (*B*) and information (*I*) available to farmers. Environmental services (*ES*), which are produced jointly with market goods (*Y*) using variable and fixed inputs, may also affect the magnitude and timing of variable input (*X*) employment in turn (Zhang, et al., 2007). *F* represents farmer traits that condition the production function and hence condition the effects of PES offers.

$$\underset{Z,ES}{\text{Max}}\, U^F\left(Z^F, ES \mid F\right) \tag{3.3}$$

$$\text{s.t.} \quad P_Z Z^F \leq \pi + NFI \tag{3.4}$$

$$\pi = r_y Y(X, FC) - r_x X\left(ES\right) - FC\left(L, K, A, B, I\right) \tag{3.5}$$

$$ES = f\left(X, FC\right) \tag{3.6}$$

Enrollment in a PES program could change a farmer's maximized utility by requiring changed land management practice accompanied by receipt of a payment. Farmer participation decision in a PES program depends on the change in utility. This change can be measured monetarily by *willingness to accept (WTA)* payment, which is the minimum payment that the farm household would require to adopt or maintain specified farming practices. *WTA* is represented as the change in expenditure levels *e* of the farm household in response to change in the level of environmental services produced from ES^0 to ES^1 at the maximized utility level (Equation 3.7).

$$WTA = e(r, ES^1, U_0 \mid F) - e(r, ES^0, U_0 \mid F) \tag{3.7}$$

In this equation, the expenditure function $e\ (r,\ ES,\ U_0)$, represents the minimum amount of income that is needed to produce a fixed change in environmental services $\Delta ES= ES^1 - ES^0$, while maintaining utility at its maximized level U_0 (Equation 3.8). The input and output prices are represented by *r* for simplicity. Farmer total spending on production is likely to increase with adoption of new practices that increases output.

$$e(r, ES, U_0) = Min[P_Z Z - \pi(r, ES) \mid U(Z, ES) \geq U_0] \tag{3.8}$$

The WTA can be measured as a function of those characteristics in the expenditure function (Equation 3.9). WTA represents farmer's cost associated with land enrollment in a PES program, which requires a bundle of farming practices and leads to improvements in ecosystem services.

$$WTA = f^F \left(P_Z\ , r, ES^1 \left(A_E \right), ES^0 \left(A_E \right), U_0 \mid F \right) \tag{3.9}$$

The supply function of land in PES program can be written as the marginal WTA, i.e. the additional PES payment required per acre enrolled (P_A), in response to land enrollment A_E, which is a specified set of inputs and farming practices with an associated bundle of expected outputs.

$$P_A = \frac{\Delta WTA}{\Delta A_E} = g^F \left(P_Z, r, ES^1, ES^0, U_0 \mid F \right) \tag{3.10}$$

Residents are also assumed to maximize utility, which depends on a bundle of market goods Z^R, the level of environmental improvements, ΔES, and is conditioned on resident-specific characteristics, *R*, such as age, education, gender and voter registration. Residents choose the level of market goods to maximize utility subject to a budget constraint that the expenditure cannot exceed income *y*, given price vector P_z.

$$\underset{Z}{Max}\, U^R\left(Z^R, ES(lake, GHG) \mid R\right) \tag{3.11}$$

$$s.t.\ \ P_Z Z^R \leq y \text{ and } ES \leq ES^0 \tag{3.12}$$

The indirect utility function V measures the maximized utility at the optimal level of the market good bundle.

$$V\left(P_Z, ES, y \mid R\right) = U^{R*}\left(Z^{R*}, ES \mid R\right) \tag{3.13}$$

Residents' WTP for nonmarket ES is derived as the monetary equivalent change in maximized utility associated with an increase in non-marketed ES consumption as shown in Equation 3.14. With a change in ecosystem services from ES^0 to ES^1, such as higher level of lake water pollution or greenhouse gas emission, the individual would be willing to give up a certain amount of income, namely their WTP, to maintain their optimized utility V^1 to the status quo level V^0.

$$V^0\left(P_Z, ES^0, y \mid R\right) = V^1\left(P_Z, ES^1, y - WTP \mid R\right) \tag{3.14}$$

The WTP can be solved as a function of those characteristics in the indirect utility function (Equation 3.15). WTP represents the benefit or utility that residents obtain from improvements in ecosystem services, and thus is a measure of resident welfare.

$$WTP = f^R\left(P_Z, \Delta ES(ES^0, ES^1), y \mid R\right) \tag{3.15}$$

For the demand curve, the payment for ES can be written as a function of price for normal good, ecosystem services and household income conditioned on resident-specific characteristics.

$$P_{ES} = \frac{\Delta WTP}{\Delta ES} = g^R(P_Z, ES, y \mid R) \tag{3.16}$$

A critical challenge in the current instance is that ES are experienced very differently by consumers than they are by producers. Making the linkage is discussed in section 3.3.2 below.

In principle, the first-best optimal condition is achieved when the economic surplus from the supply and demand of final ecosystem services is maximized with certainty and complete information. However, the economic surplus in this study is defined as the difference between the sum of individual residents' WTP for environmental improvement and farmers' total WTA for adopting practices that lead to enhanced ES. Because this involves payment prior to realization of ES outcomes, only the ***second-best optimal condition*** (referred as "economic optimum" hereafter) can be reached. Since the goods to be valued are different on the supply and demand sides, i.e., land enrollment A_E for farmers and environmental improvement ES for residents, a critical step is to link farming practices to predicted ES outcomes. In the following sections, the WTP and WTA are estimated empirically based on the supply function for land managed with more sustainable cropping systems and the WTP function derived in two previous essays using coupled stated preference datasets from Michigan. The biophysical linkage between farming practices and predicted environmental outcomes are also derived.

3.3 Data and tools

3.3.1 Survey data

The data for supply side analysis of farmer's willingness to enroll land in PES program was collected from a mail survey of 3000 Michigan corn and soybean farmers (56% response rate) in 2008. Each respondent was presented with four hypothetical cropping systems that provide sequentially increased levels of ecosystem services with increasing management requirements. For each cropping system, respondents were offered a specific payment if they would adopt the system for a period of five years, and they were asked how many acres they would enroll in such a program. Information related to farmers' previous farming practices, attitudes on ecosystem services, and demographics were also collected from the survey (Jolejole, 2009).

The data for demand side analysis of resident willingness to pay for two types of environmental improvements was collected from a mail survey of 6000 Michigan residents (40% response rate) in year 2009. The survey provided information about eutrophication of lakes and global warming, how residents would be affected and how land management practices would improve these two ES. The survey elicited resident attitudes on various environmental issues and details about demographic status (Chen, 2010). Then each respondent was asked to vote on different tax payments for three independent land stewardship programs, which provide different GHG and eutrophic lake reductions from changes in land management practices.

3.3.2 Ecosystem services from farming practice

Four hypothetical cropping systems in the farmer survey provided sequence of cropping practices linked to environmental service levels. Requirements on cover crop, corn-soybean-wheat rotation, and band fertilizer application were sequentially added to the conventional corn-soybean rotation system in Systems A-D (Table 1-1). Based on agro-ecological research, five major environmental improvements are generated from the four hypothetical cropping systems as compared to a conventional corn-soybean system. The improvements include soil fertility (Reganold, et al., 1987), surface and ground water quality improvement (Correll, 1998, Poudel, et al., 2001), global warming mitigation (Lal, et al., 2004, McSwiney, et al., 2010), reductions in air pollution and health risk (Glotfelty, et al., 1987, van den Berg, et al., 1999) (Table 1-2).

Among these outcomes, the benefit from lake water quality improvement and global warming mitigation are evaluated by the residents on the demand side, because the physical levels of these two environmental outcomes are significantly influenced by improvement in farming practices but the monetary values of the influence are absent in the literature (Chen, 2010). The farming practices required by each of the four cropping systems and their relations to the two major environmental improvements can be seen in Table 3-1.

- **Lake eutrophication**

Eutrophic lakes with excessive plant growth and algae bloom have a great impact on water-related recreational activities and on possible health risk. Excessive concentration of phosphorus is the most common cause of eutrophication in freshwater lakes, and phosphorus from fertilizer runoff has a major influence (Carpenter, et al., 1998). Since the fertilizer runoff is carried by phosphorus-rich topsoil in most cases (Carpenter, et al., 1998, Correll, 1998, Poudel, et al., 2001), farming practices that mitigate soil erosion would contribute to improving lake water quality.

Soil erosion can be lessened by switching to chisel plow tillage from intensive tillage tools such as the moldboard plow, because more crop residue kept on the soil surface slows soil detachment and transport (Ghidey and Alberts, 1998, Reganold, et al., 1987). Winter cover crops also reduce soil erosion by dissipating the energy of raindrop impact and by renewing the residue cover to hold soil (Delgado, et al., 1999, Joyce, et al., 2002, Langdale, et al., 1991). Adding wheat into corn-soybean rotation also plays a positive role since solid seeded crops like wheat provide more protection against water erosion than row crops (Peel, 1998), while crops are in the field.

The potential to reduce soil erosion with different farming practices in the hypothetical cropping system is calculated in this study using the Revised Universal Soil Loss Equation, Version 2. RUSLE2 is “a computer model containing both empirical and process-based science in a Windows environment that predicts rill and interrill erosion by rainfall and runoff” (Soil and Water Conservation Society, 1993). As the degree of erosion largely varies with the erosivity of rainfall, the erodibility of soil, the slope of the land, the nature of the plant cover and the land management (Morgan, 2005), a large scale estimate needs to capture the spatial variation of soil erosion. RUSLE2 is able to perform this task by simulating soil erosion under the prevailing climate conditions and soil textures in different counties. See Appendix 3-3 for more information about RUSLE2 and how it was used to scale up soil erosion effects to the state of Michigan. See Appendix 3-4 for the linkage between soil erosion and lake eutrophication.

- **Greenhouse gas mitigation**

Cropland management mainly contributes to the global greenhouse gases fluxes in the form of carbon dioxide (CO_2) and nitrous oxide (N_2O) (Robertson and Grace, 2004). Nitrous oxide is a major greenhouse gas that has 298 times more impact per unit weight than carbon dioxide over a 100 year period (Forster, et al., 2007). In cropping systems, its emission is closely tied to the rate of nitrogen fertilizer use in a positive but nonlinear relationship (Hoben, et al., 2011, McSwiney and Robertson, 2005). The pre-sidedress nitrate soil test (PSNT), required in all four cropping systems offered to farmers in the 2008 survey, aims to provide an accurate nitrogen fertilizer recommendation based on plant-available nitrate in soil. It may either increase or decrease fertilizer use according to different weather, soil and crop conditions, but empirical evidence suggests a general reduction in fertilizer use after PSNT in research trials in

Michigan[13] and other regions (Musser, et al., 1995). Adding wheat into a corn-soybean rotation may have either positive or negative impact on the total annual fertilizer use in the system. As wheat requires more fertilizer than soybeans but less than corn, the net effect largely depends on the pre-wheat level of fertilizer application. Winter cover crops also decrease nutrient losses and N_2O emission during periods when the primary crop is not growing (Lal, et al., 2004, McSwiney, et al., 2010). Although it is widely believed that reduced tillage favors carbon sequestration, the difference between moldboard tillage and chisel tillage in CO_2 emission is fairly small (Reicosky, et al., 1995, Reicosky and Lindstrom, 1993).

This analysis obtains rates of nitrogen fertilizer use under different management practices from the literature or personal communications with experts. Like soil erosion, GHG emissions also vary spatially by local climate, soil properties and crop yield (McSwiney, et al., 2010). Thus, in order to calculate the state-level estimates of GHG emissions in different regions with different fertilizer use levels, I used the web-based U.S. Cropland Greenhouse Gas Calculator, which aims to calculate the GHG impact of different field crop management practices (McSwiney, et al., 2010). See Appendix 3-5 for more information about the tool and its usage in the study.

3.4 Empirical analysis

There are five steps to combine the supply and demand estimates to derive the socially optimal payment for ES from changed cropping systems. These are described below.

[13] Based on personal communication with Prof. Sieglinde Snapp from the Department of Crop and Soil Science at Michigan State University during March and April 2011, and Michigan State University extension initial report by George Silva, Jon Dahl, and Natalie Rector on June 15, 2001

3.4.1 ES supply and aggregate cost

In the supply side analysis, the farmers predicted utility-maximizing enrollment of land (A) from Essay 1 is shown in Equation 3.18:

$$E(A) = \Phi(x\gamma/\sigma_e) \cdot \left[\Phi((ap^* + x\beta)/\sigma_u)(ap^* + x\beta) + \sigma\phi((ap^* + x\beta)/\sigma_u)\right] \quad (3.18)$$

In the function, p^* indicates the payment offer for each hypothetical cropping system, while x represents other variables significant at 90% level, which may include perception and attitudes of ecosystem services, total land area managed, current practices, biophysical variables, future expectations variables, experiential variables, and demographics. Equation 3.18 was estimated empirically in Essay 1 using data from the farmer survey and the double hurdle econometric results reported in Tables 1-5 and 1-6. The first term in the equation represents the probability that a farmer is willing to consider the PES program if offered a suitable payment. The willingness to consider is a prior examination of the compatibility of the proposed cropping system with farm's biophysical setting, existing farming practices and other relevant factors. The actual program payment offer was found to play a minor important role at this stage. The empirical analysis from essay 1 suggests this probability generally does not depend on the level of payment, except for System A. The second term represents the land acreage enrollment conditional on willingness to consider the program. Acreage enrollment can be either zero or positive values. The case of zero enrollment indicates that the specific payment for this PES program is not attractive to the farmer even though they are open to the idea of enrolling.

By varying the payment offer p^* from 0 to 120 dollars, land acreage enrolled in each cropping system for each responding farm from the 2008 survey can be simulated using Equation

3.18. Each farm's predicted enrollment A_i is bounded between zero and its total cropland acreage. Depending on their total cropland area, the farms surveyed were divided into four strata with different probability of being sampled. The state-level enrollment is derived by proportionally magnifying individual farm-level supply in each sample acreage stratum given the number of farms in the sample (N) and the total number in the state (TN). The procedure is shown in Equation 3.19, where *k* indicates the price, *i* indicates the individual farm, and the subscripts 1 - 4 indicate four sample strata. The per-acre payment is the marginal WTA or marginal cost to farmers to enroll in one of the four cropping systems. A supply curve can be derived from Equation 3.18 as the marginal WTA (MWTA) in response to land enrollment measured in acreage.

$$MWTA|_{p^*=k,k\in[0,120]} = f\left(\frac{TN_1}{N_1}\cdot\sum_{i_1=1}^{N_1} A_{i_1}|_{p^*=k} + \frac{TN_2}{N_2}\cdot\sum_{i_2=1}^{N_2} A_{i_2}|_{p^*=k} + \frac{TN_3}{N_3}\cdot\sum_{i_3=1}^{N_3} A_{i_3}|_{p^*=k} + \frac{TN_4}{N_4}\cdot\sum_{i_1=4}^{N_4} A_{i_4}|_{p^*=k} \right) \quad (3.19)$$

This state-level empirical marginal WTA is derived directly from respondent farms using the supply response function in Equation 3.18. The state-level function that measures the total WTA for each level of payment (P*) is derived by numerically integrating the empirical marginal WTA.

$$WTA|_{P^*=k} = \int_{j=0}^{k} MWTA|_{P^*=j}\, dj \quad (3.20)$$

3.4.2 Measuring additionality of ES supply from changes in farming practices

The WTP from residents on the demand side is based on improvement in lake water quality and reduction in GHG emissions, while the WTA on the supply side did not require changes in farm management. To insure the additionality of ES supply for comparison to WTP for additional ES on the demand side, WTA for *effective acreage* that entails real change in each practice is calculated as the difference between the land acreage enrolled and acreage where it was previously adopted for each respondent farm from the 2008 survey. The additional effective acreage is calculated conservatively to avoid exaggerating likely environmental outcomes. The additional land that switches to chisel from moldboard plow tillage is calculated as the enrolled land acreage minus land using all other types of tillage previously. This only applies to farms that indicated the use of moldboard plow tillage previously. All other farms are assumed to have zero additionality in reduced tillage, no matter how many acres they enroll. The additional land adopting winter cover crops is simply the difference between land area enrolled and previous cover crop acreage. As PSNT only applies to corn production, the additional PSNT acreage is the difference between enrolled corn acreage (1/2 of area for systems A and B with corn-soybean rotation; 1/3 of area for systems C and D with corn-soybean-wheat rotation) and corn land previously using PSNT. The additional land switching from corn-soybean rotation to corn-soybean-wheat rotation is 1/3 of the enrolled land area minus the previous wheat acreage. The additional land with band application of fertilizer is the total enrolled acreage if the farm previously broadcasted fertilizer at the full rate, and is zero otherwise. Tables 3-2 and 3-3 summarize the formulas used to calculate additional acreage for each practice in each cropping system for eutrophic lakes and GHG reduction, respectively.

3.4.3 Link additional change in practices to ES improvements

As identified in the conceptual model, a key step to match supply and demand is to link change in farming practices to the environmental improvements perceived by residents. In particular, given the additional effective land acreage calculated in the previous step, the task is to derive the effect on the number of eutrophic lakes and the amount of GHG emissions of one additional acre enrolled in each practice. The percentage change of soil erosion between cropping systems with and without a certain practice is calculated using RUSLE 2 (see Appendix 3-3 for details). Since the erosion rate highly depends on weather conditions and soil type, the final estimate is an area-weighted average of the dominant soil type in each of Michigan's 34 major counties for corn, soybean and wheat production. The major counties are selected based on the total planted area of these crops. A representative soil type in each county is selected for erosion estimates (see Appendix 3-2 for details). The effect of cropping practice adoption on the number of eutrophic lakes is described in Appendix 3-4, based on phosphorus leaching reduction rate, percentage of C-S rotation to cropland erosion, total cropland area under corn-soybean rotation, fertilizer phosphorus contribution to lakes, and the current number of lakes falling into different trophic status levels using the method developed by Chen (2010). The synergy among practices is considered by conditioning marginal change in each practice on other required practices in the cropping system. For example, the erosion effect from adding wheat into rotation is conditioned on adopting chisel plow and cover crops[14].

As explained in section 3.3.2, the reduction in GHG emissions is only calculated for N_2O reduction given the ambiguous results of CO_2 emission from reduced tillage in the literature. The

[14] In some cases, the exact practice combination is not available in RUSLE 2, a close alternative is chosen for comparison. The "with" and "without" scenario to examine one practice is only different in the practice itself.

differences among practices are due to differences in the rates of fertilizer use. The state average rate of nitrogen fertilizer using the US Cropland Greenhouse Gas Calculator (see Appendix 3-5) is 142 lb/acre for corn, zero for soybean and 66.1 lb/acre for wheat. According to a long-term N credit experiment with different crop management practices conducted by Gentry et al (2011) in Kalamazoo Michigan, use of the PSNT combined with 2 Mg/ha of red clover biomass provided a N credit of 35.7 lb/acre to corn. Silva et al. (2011) verified possible N fertilizer reduction ranging from 30 to 90 lb/ acre from three corn fields in Michigan despite unfavorable weather conditions due to PSNT. A three-year PSNT experiment in Pennsylvania corn production found the average reduction of N fertilizer from over 100 observations to range from 15 to 60 lb/ acre each year (Musser, et al., 1995). Based on these studies, we assume the N fertilizer rate reduction due to PSNT is 30 lb/ acre for adopting PSNT, 5.7 lb/acre for adopting winter cover crops, 30 lb/acre further less for incorporating wheat, and a 1/3 reduction of the remaining fertilizer use (142-30-5.7-30 lb/acre) for adopting band fertilization. Like the erosion estimates, the 34-county area-weighted average of GHG emissions is used to estimate the mitigation of GHG due to different farming practices. The synergy among practices is calculated by summing up the marginal changes from each practice in the cropping system. For example, the GHG effect from adopting a band application is based on prior adoption of PSNT, cover crops and adding wheat to the corn-soybean rotation. The estimates of these per-acre reductions in eutrophic lakes and GHG are shown in Tables 3-4 and 3-5.

The estimates of reductions in eutrophic lakes and GHG from land enrollment for each farm are obtained by multiplying the state-level additional acreages calculated in Tables 3-2 and 3-3 under each practice by the average per-acre reductions in Tables 3-4 and 3-5. The estimates for environmental improvements for each farm are calculated at each price level ranging from 0 to \$120.

3.4.4 ES demand and aggregate benefit

The benefit (WTP) function for residents is derived and estimated in Essay 2. For matching demand with supply at the level of the State of Michigan, the conditional WTP function is estimated to ensure three properties. First, it is increasing and concave with respect to reductions in eutrophic lakes and GHG emissions, due to the assumption of diminishing marginal utility. Second, the conditional WTP should be greater than zero since only respondents indicating a positive WTP are included in the regression. Respondents that have either zero or positive WTP are analyzed in the prior spike model to estimate an average participation rate. Third, the WTP should approach zero with no environmental improvements. Both semi-log function and mixed log-log function are adopted and compared in Essay 2 (Equations 2.12 and 2.13). Although the shape of WTP curves are different due to the inherent functional form assumptions (Figures 2-6 and 2-7), the predicted WTP in response to environmental improvements using two functional forms lies in a common range, and the goodness of fit of the two functions is not statistically different. The mixed log-log function (Equation 2.13), which displays diminishing marginal utility starting near the origin, and has higher statistical significance based on the Wald test, was chosen for estimating resident conditional WTP (CWTP):

$$CWTP = \exp\left(\delta + \alpha \ln(Lake) + \beta \ln(GHG) + \varphi \ln(GHG) * Concern + \gamma R_i + \varepsilon_{ij}\right) \qquad (3.20)$$

In this function, *lake* and *GHG* measure the number of eutrophic lakes reduced and tons of GHG emissions abated. The natural logarithm of CWTP is a function of natural logarithms of *lake* and

GHG. Since CWTP for GHG abatement is closely related to respondents' concern about global warming, an interaction of the two variables is included in the function. *R* indicates resident-specific characteristics. Preference certainty is not included in the estimation because the unbiased WTP estimates from certainty-adjusted models are not statistically different from the conventional model, and there is still no consensus regarding the theoretical foundation and the methodology in the literature (Table 2-12). The average probability of having positive willingness to pay, η=0.876, which is estimated from the spike model (Essay 2 in Ma, 2011), is multiplied by the conditional WTP to derive the unconditional state-level WTP.

$$WTP = \eta \cdot CWTP \tag{3.21}$$

In the previous step, I have calculated the predicted reductions in lake eutrophication and GHG emissions from additional effective acres enrolled. , However, the empirical results that extrapolate down to zero payment from the payment range offered in the survey suggest that some farmers are willing to enroll land in the PES program with no payment. Some of this land would even provide additional environmental improvement. Such voluntary enrollment and environmental stewardship is possible if technical assistance is available and information on the private and public benefits from conservation practices is clearly conveyed[15]. Although it is theoretically possible that farmers may adopt environmental stewardship practices without

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[15] Some of the acreage enrollment is due to zero additionality, namely farmers who have already adopted certain practices and are willing to enroll with even zero payment. The 2008 focus group study associated with the Michigan farmer survey found that farmers revealed zero WTA. Referring to his bid in an experimental auction, one participant said, "I'm already doing some of it, A and B, so, I could have bid 0 on those I guess." However, the significant positive abatement in eutrophic lakes and GHG in hypothetical systems indicate willingness to make real changes in farming practices for zero payment. These voluntary changes in practice may be influenced by implicit factors associated with the proposed PES setting such as information, technology support, and positive utility from ecosystem services. The positive enrollment and environmental improvement for zero payment may also be partly attributed to the extrapolation of results beyond the lower bound of payments offered in the survey (System A: \$4, System B:\$10, System C:\$15 and System D: \$20).

compensation and the predicted WTA function suggests such behavior, this analysis builds on the more conservative assumption that adoption of changed cropping systems requires a non-zero positive payment for ES. To derive the economic optimal conditions for facilitating ES supply, I assume that resident WTP corresponds only to additional environmental improvements that are not likely to occur without incentive payment. Thus, the levels of reductions in eutrophic lakes and GHG emissions used to predict the state-level WTP is calculated as the difference between state-level environmental improvements derived in section 3.4.3 and those achieved with zero payment in each cropping system. . The resident survey was targeted to adults, and the adult population of Michigan residents was 7,539,572 in 2010[16]. Of that population, 81.4% is used for state-level estimates because the survey registered an 18.6% protest rate of residents who disliked the survey provision mechanisms (e.g., taxes and agricultural subsidies).

3.4.5 Welfare maximization by combining supply and demand

The optimal condition for aggregate supply of and demand for ecosystem services from cropland is achieved by maximizing the economic surplus, which is the difference between resident WTP and farmer WTA at the state level. The optimal condition in each of the four cropping systems is identified, as is a mixed choice option designed to offer a low-cost choice among the four systems. In the mixed-choice alternative, each farm is assumed to choose from the four systems offered at each payment level the one that minimizes the average farm-level cost of generating additional ecosystem services. The farm-level average cost per acre is calculated based on the per-acre payment offer and the corresponding acreage enrollment chosen

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[16] US Census Bureau, 2010. Demographic Profile Data: Profile of General Population and Housing Characteristics. http://2010.census.gov/2010census/popmap/ipmtext.php?fl=26

by each respondent farmer. Since the option of zero payment for adopting the specified cropping systems was not offered to farmers in the survey, voluntary enrollment for no payment is not included in calculating the average cost. Consequently, on farms where a cropping system offering greater ES was already practiced (e.g., systems C or D), it is possible for the mixed choice system choice algorithm not to recognize an existing system (available at zero added cost) as being the least costly at delivering ES.

The state-level enrollment for each system at each payment level is derived by proportionally scaling up the individual farm-level enrollments of those who choose the system in each sample acreage stratum, given the number of farms in the sample and the total number of farms in the state. The total state-level acreage enrollment is the sum of the enrollments in the four cropping systems. The state-level environmental improvements in lakes and GHG levels are calculated as the sum of the products of the state-level acreage enrollments and the per-acre improvements from the four systems. See Appendix 3-6 for details.

Two variants of the economic optimal condition are examined here. The first variant is to pay farms based on the land acres enrolled in the hypothetical cropping system, which is the actual setting in the survey. In this case, farmers are still get paid even if no new practice is adopted with land enrollment. The second variant is to target only farms that offer additionality in environmental improvement from land enrollment. As some farmers have already adopted certain practices on some of their land enrolled in the PES program, payments to these farms do not necessarily pay for additional environmental improvement. To examine a more cost-effective case, this policy scenario only pays farms that adopt new practices contributing to at least one of the two environmental improvements, i.e., eutrophic lake abatement and GHG mitigation. Finally, in order to examine the possibility of expanding PES payments within the budget of the current government subsidy system, the cost of the previous scenarios is compared to the value of USDA subsidy direct payments to Michigan growers of corn, soybean and wheat.

3.5 Results and discussion

The results below report predicted economically optimal conditions for these PES programs. Summarizing the procedures described in the previous section, farmer WTA and resident WTP are derived and combined as follows: Farmer land enrollment in different cropping systems is predicted using the supply function estimated from the double hurdle model reported in Tables 1-5 and 1-6. The total WTA in response to land enrollment is empirically aggregated from the supply response illustrated in Figure 1-4. The enrolled cropland acreage that provides additional ecosystem services by newly adopting required farming practices is identified from total enrollment following Tables 3-2 and 3-3. The environmental improvements, measured by the reductions in the number of eutrophic lakes and GHG mitigation percentage from year 2000 level, are derived following Tables 3-4 and 3-5. The resident WTP is estimated based on the conditional WTP regression results from Table 2-8 using the mixed log-log function and the conventional dichotomous random-effect model, along with the average spike probability calculated as predicted values based on the econometric results in Table 2-6.

3.5.1 Payment for enrollment scenario

The State of Michigan aggregate benefit (WTA) and cost (WTP) simulated for the four individual hypothetical PES programs are shown in Figures 3-2 to 3-5. The detailed calculations of welfare measures and environmental improvements at each payment level are shown in Appendix 3-7. The results reveal that the public benefits from these cropland PES programs are greater than the costs to farmers over the payment range from $0 to $120 per acre.

Economic welfare is maximized where the deviation is largest between aggregate benefit (WTP) and aggregate cost (WTA). Measures of per-acre payment, land enrollment, welfare and environmental improvements at the economic optimum are shown in Table 3-6. As shown in these tables and graphs, the maximized economic welfare is achieved with a set of optimal conditions in all five system alternatives, among which four alternatives other than System A exhibit small variation across systems.

At the economic optimum, the marginal per-acre PES payment is highest for System D at $21/acre, which has the most stringent requirements. It is lowest in the most basic alternative, System A at $14/acre. These per-acre payments are all within the range of current conservation program payments. Welfare-maximizing land enrollment levels are similar in the five programs, ranging from 0.91 to 1.2 million acres. These predictions suggest that about half of Michigan's approximately 2.3 million acres under corn-soybean rotation (Appendix 3-1) would be enrolled in these PES programs under economic welfare-maximizing conditions. When comparing economic welfare across the five programs, System A apparently generates the lowest economic surplus, $120 million, and lowest benefit-cost ratio 0.4, due to its low environmental performance. All remaining systems result in similar economic surplus, ranging between $140 and $142 million. The mixed-choice alternative, which intends to minimize the average payment per unit of environmental improvement, gives the largest improvement in both lake quality and GHG mitigation, equally high economic surplus with System C, and the second largest benefit-cost ratio, next to System B. The mixed-choice alternative seems to be the most cost-effective alternative among the five. The component cropping systems enrolled in the mixed-choice alternative among farms at different payment levels are shown in Figure 3-7. The percentages of farms that enroll in systems A-D are 10%, 13%, 57%, and 20% respectively. The pervasiveness of System C, which requires corn-soybean-wheat rotation, cover crop, PSNT and chisel tillage, is presumably due to its high economic surplus and large contribution to eutrophic lake mitigation[17]. If the focus of public demand for ES is on improvement in eutrophic lakes, as revealed in the 2008 resident survey, System C would be a good choice if a single system scheme were implemented.

3.5.2 Payment for additionality scenario

In the farm sample, very few farm**er**s agreed to adopt the proposed practices on completely new land, but likewise very few accepted payment while making no change in at all in their previous practices. Most farms provide partial additionality from enrollment in PES. Given the design of the survey, it is impossible to distinguish between the payments for land enrollment with and without additional ecosystem services. To examine the program design that promotes cost effectiveness based on additionality, a scenario targeting farms that provide additionality in at least one ecosystem service is analyzed and compared to the scenario above that pays for *enrollment*. The results for the "payment for enrollment" scenario and the "payment for additionality" scenario are shown in Table 3-7. The economic surplus sequentially increases from System A at $131 million to the mixed-choice alternative at $143 million, although the differences among the five cropping system alternatives remain relatively small. The targeting scheme has the largest impact on System A, the one with least requirements in farming practices and lowest environmental performance. Compared the "payment for enrollment" scenario, with

[17] The average cost of abating eutrophication was given lexicographic priority in the system selection process over the average cost of GHG mitigation, since residents showed higher willingness to pay for water quality improvement.

only 1/5 of the previous enrolled lands being targeted, System A yields 6 times more improvement in lakes but 2/3 less GHG mitigation using half of the previous total government spending. System D, the most stringent one, also benefit from a targeting scheme. With higher per-acre payment and larger enrollment in System D, the benefit-cost ratio increases from 25.5 to 31.9, ranking first among the five alternatives. System D also has the largest GHG mitigation potential due to its restriction on fertilizer use. Based on these observations, the targeting strategy would enhance the cost-effectiveness of PES programs by eliminating land enrollment with little additionality, such as System A, or by facilitating enrollment in high-cost stringent program with higher payment, such as System D.

Despite the potential cost-effectiveness of the "payment for additionality" scenarios, there are still problems associated with this seemingly efficient program. First, as the policy targets changes in practices, it is essential to verify the baseline practices of each participating farm, which would require extra administrative cost. Second, this policy may also be criticized for its inequity, because it would disqualify prior adopters of conservation practices for PES payment. In the extreme, good environmental stewards may even opt temporarily to switch back to conventional farming practices in order to qualify to be paid through the PES program. It seems that one practical strategy is to differentiate payment for land enrollment providing additionality with new practices and to maintain environmental benefits from existing practices. This type of payment scheme has been proposed by the USDA Natural Resource Conservation Service (NRCS). In the recently released final rule for the Conservation Stewardship Program, the NRCS is implementing a split payment structure with one payment rate for new practices and a lower rate for existing practices to encourage producers to apply more new activities and generate greater environmental benefits (USDA-NRCS, 2010). The issue of inequity is still a major concern, even for this payment scheme.

3.5.3 Comparison with current commodity subsidies

To examine the role that PES programs could play in government subsidies, the costs of the hypothetical PES program described above are compared with current USDA direct payments to Michigan growers of corn, soybean and wheat. The commodity subsidies in various forms still account for the largest proportion of farm subsidies in Michigan. Based on data from 1995 to 2010, the average annual subsidy for corn, soybean and wheat was about $190 million (Environmental Working Group, 2011). Among major types of commodity subsidies (i.e., direct payments, counter-cyclical payments, and marketing loans), direct payments to corn, soybean and wheat farmers cost the federal government $78.6 million annually over 1995-2010. The direct payments were established in 1996 to wean farmers off traditional subsidies that had been triggered during periods of low prices for corn, wheat, soybeans, cotton, rice, and other crops (Environmental Working Group, 2011). However, the direct payment program is difficult to justify, especially in the face of rapidly expanding federal debt, because it has been maintained beyond its intended transition period and is provided to recipients without economic need. Further, with the pressure to comply with WTO provisions, the reform of converting direct commodity payments to conservation payments is taking place in Europe and the U.S. (Swinton, et al., 2006). The size and scope of U.S. conservation programs have substantially increased since the 2002 farm bill to partly replace the trade-distorting commodity subsidies (Baylis, et al., 2004).

To examine the possibility to transition commodity subsidies and especially the direct payment to conservation payment, government spending at the economic optimum for our hypothetical PES programs is compared with the actual commodity subsidies in Michigan. The government spending needed at for different cropping systems ranges from \$15 to \$24 million if farmers are paid based on land enrollment. The spending is estimated between \$6.5 and \$27 million if the PES program targets farms with additionality in abating eutrophic lakes and GHG. Thus, even only replacing the direct commodity payment in corn, soybean and wheat subsidies would be amply sufficient to achieve the economic optimal conditions for any of these systems. Recent average expenditures for direct payments to these farmers are more than three times the PES spending needed to induce adoption of 1.2 million acres in the mixed system, the most cost-effective choice among the five alternatives. Since our PES programs would target the same farmers as the commodity subsidies, predictions from this study highlight the opportunity to transfer income to the intended recipients of commodity subsidies trade-neutrally via conservation payments. This transition would also improve the economic efficiency of government subsidy programs.

3.6 Conclusion

This essay combines a supply-side cost function of farmers' willingness to adopt ES-providing practices with a demand-side benefit function of residents' willingness to pay (WTP) for resulting ES to derive the welfare-maximizing conditions for efficient design of cropland PES programs. This study contributes to the literature by proposing agricultural PES policies based on the underlying supply-demand mechanism embedded in empirical stated preference estimates. Land enrollment in PES programs is viewed as a bundle for five potential conservation farming programs and two types of resulting environmental improvements. The payment and quantity of enrollment, as well as derived environmental and welfare measures are calculated under different policy variants. These include a welfare-maximizing scenario that pays farmers for land enrollment, a scenario that targets farms with additionality in abating eutrophic lakes and GHG emissions, and a simple comparison with current commodity subsidies. In each scenario, five PES programs are examined--four single cropping system programs that provide sequentially increased levels of lake eutrophication reduction and greenhouse gas mitigation with increasing management requirements and payments to farmers plus one mixed-choice program that requires farmers to enroll in the cropping system alternative with the lowest average unit cost for environmental improvements. Farmer costs (and hence PES program costs) are well covered by resident benefits in all five hypothetical programs under all policy scenarios. In the welfare-maximizing "payment for land enrollment" scenario, the economically optimal conditions are achieved in a reasonable payment range of \$14 to \$21 dollar/acre, for all five programs. Comparing across programs, the mixed-choice alternative, which allows each farmer to choose the one of the four cropping systems that minimizes average farm-level cost, is relatively more cost-effective than the others. However, the mixed-choice alternative would require great flexibility in program design to allow farmers to identify the most cost-effective changes on each individual farm, and it would pose major monitoring challenges for PES program administrators. It is clear that System A, the one with fewest required farming practices and lowest environmental improvement is dominated by the other four system alternatives. Given the trivial difference in economic welfare among those four, however, and given the trade-offs in cost and levels of different ES benefits that each offers, it is difficult to identify any one best system. With particular goals in different PES programs and the evolution of demand for ES, any of the four systems could be desired.

When the PES program targets farms with additionality, cost-effectiveness is generally improved in all of the five system alternatives. Targeting would especially improve performance in the low-cost, low benefit cropping system (System A) by eliminating land enrollment with little additionality. It would also help the high-cost, high benefit cropping system (System D) by facilitating enrollment with higher payment. Although targeting payments only to additional effective acres appears to reduce the cost and improve the efficiency of PES programs, it may increase administrative costs. It may also cause perceptions of unfairness if pre-PES adopters of conservation practices are excluded from incentive payments. Therefore, a split-payment scheme that offers a higher rate for improved stewardship practice and a lower (but positive) rate for existing practices may be a reasonable solution.

Finally, I compare government spending at the economic optimum in different programs with current direct payment of commodity subsidy for corn, soybean and wheat in Michigan. The results confirm the opportunity to replace the direct payment with a PES conservation payment to the same recipients with less total spending, which would potentially improve the economic welfare of subsidy policies.

Under the current global trend of rapid-growing population accompanied by degradation in environmental quality and natural resources, agriculture faces a critical challenge of securing the global food supply while maintaining a good environmental stewardship. The working land PES program provides a unique opportunity for conserving the environment without sacrificing land under production. Improving the efficiency of working land PES programs has long been a target of PES design, and it becomes especially urgent during this financially difficult period. By combining the supply and demand estimates from stated preference surveys in Michigan, this study highlights the possibility of designing an efficient program and outlines the features of such a program. A detailed examination of strategies for targeting farms and differentiating payments for different degrees of practice adoption is needed in future studies to further improve the efficiency of agricultural PES programs.

Figures and Tables

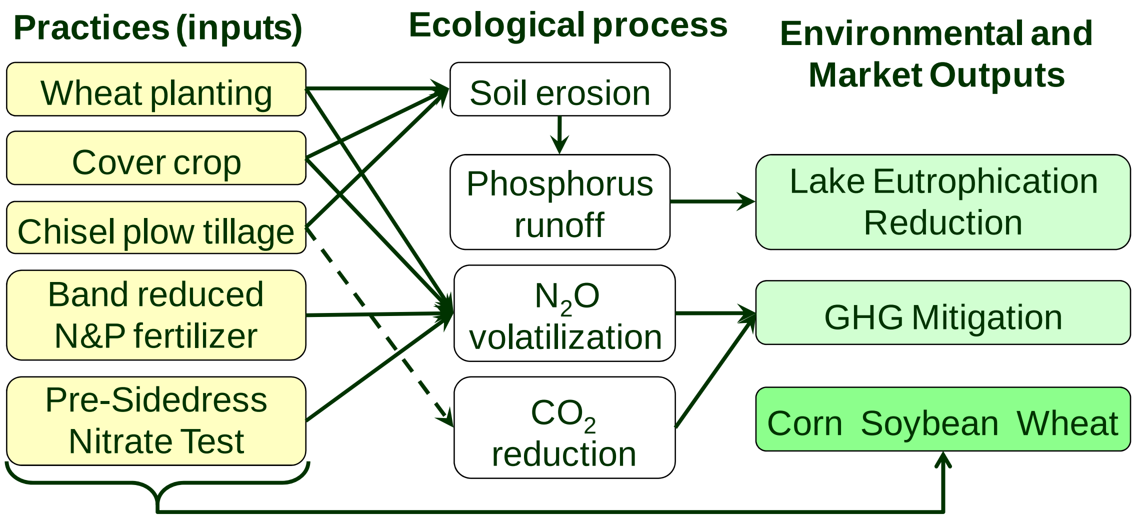

Figure 3-1 Input-output system of ecosystem services from croplands

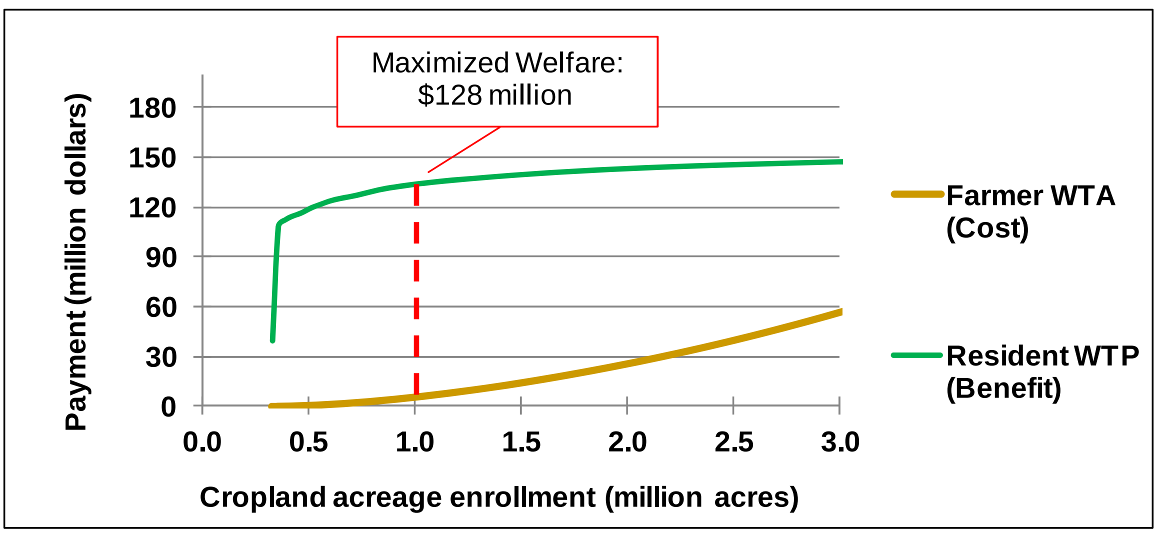

Figure 3-2 State-level benefit (WTP) and cost (WTA) for ES from Michigan cropland (System A)

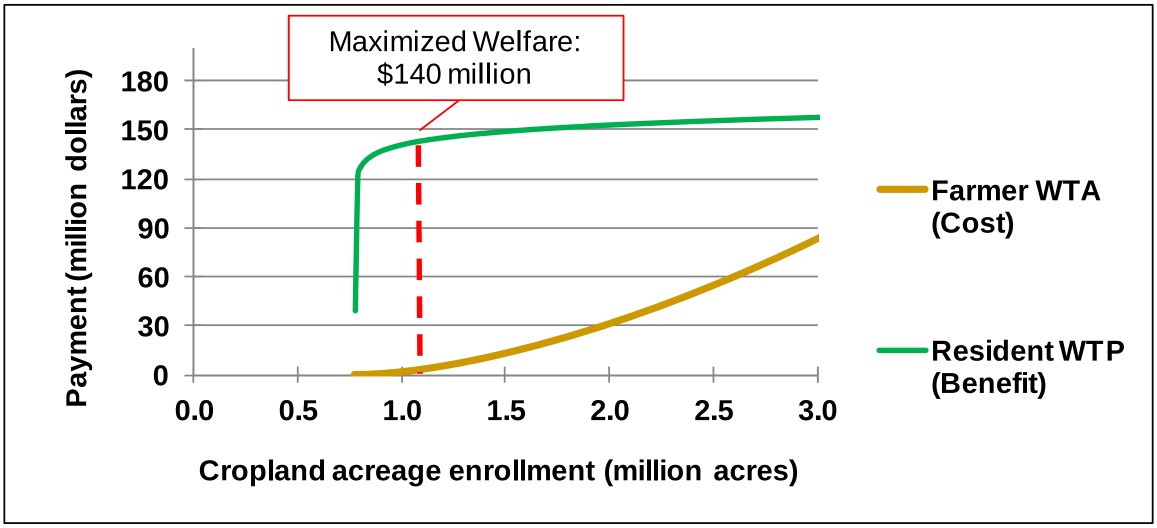

Figure 3-3 State-level benefit (WTP) and cost (WTA) for ES from Michigan cropland (System B)

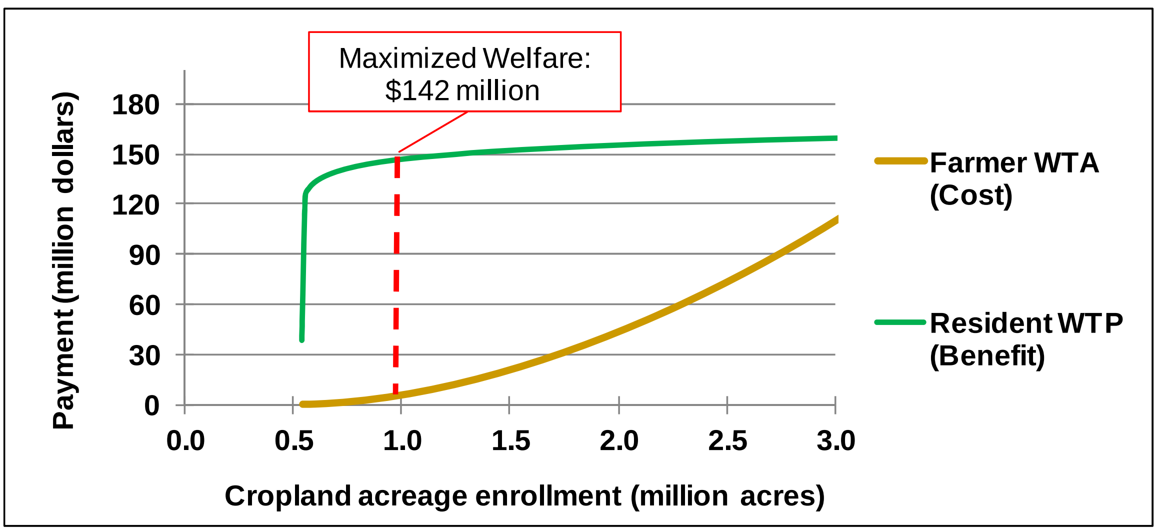

Figure 3-4 State-level benefit (WTP) and cost (WTA) for ES from Michigan cropland (System C)

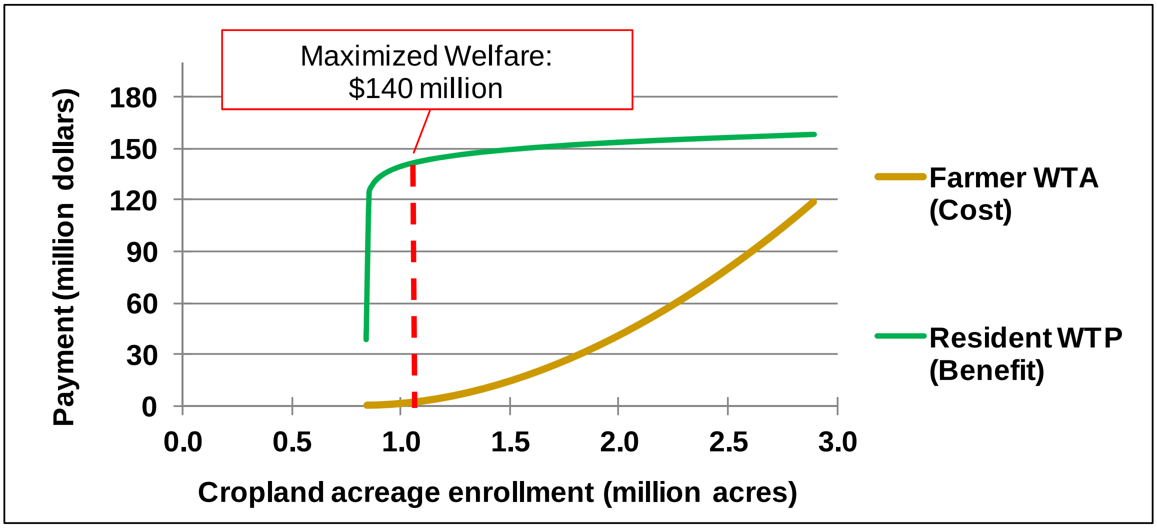

Figure 3-5 State-level benefit (WTP) and cost (WTA) for ES from Michigan cropland (System D)

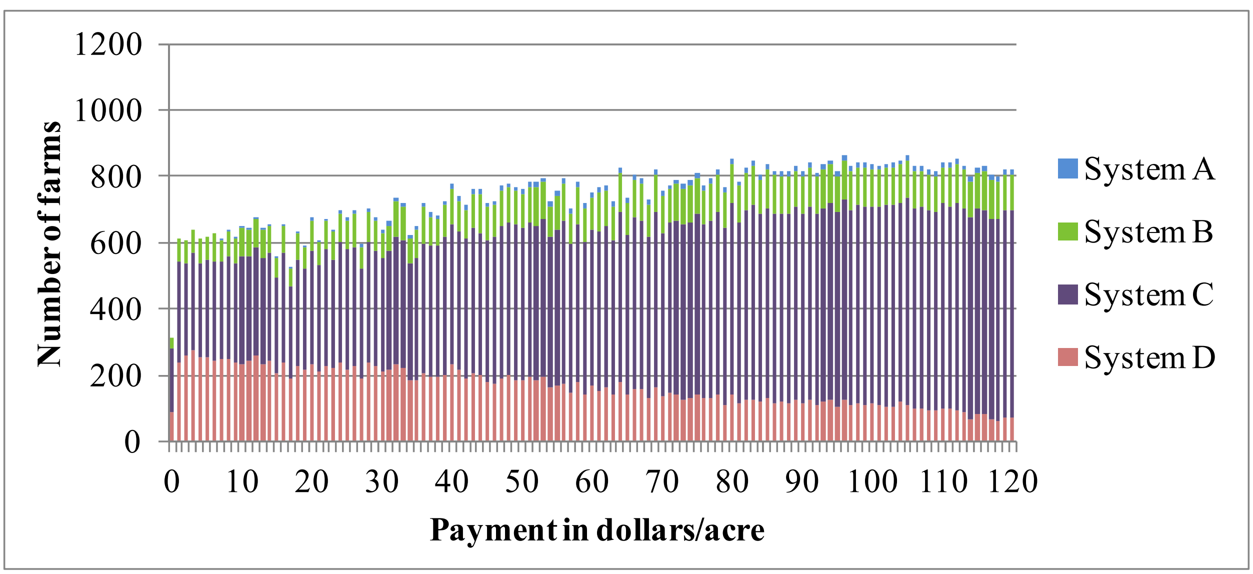

Figure 3-6 Number of farms using each cropping system at different price levels for the scenario with mixed choice of systems but no requirement of additionality.

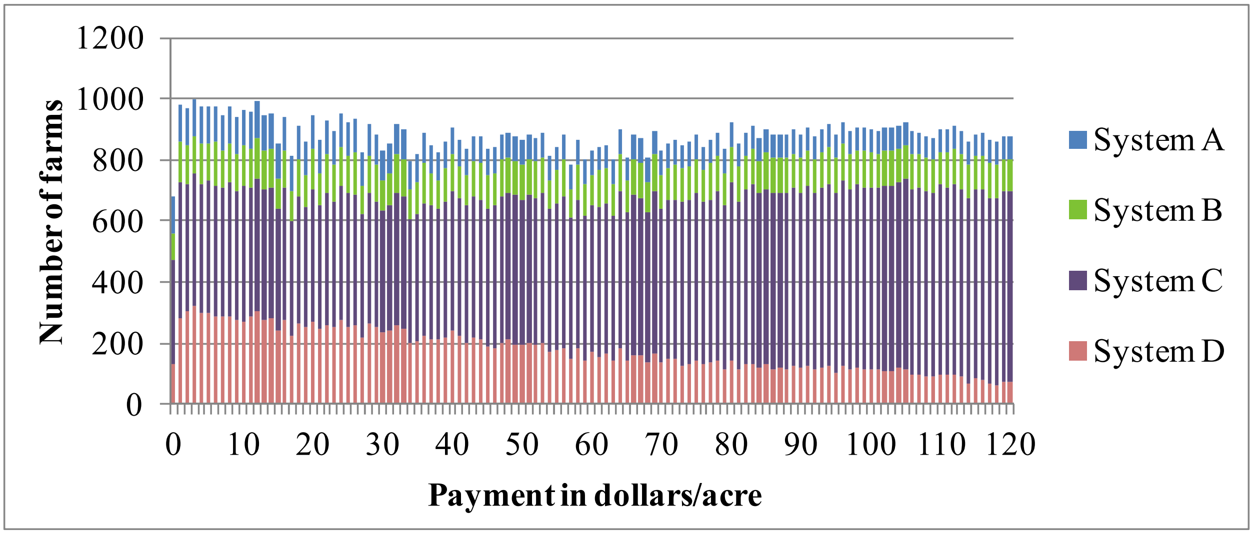

Figure 3-7 Number of farms using each cropping system at different payment levels for the scenario allowing mixed choice of system and paying for farms with additionality in at least one environmental improvement.

Table 3-1 Environmental improvements from farming practices in four cropping systems

Final ES	**Eutrophic Lakes Reduction**		
Intermediate ES	Soil Erosion Reduction		
Practice	Moldboard **tillage** → Chisel plow	No **cover crop**→ cover crop	Corn-soybean → corn-soybean-**wheat**
System A	√		
System B	√	√	
System C	√	√	√
System D	√	√	√

Final ES	**Greenhouse Gas Emission Reduction**				
Intermediate ES	N_2O Reduction				CO_2 Reduction
Practice	No **PSNT** → PSNT	No **cover crop** → cover crop	Corn-soybean → corn-soybean-**wheat**	Broadcast **fertilizer** at full rate→ Band at 2/3 rate	Moldboard **tillage** → Chisel plow?
System A	√				√
System B	√	√			√
System C	√	√	√		√
System D	√	√	√	√	√

Table 3-2 Calculation of effective acreage for each practice in four cropping systems that results in eutrophic lakes reduction

Final ES	Eutrophic Lakes Reduction		
Intermediate ES	Soil Erosion Reduction		
Practice	Moldboard tillage → Chisel plow as principal tillage	No cover crop → cover crop	Corn-soybean → corn-soybean-wheat
System A	Max (Acres - Chisel acres - Other tillage acres, 0)		
System B		Acres -previous cover crop acres	
System C			(1/3)* Acres -previous wheat acres
System D			

Table 3-3 Calculation of effective acreage for each practice in the four cropping systems that results in greenhouse gas reduction

Final ES	Greenhouse Gas Emission Reduction				
Intermediate ES	N_2O Reduction				CO_2 Reduction
Practice	No PSNT → PSNT	Corn-soybean → corn-soybean-wheat	Broadcast fertilizer at full rate → Band at 2/3 rate	No cover crop → cover crop	Moldboard → Chisel plow?
System A	(1/2)* Acres - previous PSNT acres				Max (Acres - Chisel acres - Other tillage acres, 0)
System B				Acres - previous cover crop acres	
System C	(1/3)* Acres - previous PSNT acres	(1/3)* Acres - previous wheat acres			
System D			= Acres if do not currently band; =0 if currently band		

Note: See Appendices 3-3 and 3-4 for calculations and references.

Table 3-4 Average reduction in eutrophic lakes from farming practices.

Practices	Erosion reduct-ion rate	Standard deviation	Eutrophic lake reduction/ acre	Ref.	Crops	Location	Soil	Time
Moldboard →chisel plow	30%	1.4%	0.0000197	RUSLE2	corn-soybean	34 major field crop production counties (total C-S-W harvest area greater than 40,000 acres)	One major representative soil type for C-S-W cropland in each county (matching CDL with STATSGO2)	Average year in a multi-year rotation
Add cover crop	37%	1.2%	0.0000251					
Add wheat in C-S	9%	1.9%	0.0000059		corn-soybean-wheat			

Table 3-5 Average reduction in GHG emission due to farming practices.

Practices	GWP-CO_2 lb/acre/ year	Standard deviation	Ref.	Crops	Location	Soil	Time
Use PSNT	72	10.0	Snapp et al., 2010+ MSU extension +GHG calculator	corn-soybean	34 major field crop production counties (total C-S-W harvest area greater than 40,000 acres)	One major representative soil type for C-S-W cropland in each county (matching CDL with STATSGO2)	Average year in a multi-year rotation
Add cover crop	16	10.0					
Reduce 1/3 N fertilizer	92	8.8	GHG calculator				
Add wheat in C-S	-21	10.2	GHG calculator	corn-soybean-wheat			

Note: See Appendix 3-5 for calculations and references. GWP-CO_2=global warming potential in carbon dioxide equivalent units.

Table 3-6 Economically optimal conditions for the "payment for land enrollment" scenario in five cropping system alternatives.

	Pay-ment/ Acre ($)	Total acres (million $)	Farmer WTA (million $)	Resident WTP (million $)	Spending (million $)	Farmer Welfare (million $)	Resident Welfare (million $)	Econo-mic surplus (million $)	Eutro-phic Lakes Reduced (number)	GHG Abate-ment (% of 2000 emission level)	Benefit/ Cost ratio
System A	14	1.04	6.10	134	14.6	8.47	120	128	0.38	0.0066	0.4
System B	19	1.14	4.10	144	21.7	17.6	123	140	8.5	0.0074	27.6
System C	18	0.91	3.79	146	16.4	12.7	129	142	9.7	0.0090	22.7
System D	21	1.16	3.56	144	24.4	20.8	119	140	7.5	0.0070	25.5
Mixed choice	18	1.23	4.47	146	22.1	17.6	124	142	11	0.0093	26.4

Table 3-7 Economically optimal conditions for the "additionality targeting" scenario in five cropping system alternatives

	Pay-ment/ Acre ($)	Total acres (million $)	Farmer WTA (million $)	Resident WTP (million $)	Spen-ding (million $)	Farmer Welfare (million $)	Resident Welfare (million $)	Econo-mic surplus (million $)	Eutro-phic Lakes Reduced (number)	GHG Abate-ment (% of 2000 emission level)	Benefit/ Cost ratio
System A	27	0.22	4.66	136	6.05	1.4	130	131	2.5	0.0019	2.5
System B	19	1.10	3.98	142	20.9	17.0	121	138	8.5	0.0041	27.6
System C	18	0.89	3.84	142	16.0	12.2	125	138	9.7	0.0029	22.7
System D	22	1.25	3.54	144	27.6	24.1	117	141	7.8	0.0077	31.9
Mixed choice	12	0.918	1.25	144	11.0	9.8	133	143	8.4	0.0073	23.5

APPENDICES

APPENDIX 3-1: CALCULATION OF CROPLAND UNDER CORN-SOYBEAN ROTATION IN MICHIGAN

The farmer survey used for the aggregate supply and demand analysis primarily focused on cropland under corn-soybean rotation. The total corn-soybean rotation area in Michigan is used in this essay to calculate the impact of farming practices on eutrophic lake reduction. However, this information is not available in current agricultural statistics, so an approximation is obtained using data from the USDA Agricultural Resource Management Survey (ARMS, 2000-2006). The ARMS is a national survey that provides field-level information about crop production, farm production, business, and households based on representative sample.

From the online ARMS database, we can obtain the information on "planted area of previous crop harvested" for corn or soybean in selected survey years under the "Crop Production Practices Tailored Reports". The percentage of soybean land previously planted in corn and the percentage of corn planted in the previous year of soybean are calculated in Table 3-A1. The two land percentages can be taken as the rotation rate approximately. The only caveat is that the data is only for the most recent crop year before the surveyed crop year, rather than for multiple years of rotations. Combine the rotation rate for corn and soybean with their planted area data from year 2008 to 2010 from Michigan Agricultural Statistics, we can deduce the cropland area under corn-soybean rotation in Michigan in Table 3-A2.

Table 3-A1 Rotation rate calculation based on Michigan ARMS data

year	total **corn** planted area (acres)	previous **soybean** area (acres)	soybean/corn %
2005	2250.00	950.49	42.2%
2001	2201.21	936.06	42.5%
2000	2200.73	1047.31	47.6%
Average			**44.1%**
year	total **soybean** planted area (acres)	previous **corn** area (acres)	corn/soybean %
2006	2000.01	1415.33	70.8%
2002	2049.89	1137.90	55.5%
2000	2099.50	1314.58	62.6%
Average			**63.0%**

Data Source: USDA ARMS Farm Financial and Crop Production Practices: Tailored Reports, Michigan, 2000-2006.

Table 3-A2 Corn-soybean rotation area calculation

year	crop	total planted area (acres)	rotation %	planted area (acres)	corn-soybean planted area (acres)
2010	corn	2,400,000	44.1%	1,058,860	2,349,608
	soybean	2,050,000	63.0%	1,290,748	
2009	corn	2,350,000	44.1%	1,036,800	2,296,067
	soybean	2,000,000	63.0%	1,259,267	
2008	corn	2,400,000	44.1%	1,058,860	2,255,163
	soybean	1,900,000	63.0%	1,196,303	
Average corn-soybean rotation area					**2,300,279**

Data Source: 1) USDA ARMS Farm Financial and Crop Production Practices: Tailored Reports, Michigan, 2000-2006; 2) Planted area for major crops, Michigan Agricultural Statistics, 2008-2010.

APPENDIX 3-2: MAJOR CROP PRODUCTION COUNTIES AND REPRESENTATIVE SOIL TYPES IN MICHIGAN

The estimated soil erosion and GHG emissions depend on not only crop and farm management practices, but also on soil textures that vary across the state. To capture the variation of estimates due to soil properties, a subset of Michigan counties that play a major role in corn, soybean and wheat production was selected. The subset contains 34 counties with total corn, soybean and wheat harvest area greater than 40,000 acres each, all of which cluster in the South Lower Peninsula of Michigan (Figure 3-A1). The representative soil types for cropland area in each county were selected as the largest area of soil for corn, soybean and wheat production by overlaying the Cropland Data Layer (CDL) database with the U.S. General Soil Map (STATSGO). A list of major counties and their representative soil types is shown in Table 3-A3.

The soil type information is used as a key input in RUSEL2 to calculate the soil erosion associated with different cropping systems in 34 counties. The GHG calculator automatically retrieves the average soil and climate information once a specific county is identified. The state-level approximation of percentage reductions in soil erosion and GHG emissions due to adoption of conservation practices are calculated as the average of 34 county-level estimates weighted by the total planted area of corn, soybean and wheat in each county.

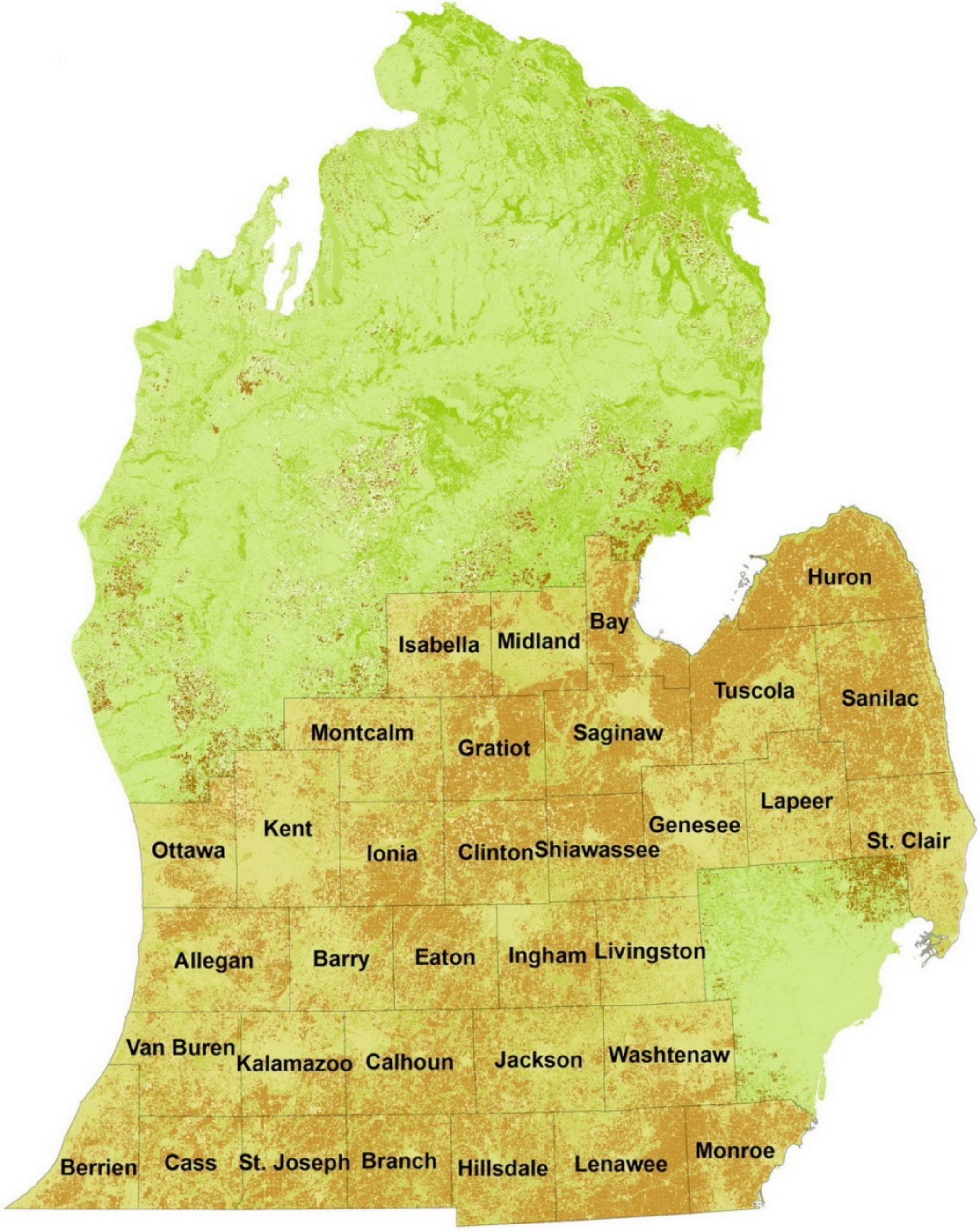

Figure 3-A1 Major counties for corn, soybean and wheat production in Michigan

Table 3-A3 Major counties and their representative soil types

County	CSW Harvested Area (acres)	STATSGO Soil type	Primary texture
Allegan	143,230	CAPAC-RIDDLES-SELFRIDGE	loam
Barry	66,267	MARLETTE-CAPAC-PARKHILL	loam
Bay	105,489	LONDO-TAPPAN-WIXOM	loam
Berrien	89,282	RIDDLES-CROSIER-OSHTEMO	loam
Branch	161,328	BARRY-LOCKE-HATMAKER	loam
Calhoun	136,873	OSHTEMO-KALAMAZOO-HOUGHTON	sandy loam
Cass	119,624	OSHTEMO-KALAMAZOO-HOUGHTON	sandy loam
Clinton	166,768	PARKHILL-CAPAC-LONDO	loam
Eaton	141,541	MARLETTE-CAPAC-PARKHILL	loam
Genesee	78,182	CONOVER-BROOKSTON-PARKHILL	loam
Gratiot	186,227	PARKHILL-CAPAC-LONDO	loam
Hillsdale	147,048	BARRY-LOCKE-HATMAKER	loam
Huron	190,493	KILMANAGH-SHEBEON-GRINDSTONE	loam
Ingham	122,676	PARKHILL-CAPAC-LONDO	loam
Ionia	133,362	MARLETTE-CAPAC-PARKHILL	loam
Isabella	95,753	PARKHILL-CAPAC-LONDO	loam
Jackson	93,304	RIDDLES-HILLSDALE-GILFORD	sandy loam
Kalamazoo	89,310	SCHOOLCRAFT-KALAMAZOO-ELSTON	loam
Kent	70,540	MARLETTE-CAPAC-SPINKS	loam
Lapeer	77,443	PARKHILL-CAPAC-LONDO	loam
Lenawee	234,413	HOYTVILLE-NAPPANEE-BLOUNT	clay
Livingston	41,872	MIAMI-CONOVER-BROOKSTON	loam
Midland	42,856	PARKHILL-CAPAC-LONDO	loam
Monroe	169,264	PEWAMO-SELFRIDGE-TEDROW	loam
Montcalm	91,212	REMUS-SPINKS-COLOMA	sandy loam
Ottawa	57,903	PERRINTON-ITHACA-COLOMA	loam
Saginaw	223,686	PARKHILL-CAPAC-LONDO	loam
Sanilac	247,322	PARKHILL-CAPAC-LONDO	loam
Shiawassee	154,580	CONOVER-BROOKSTON-PARKHILL	loam
St Clair	97,819	BLOUNT-PEWAMO-GLYNWOOD	silty loam
St Joseph	139,210	COLOMA-SPINKS-OSHTEMO	loamy sand
Tuscola	188,072	LONDO-TAPPAN-WIXOM	loam
Van Buren	72,037	COLOMA-SPINKS-OSHTEMO	loamy sand
Washtenaw	97,059	MIAMI-CONOVER-BROOKSTON	loam

APPENDIX 3-3: CALCULATION SOIL EROSION REDUCTION USING RUSLE2

The Revised Universal Soil Loss Equation (RUSLE) is “a set of mathematical equations that estimate average annual soil loss and sediment yield resulting from interrill and rill erosion” (Soil and Water Conservation Society, 1993). It is a well-validated and documented equation derived from the theory of erosion processes, more than 10,000 plot-years of data from natural rainfall plots, and numerous rainfall-simulation plots (Soil and Water Conservation Society, 1993). The RUSLE2 program is an upgraded computer model containing both “empirical and process-based science in a Windows environment”, as well as official NRCS databases for climate, soil and crop management.

RUSLE retains the structure of its predecessor, the Universal Soil Loss Equation, namely, $A = R\ K\ LS\ C\ P$ (Soil and Water Conservation Society, 1993). *A* refers to average annual soil loss in tons per acre per year. *R* represents the erosivity of rainfall and runoff. *K* is the inherent erodibility of the soil or surface material under standard experimental conditions. *LS* represent the effect of topography, specifically hillslope length and steepness, on rates of soil loss. *C* represents the effects of surface vegetative cover and roughness, soil biomass, and soil-disturbing activities on rates of soil loss. *P* embodies the effects of conservation practices. The values of these factors all apply to specific locations. For every county identified in Appendix 3-2, the changes in erosion rate due to tillage, cover crop and crop rotation in the PES program were calculated by comparing specific scenarios that have different composition of farming practices with values in *C* and *P*, coupled with local weather, soil and management conditions. Details of the scenarios and the calculated erosion reduction rate for each practice are shown in Table 3-A4, and detailed operations in each scenario are shown in Table 3-A5.

Table 3-A4 Calculation of erosion reduction rate with RUSLE 2

scenario	change in practice	rotation	tillage	cover crop	soil loss (t/ac/yr)	erosion reduction
1	moldboard to chisel	corn-soybean	spring moldboard plow		4.9	30%
2		corn-soybean	spring straight point chisel		3.5	
3	winter cover crop	corn-soybean	spring disk[18]		3.6	37%
4		corn-soybean	spring disk	rye	2.3	
5[19]	wheat in rotation	corn-soybean	spring disk	rye	2.3	9%
6		corn-soybean-wheat	spring disk	rye	2.1	

Table 3-A5 Operations in each management scenario assumed with RUSLE 2

Scenario	**Date**	**Operation**	**Crops**
1	4/20/1	Plow, moldboard	
	4/24/1	Disk, tandem secondary operation	
	4/28/1	Cultivator, field 6-12 in sweeps	
	5/1/1	Planter, double disk opener	Corn, grain
	10/20/1	Harvest, killing crop 50pct standing stubble	
	5/5/2	Plow, moldboard	
	5/10/2	Disk, tandem secondary operation	
	5/15/2	Cultivator, field 6-12 in sweeps	
	5/15/2	Drill or airseeder, double disk	Soybean, Midwest, 7in rows
	10/10/2	Harvest, killing crop 20pct standing stubble	
2	4/24/1	Chisel, straight point	
	4/28/1	Cultivator, field 6-12 in sweeps	
	5/1/1	Planter, double disk opener	Corn, grain
	10/20/1	Harvest, killing crop 50pct standing stubble	
	5/5/2	Chisel, straight point	
	5/15/2	Cultivator, field 6-12 in sweeps	
	5/15/2	Drill or airseeder, double disk	Soybean, Midwest, 7in rows
	10/10/2	Harvest, killing crop 20pct standing stubble	

[18] Spring chisel is not available with cover crop management in the default management database, another type of reduced tillage, disk till, is selected instead.

[19] Same scenario as 4.

Table 3-A5 (cont'd)

3	4/23/1	Disk, tandem secondary op.	
	4/27/1	Cultivator, field 6-12 in sweeps	
	4/30/1	Planter, double disk opener	Corn, grain
	10/19/1	Harvest, killing crop 50pct standing stubble	
	10/20/2	Disk, tandem secondary operation	
	10/30/2	Cultivator, field 6-12 in sweeps	
	10/30/2	Drill or airseeder, double disk	Soybean, Midwest, 7in rows
	3/27/3	Harvest, killing crop 20pct standing stubble	
4 & 5	10/21/1	Drill or airseeder, double disk	Rye, winter cover
	4/20/2	Disk, tandem secondary operation	
	4/25/2	Cultivator, field 6-12 in sweeps	
	5/1/2	Planter, double disk opener	Corn, grain
	10/10/2	Harvest, killing crop 50pct standing stubble	
	10/11/2	Drill or airseeder, double disk	Rye, winter cover
	4/27/3	Disk, tandem secondary operation	
	5/1/3	Cultivator, field 6-12 in sweeps	
	5/15/3	Drill or air seeder single disk openers 7-10 in space	Soybean, Midwest, 7in rows
	10/10/3	Harvest, killing crop 20pct standing stubble	
6	10/11/1	Drill or airseeder, double disk	Rye, winter cover
	4/10/2	Disk, tandem secondary operation	
	4/15/2	Cultivator, field 6-12 in sweeps	
	4/21/2	Planter, double disk opener	Corn, grain
	10/10/2	Harvest, killing crop 50pct standing stubble	
	10/11/2	Drill or airseeder, double disk	Rye, winter cover
	4/27/3	Disk, tandem secondary operation	
	5/1/3	Cultivator, field 6-12 in sweeps	
	5/15/3	Drill or air seeder single disk openers 7-10 in space	Soybean, Midwest, 7in rows
	10/10/3	Harvest, killing crop 20pct standing stubble	
	10/11/3	Drill or airseeder, double disk	Rye, winter cover
	3/22/4	Disk, tandem secondary operation	
	3/22/4	Cultivator, field 6-12 in sweeps	
	3/31/4	Drill or air seeder single disk openers 7-10 in space	Wheat, spring 7in rows
	7/14/4	Harvest, killing crop 50pct standing stubble	

APPENDIX 3-4: CALCULATION OF EUTROPHIC LAKE REDUCTION FROM REDUCED SOIL EROSION

The number of eutrophic lakes reduced from soil erosion abatement is derived using the method developed by Chen (2010). The total phosphorus leaching reduction rate, percentage of C-S rotation to cropland erosion, total cropland area under corn-soybean rotation (see appendix 3-1), fertilizer contribution to phosphorus input to lakes, and the current number of lakes falling into different trophic categories are necessary to calculate lake improvement.

The recreational quality of lakes is classified based on their primary biological productivity, which can be measured by the total phosphorus (TP) level (Fuller, 2008). A eutrophic lake has high primary productivity due to excessive nutrients and commonly exhibits poor water quality with algal blooms. Based on the regional characteristics of Michigan, a lake is classified as eutrophic if the TP level is in the range of 20-50μg/L. The hypereutrophic lake, which features severe nuisance algal blooms and low transparency, has a greater TP level than 50μg/L. A lake is classified as mesotrophic if TP is less than 20μg/L and as oligotrophic if TP is less than 10μg/L. These two categories indicate low primary productivity and clear water bodies. The reduction in the number of eutrophic lakes is measured by those lakes that transition from the eutrophic class to the mesotrophic and oligotrophic classes, namely the level of TP drops below 20 μg/L. Assume r is the change in phosphorus runoff from phosphorus fertilizer application, and $N_{Eutrophic}$ is the original number of eutrophic lakes. The following four assumptions are used to calculate the reduction in the number of eutrophic lakes.

1. Phosphorus runoff from Phosphorus fertilizer application is proportional to the soil erosion rate.

2. Reduction of phosphorus to lakes leads to proportional decrease in TP concentration.

3. Reduced phosphorus input to the waters by different cropping systems leads to uniform decrease in total phosphorus in inland lakes all over the state.

4. The TP concentration in eutrophic inland lakes is uniformly distributed in the range of 20-50μg/L.

Equation A4.1 shows the derivation of change in phosphorus runoff (*r*). It is the product of change in soil erosion ($\Delta erosion\%$), the percentage contribution of corn-soybean cropland phosphorus runoff to total cropland phosphorus runoff ($P_{C\text{-}S}/ P_{cropland}$), the percentage contribution of cropland phosphorus runoff to annual total phosphorus runoff from all sources ($P_{cropland}/ TP$), and flow-to-stock ratio of phosphorus in lakes (TP/ TP^0), where TP^0 is the existing level of phosphorus stock in the lake at status quo. $\Delta erosion\%$ is derived from the RUSLE2 model in Appendix 3-3. $P_{C\text{-}S}/ P_{cropland}$ is calculated approximately by Chen (2006) as 28%. $P_{fertilizer}/ TP$ is assumed to be 54.8% following Robertson (1996), where he calculated the percentage of Phosphorus fertilizer input contribution to total Phosphorus input into Western Lake Michigan from Wisconsin and Michigan drainages. The flow-to-stock ratio ranges from 0% to 100% depending on specific lake depth, volume, discharge of the outlet and time (Ahlgren, et al., 1988). As this ratio negatively correlates with total phosphorus concentrations (Janus and Vollenweider, 1984), the flow-to-stock ratio for lakes for the study area can be derived as approximately 50% -75%, given the median total phosphorus concentration for southern Michigan lakes is 0.014 mg/L (Fuller, 2008). The lower bound of 50% is chosen as a conservative estimate[20].

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[20] A major barrier in restoration of eutrophic lakes by mitigating P input is the phenomenon of "internal loading". Bottom sediments in eutrophic lakes often act as a sink for absorbing excess P. Once P inputs are reduced by conservation practice, the equilibrium between sediment-sorbed P

$$r = \Delta erosion\% * \frac{P_{C-S}}{P_{cropland}} * \frac{P_{cropland}}{TP} * \frac{TP}{TP^0} \qquad (3.A1)$$

Equation A4.2 characterizes the number of lakes transitioning from eutrophic to mesotrophic or oligotrophic classes (*ΔLake*).

$$\Delta Lake = \frac{r*20}{(50-20)*(1-r)} * N_{eutrophic} \qquad (3.A2\ )$$

The parameter *r* can be calculated from Equation A4.1 and $N_{eutrophic}$ represents the number of eutrophic lakes in Michigan. According to a USGS Survey of inland lake quality in 2004, 27% of the 11000 inland lakes in Michigan are eutrophic (Minnerick, 2005). Thus, $N_{eutrophic}$ is calculated as 2970. The reduction of eutrophic lakes due to each farming practice is shown in Table 3-4.

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and dissolved P can be altered and as a result, the sediments can become a source of P, which is known as "internal loading". Thus, the benefits of P mitigation efforts may be delayed for 15-50 years (Hamilton, 2011). This effect is not considered in the paper as the primary focus is the long-term equilibrium condition.

APPENDIX 3-5: GHG REDUCTION CALCULATION USING US CROPLAND GHG CALCULATOR

The Farming Systems Greenhouse Gas Emissions Calculator (FSGGEC)[21] is a web-based tool developed by researchers at the W.K. Kellogg Biological Station for calculating the GHG impact of different crop management practices. It is linked to the Soil Organic Carbon Reserves and Transformations in EcoSystems (SOCRATES) soil carbon process model (McSwiney, et al., 2010). To obtain the GHG estimates of a cropping system, we need to specify the county of interest, crops, yields, tillage practices, or nitrogen fertilizer rates with the tool. Default values are provided based on conventional systems and county averages. Outputs are the GHG emissions measured in CO_2 equivalents (Mt/ac/year) from soil carbon change, nitrous oxide (N_2O) emission, fuel use, and fertilizer (McSwiney, et al., 2010).

To calculate the GHG emissions effects due to change of different farming practices, five scenarios are estimated by the GHG calculator. The baseline scenario is a corn-soybean rotation system with average nitrogen fertilizer use of 142 lb/acre for the corn crop only. The second scenario with PSNT has 30 lb/ac less fertilizer rate. The third scenario with both PSNT and cover crops has 35.7 lb/acre less fertilizer use compared with the baseline. The fourth scenario with wheat in the rotation has the same fertilizer rate for corn as the previous system and 30 lb/acre less fertilizer use for wheat compared to its default value 66.1 lb/acre. The last scenario with band fertilizer application further reduces the N fertilizer rate by 1/3. The marginal reduction of GHG emissions due to each practice is the difference between each successive pair of systems as shown in Table 3-A6.

[21] http://surf.kbs.msu.edu/ghgcalculator/

Table 3-A6 Calculation of GHG emissions rate with Farming Systems Greenhouse Gas Emission Calculator

Scenario	Rotation	PSNT	Cover Crop	Band Fertilizer	N Fertilizer Rate (lb/acre/year)	GHG emissions (lb/acre)	Marginal Change in GHG (lb/acre)	Marginal Practice
1	corn-soybean	No	No	No	71	1044	--	--
2	corn-soybean	Yes	No	No	56	972	72	PSNT
3	corn-soybean	Yes	Yes	No	53.2	956	16	Cover crop
4	corn-soybean-wheat	Yes	Yes	No	47.5	977	-21	Wheat
5	corn-soybean-wheat	Yes	Yes	Yes	31.6	885	92	Band fertilizer

APPENDIX 3-6: OPTIMAL CHOICE BY COMBINING FOUR SYSTEMS

The economic theory of pollution control suggests the cost effective level of control of multiple technologies is achieved when their marginal costs are equal (Tietenberg and Lewis, 2000). In this study, the four cropping systems can be viewed as four technologies to mitigate negative environmental impact from crop production. However, the optimal condition cannot be reached in the hypothetical PES program because the marginal costs of environmental improvements vary among farms due to their different levels of additionality. Thus, to explore the cost-minimizing conditions by combining the multiple cropping systems, the marginal cost of acreage enrollment at each payment is defined as the sum of the average costs for individual farms to adopt the cropping systems. Each farm is assumed to choose a system among the four at each payment level to minimize the average cost of additional ecosystem services. This condition is calculated following steps:

1. At each payment level from 0 to 120 dollars per acre, farm *i*'s land acreage enrolled at payment *k*, $A^{i,k}$, in each cropping system can be simulated following Section 3.4.1 and Equation 3.18.
2. At each price level, calculate each farmer's *additional effective acreage* for each practice, defined as the enrolled land acreages that newly adopt the specified practice in each cropping system. See section 3.4.2 and Tables 3-2 and 3-3 for details.
3. Following section 3.4.3, translate each farm's additional effective acres into abatement in eutrophic lakes $Lake^{i,k}$ and GHG emissions $GHG^{i,k}$.

4. Calculate each farmer's average cost for improving eutrophic lakes and mitigating GHG emissions in each of the four cropping system using the following equation. Since zero payment is not offered in the survey, the voluntary enrollment with no incentive payment by farmers is not included in the average cost.

$$AC_{Lake}^{i,k} = \frac{Payment^{j} \cdot A^{i,k}}{Lake^{i,k}} \qquad (3.A3)$$

$$AC_{GHG}^{i,k} = \frac{Payment^{j} \cdot A^{i,k}}{GHG^{i,k}} \qquad (3.A4)$$

5. At each payment level, select the system with the lowest cost for environmental improvement[22] for each farm, and summarize farms' land enrollment $A^{i,k}$ and environmental improvement $Lake^{i,k}$ and $GHG^{i,k}$ by stratum to extrapolate state-level estimates. The state-level enrollment for system *t* at payment *k*, A_t^k is derived by proportionally scaling up individual farms that choose system *t* in each acreage stratum given the number of farms in the sample (N'), the total number in the state (TN) in Equation A6.3. The total state-level enrollment is the sum of the enrollment in the four cropping systems as shown in Equation A6.4. The state-level environmental improvement in lake and GHG are calculated as the sum of products between the state-

[22] The system with lowest average cost of eutrophic lake improvement is selected first. The reductions in the number of eutrophic lakes and GHG emissions are highly correlated (coefficients ranging from 0.7 to 0.99), so the systems with lowest cost for lake quality improvement and GHG mitigation are likely to be the same. If the lowest cost systems are different for a farm, the system with the lowest cost for lake quality improvement is still chosen, because the residents generally showed significant WTP for lake improvement while only those who are very concerned about global warming were willing to pay for GHG mitigation. If there are no improvement in lake quality for certain farms, the system with the lowest average cost in GHG mitigation will be chosen.

level acreage enrollment, A_t^k, and the per-acre improvement $Lake_t$ or GHG_t in the four systems as shown in Equations 3.A7 and 3.A8.

$$A_t^k = \frac{TN_1}{N_1^{'}} \cdot \sum_{i_1=1}^{N_1^{'}} A_{1,t}^{i,k} + \frac{TN_2}{N_2^{'}} \cdot \sum_{i_2=1}^{N_2^{'}} A_{2,t}^{i,k} + \frac{TN_3}{N_3^{'}} \cdot \sum_{i_3=1}^{N_3^{'}} A_{3,t}^{i,k} + \frac{TN_4}{N_4^{'}} \cdot \sum_{i_1=4}^{N_4^{'}} A_{4,t}^{i,k} \quad (3.A5)$$

$$A^k = \sum_{t=1}^{4} A_t^k \quad (3.A6)$$

$$Lake^k = \sum_{t=1}^{4} A_t^k \cdot Lake\_acre_t \quad (3.A7)$$

$$GHG^k = \sum_{t=1}^{4} A_t^k \cdot GHG\_acre_t \quad (3.A8)$$

APPENDIX 3-7: DETAILED RESULTS FOR BENEFIT AND COST SIMULATION

Table 3-A7 Enrollment, environmental and welfare measures for cropping system A

Price/acre	Farmer WTA (million $)	Resident WTP (million $)	Economic surplus (million $)	Farmer Welfare (million $)	Resident Welfare (million $)	Spending (million $)	Enrollment (million acre)	Lake (number)	GHG (% of 2000 emission level)
0	0.00	39	39	0.00	39	0.00	0.33	0	0
1	0.03	108	108	0.33	108	0.358	0.36	0.000881	0.000245
2	0.09	112	112	0.69	111	0.777	0.39	0.00179	0.00053
3	0.19	114	114	1.08	113	1.27	0.42	0.00271	0.00084
4	0.35	116	116	1.50	114	1.85	0.46	0.00366	0.00121
5	0.57	119	118	1.96	116	2.53	0.51	0.00793	0.00161
6	0.84	121	120	2.47	118	3.30	0.55	0.0144	0.00203
7	1.18	124	122	3.02	119	4.20	0.60	0.0264	0.00250
8	1.62	125	124	3.62	120	5.24	0.66	0.0396	0.00301
9	2.15	127	124	4.27	120	6.42	0.71	0.0543	0.00356
10	2.75	128	126	4.99	121	7.74	0.77	0.0887	0.00412
11	3.43	130	127	5.76	121	9.20	0.84	0.148	0.00470
12	4.23	132	128	6.60	121	10.8	0.90	0.212	0.00531
13	5.10	133	128	7.50	121	12.6	0.97	0.287	0.00592
14	6.10	134	128	8.47	120	14.6	1.04	0.377	0.00659
15	7.24	135	128	9.51	119	16.8	1.12	0.487	0.0073
16	8.47	136	128	10.6	117	19.1	1.19	0.590	0.0080
17	9.82	137	127	11.8	115	21.6	1.27	0.694	0.0087
18	11.3	138	127	13.1	114	24.4	1.35	0.835	0.0095
19	12.9	139	126	14.4	111	27.3	1.44	1.02	0.0102

Table 3-A7 (cont'd)

20	14.6	140	125	15.9	109	30.5	1.53	1.24	0.0111
21	16.6	141	124	17.4	107	34.0	1.62	1.48	0.0119
22	18.6	141	123	19.0	104	37.7	1.71	1.73	0.0128
23	20.9	142	121	20.7	100	41.6	1.81	1.97	0.0137
24	23.1	143	119	22.5	96.9	45.7	1.90	2.26	0.0146
25	25.5	143	118	24.4	93.2	49.9	2.00	2.54	0.0154
26	27.9	144	116	26.4	89.3	54.3	2.09	2.80	0.0163
27	30.4	144	114	28.5	85.2	58.9	2.18	3.05	0.0171
28	33.1	145	111	30.7	80.8	63.8	2.28	3.32	0.0180
29	35.8	145	109	33.0	76.2	68.8	2.37	3.55	0.0189
30	38.5	145	107	35.4	71.4	73.9	2.46	3.76	0.0197
31	41.3	146	104	37.8	66.5	79.1	2.55	4.00	0.0206
32	44.1	146	102	40.4	61.5	84.5	2.64	4.24	0.0214
33	47.0	146	99.3	43.0	56.3	90.0	2.73	4.50	0.0222
34	50.0	147	96.6	45.7	50.9	95.7	2.82	4.75	0.0230
35	53.0	147	93.9	48.6	45.3	102	2.90	5.00	0.0238
36	56.1	147	91.1	51.5	39.7	108	2.99	5.27	0.0246
37	59.1	147	88.4	54.5	33.9	114	3.07	5.48	0.0253
38	62.1	148	85.6	57.5	28.1	120	3.15	5.75	0.0260
39	65.1	148	82.9	60.7	22.2	126	3.22	6.01	0.0267
40	68.0	148	80.2	63.9	16.3	132	3.30	6.25	0.0274
41	70.9	148	77.5	67.2	10.3	138	3.37	6.46	0.0280
42	73.8	149	74.8	70.6	4.2	144	3.44	6.68	0.0287
43	76.7	149	72.1	74.0	-1.9	151	3.50	6.91	0.0293
44	79.5	149	69.4	77.5	-8.1	157	3.57	7.11	0.0299
45	82.2	149	66.8	81.1	-14.2	163	3.63	7.29	0.0304
46	84.9	149	64.3	84.7	-20.4	170	3.69	7.45	0.0310
47	87.7	149	61.7	88.4	-26.7	176	3.75	7.62	0.0315
48	90.4	150	59.1	92.1	-33.0	183	3.80	7.82	0.0320
49	93.1	150	56.6	95.9	-39.4	189	3.86	8.02	0.0325
50	95.7	150	54.1	99.8	-45.7	196	3.91	8.21	0.0330

Table 3-A7 (cont'd)

51	98.3	150	51.6	104	-52	202	3.96	8.41	0.0335
52	101	150	49.2	108	-58	208	4.01	8.58	0.0339
53	103	150	46.9	112	-65	215	4.06	8.76	0.0343
54	106	150	44.6	116	-71	221	4.10	8.94	0.0347
55	108	150	42.4	120	-77	228	4.14	9.11	0.0351
56	110	150	40.2	124	-84	234	4.18	9.26	0.0355
57	113	151	38.0	128	-90	241	4.22	9.42	0.0358
58	115	151	35.9	132	-96	247	4.26	9.57	0.0362
59	117	151	33.9	137	-103	253	4.30	9.69	0.0365
60	119	151	32.0	141	-109	260	4.33	9.81	0.0368
61	121	151	30.1	145	-115	266	4.36	9.94	0.0371
62	123	151	28.2	150	-121	272	4.39	10.1	0.0374
63	125	151	26.4	154	-128	279	4.42	10.2	0.0377
64	126	151	24.6	158	-134	285	4.45	10.4	0.0379
65	128	151	22.8	163	-140	291	4.48	10.5	0.0382
66	130	151	21.1	167	-146	297	4.51	10.6	0.0384
67	132	151	19.4	172	-153	304	4.53	10.8	0.0387
68	134	151	17.7	176	-159	310	4.56	10.9	0.0389
69	135	151	16.0	181	-165	316	4.58	11.0	0.0392
70	137	151	14.5	186	-171	323	4.61	11.1	0.0394
71	138	152	13.1	190	-177	329	4.63	11.3	0.0396
72	140	152	11.7	195	-183	335	4.65	11.4	0.0397
73	141	152	10.4	199	-189	341	4.67	11.5	0.0399
74	143	152	9.0	204	-195	347	4.69	11.6	0.0401
75	144	152	7.8	209	-201	353	4.70	11.7	0.0403
76	145	152	6.6	213	-207	359	4.72	11.8	0.0404
77	146	152	5.5	218	-213	365	4.73	11.8	0.0406
78	147	152	4.4	223	-219	370	4.75	11.9	0.0407
79	149	152	3.3	228	-224	376	4.76	12.0	0.0408
80	150	152	2.3	232	-230	382	4.77	12.0	0.0409

Table 3-A8 Enrollment, environmental and welfare measures for cropping system B

Price/acre	Farmer WTA (million $)	Resident WTP (million $)	Economic surplus (million $)	Farmer Welfare (million $)	Resident Welfare (million $)	Spending (million $)	Enrollment (million acre)	Lake (number)	GHG (% of 2000 emission level)
0	0.000	39	38.9	0.0	39	0.00	0.77	0	0
1	0.0127	123	123	0.8	122	0.788	0.79	0.3	0.0002
2	0.0393	127	127	1.6	126	1.60	0.80	0.579	0.0005
3	0.0815	130	130	2.4	127	2.44	0.81	0.894	0.0008
4	0.141	132	132	3.2	129	3.32	0.83	1.23	0.0011
5	0.220	133	133	4.0	129	4.23	0.85	1.59	0.0014
6	0.319	135	134	4.9	130	5.17	0.86	1.96	0.0017
7	0.440	136	136	5.7	130	6.16	0.88	2.36	0.0021
8	0.585	137	136	6.6	130	7.18	0.90	2.78	0.0024
9	0.757	138	137	7.5	130	8.25	0.92	3.21	0.0028
10	0.951	139	138	8.4	129	9.36	0.94	3.66	0.0032
11	1.17	140	138	9.3	129	10.5	0.96	4.13	0.0036
12	1.43	140	139	10.3	129	11.7	0.98	4.62	0.0040
13	1.71	141	139	11.3	128	13.0	1.00	5.13	0.0045
14	2.02	142	140	12.3	127	14.3	1.02	5.65	0.0049
15	2.35	142	140	13.3	127	15.6	1.04	6.15	0.0054
16	2.71	143	140	14.3	126	17.1	1.07	6.68	0.0058
17	3.13	143	140	15.4	125	18.5	1.09	7.25	0.0063
18	3.59	144	140	16.5	124	20.1	1.12	7.85	0.0069
19	4.10	144	140	17.6	123	21.7	1.14	8.47	0.0074
20	4.65	145	140	18.8	121	23.4	1.17	9.11	0.0080
21	5.26	145	140	19.9	120	25.2	1.20	9.79	0.0086
22	5.92	146	140	21.1	119	27.0	1.23	10.5	0.0092
23	6.65	146	140	22.4	117	29.0	1.26	11.2	0.0098
24	7.44	147	139	23.6	116	31.1	1.29	12.0	0.0105
25	8.29	147	139	24.9	114	33.2	1.33	12.8	0.0112
26	9.21	148	138	26.2	112	35.4	1.36	13.7	0.0119

Table 3-A8 (cont'd)

27	10.2	148	138	27.6	110	37.8	1.40	14.6	0.0127
28	11.2	149	137	29.0	108	40.3	1.44	15.5	0.0135
29	12.4	149	137	30.4	106	42.8	1.48	16.4	0.0143
30	13.6	149	136	31.9	104	45.5	1.52	17.4	0.0151
31	14.8	150	135	33.4	102	48.2	1.56	18.4	0.0160
32	16.1	150	134	35.0	99.0	51.1	1.60	19.4	0.0169
33	17.5	151	133	36.6	96.4	54.1	1.64	20.5	0.0178
34	18.9	151	132	38.2	93.7	57.1	1.68	21.5	0.0186
35	20.4	151	131	39.9	90.9	60.3	1.72	22.6	0.0195
36	21.9	152	130	41.6	88.0	63.6	1.77	23.6	0.0205
37	23.5	152	128	43.4	84.9	66.9	1.81	24.7	0.0214
38	25.2	152	127	45.2	81.7	70.4	1.85	25.9	0.0224
39	27.0	152	125	47.1	78.4	74.1	1.90	27.1	0.0234
40	28.9	153	124	49.0	75.0	77.8	1.95	28.3	0.0244
41	30.8	153	122	50.9	71.4	81.7	1.99	29.5	0.0254
42	32.8	153	121	52.9	67.7	85.7	2.04	30.7	0.0264
43	34.8	154	119	54.9	63.9	89.7	2.09	31.9	0.0275
44	36.9	154	117	57.0	60.0	93.9	2.13	33.2	0.0285
45	39.0	154	115	59.2	56.0	98.2	2.18	34.4	0.0295
46	41.2	154	113	61.3	51.9	103	2.23	35.7	0.0306
47	43.5	155	111	63.6	47.6	107	2.28	36.9	0.0317
48	45.9	155	109	65.8	43.2	112	2.33	38.2	0.0327
49	48.4	155	107	68.2	38.7	117	2.38	39.5	0.0339
50	50.9	155	105	70.6	34.0	121	2.43	40.9	0.0350
51	53.5	156	102	73.0	29.2	127	2.48	42.2	0.0361
52	56.1	156	99.8	75.5	24.4	132	2.53	43.5	0.0372
53	58.7	156	97.4	78.0	19.4	137	2.58	44.8	0.0383
54	61.4	156	95.0	80.6	14.4	142	2.63	46.2	0.0394
55	64.2	157	92.4	83.2	9.2	147	2.68	47.5	0.0405
56	67.0	157	89.8	85.9	3.9	153	2.73	48.9	0.0417
57	69.9	157	87.1	88.6	-1.5	158	2.78	50.3	0.0428

Table 3-A8 (cont'd)

58	72.8	157	84.4	91.4	-7.0	164	2.83	51.7	0.0439
59	75.7	157	81.7	94.2	-12.5	170	2.88	53.0	0.0450
60	78.6	158	79.0	97.1	-18.1	176	2.93	54.3	0.0461
61	81.4	158	76.3	100	-23.7	181	2.98	55.5	0.0471
62	84.4	158	73.5	103	-29.5	187	3.02	56.8	0.0482
63	87.3	158	70.8	106	-35.2	193	3.07	58.0	0.0492
64	90.1	158	68.1	109	-41.0	199	3.11	59.3	0.0502
65	93.1	158	65.3	112	-46.9	205	3.16	60.5	0.0512
66	95.9	159	62.6	115	-52.8	211	3.20	61.6	0.0521
67	98.7	159	59.9	119	-58.6	217	3.24	62.8	0.0530
68	101	159	57.4	122	-64.5	223	3.28	63.9	0.0539
69	104	159	54.8	125	-70	229	3.32	64.9	0.0548
70	107	159	52.2	128	-76	235	3.36	65.9	0.0556
71	109	159	49.6	132	-82	241	3.40	66.9	0.0565
72	112	159	47.1	135	-88	247	3.44	67.9	0.0573
73	115	159	44.6	139	-94	253	3.47	68.8	0.0581
74	117	159	42.0	142	-100	260	3.51	69.8	0.0589
75	120	160	39.39	146	-106	266	3.54	70.8	0.0597
76	123	160	36.80	149	-112	272	3.58	71.7	0.0605
77	125	160	34.28	153	-118	278	3.61	72.6	0.0613
78	128	160	31.79	156	-125	284	3.65	73.5	0.0620
79	131	160	29.37	160	-131	291	3.68	74.4	0.0627
80	133	160	26.93	164	-137	297	3.71	75.3	0.0634

Table 3-A9 Enrollment, environmental and welfare measures for cropping system C

Price/acre	Farmer WTA (million $)	Resident WTP (million $)	Economic surplus (million $)	Farmer Welfare (million $)	Resident Welfare (million $)	Spending (million $)	Enrollment (million acre)	Lake (number)	GHG (% of 2000 emission level)
0	0.00	39	38.9	0.00	38.9	0.00	0.543	0	0
1	0.02	125	125	0.54	125	0.56	0.559	0.410	0.0004
2	0.05	130	130	1.10	128	1.15	0.575	0.832	0.0008
3	0.10	132	132	1.68	130	1.78	0.592	1.27	0.0012
4	0.17	134	134	2.27	132	2.44	0.610	1.72	0.0016
5	0.26	136	135	2.88	133	3.14	0.628	2.19	0.0020
6	0.37	137	137	3.51	133	3.88	0.647	2.67	0.0025
7	0.51	138	138	4.15	133	4.66	0.666	3.16	0.0029
8	0.66	139	138	4.82	134	5.48	0.685	3.67	0.0034
9	0.84	140	139	5.50	134	6.35	0.705	4.19	0.0039
10	1.05	141	140	6.21	133	7.26	0.726	4.73	0.0044
11	1.29	141	140	6.94	133	8.22	0.748	5.29	0.0049
12	1.55	142	141	7.68	133	9.24	0.770	5.87	0.0054
13	1.85	143	141	8.45	132	10.3	0.792	6.47	0.0060
14	2.17	143	141	9.25	132	11.4	0.816	7.09	0.0066
15	2.53	144	141	10.1	131	12.6	0.839	7.73	0.0072
16	2.91	145	142	10.9	131	13.8	0.863	8.38	0.0078
17	3.34	145	142	11.8	130	15.1	0.888	9.05	0.0084
18	3.79	146	142	12.7	129	16.4	0.913	9.74	0.0090
19	4.28	146	142	13.6	128	17.8	0.939	10.4	0.0096
20	4.80	146	142	14.5	127	19.3	0.965	11.2	0.0103
21	5.36	147	142	15.5	126	20.8	0.992	11.9	0.0110
22	5.96	147	141	16.5	125	22.4	1.02	12.6	0.0116
23	6.60	148	141	17.5	124	24.1	1.05	13.4	0.0123
24	7.29	148	141	18.5	122	25.8	1.08	14.2	0.0131
25	8.02	149	141	19.6	121	27.6	1.10	15.0	0.0138

Table 3-A9 (cont'd)

26	8.80	149	140	20.7	119	29.5	1.13	15.8	0.0146
27	9.62	149	140	21.8	118	31.5	1.17	16.7	0.0154
28	10.5	150	139	23.0	116	33.5	1.20	17.5	0.0161
29	11.3	150	139	24.2	114	35.5	1.23	18.3	0.0169
30	12.3	150	138	25.4	113	37.7	1.26	19.2	0.0177
31	13.2	151	137	26.7	111	39.9	1.29	20.0	0.0185
32	14.2	151	137	28.0	109	42.2	1.32	20.9	0.0193
33	15.3	151	136	29.3	107	44.6	1.35	21.8	0.0201
34	16.4	151	135	30.6	104	47.0	1.38	22.6	0.0209
35	17.5	152	134	32.0	102	49.5	1.42	23.5	0.0217
36	18.7	152	133	33.4	99.9	52.1	1.45	24.4	0.0226
37	19.9	152	132	34.9	97.5	54.8	1.48	25.3	0.0234
38	21.1	153	131	36.4	95.0	57.5	1.51	26.2	0.0243
39	22.4	153	130	37.9	92.5	60.3	1.55	27.1	0.0251
40	23.8	153	129	39.4	89.8	63.2	1.58	28.1	0.0260
41	25.2	153	128	41.0	87.1	66.2	1.61	29.0	0.0269
42	26.6	154	127	42.6	84.3	69.2	1.65	30.0	0.0278
43	28.1	154	126	44.3	81.4	72.4	1.68	30.9	0.0287
44	29.6	154	124	46.0	78.4	75.5	1.72	31.9	0.0296
45	31.1	154	123	47.7	75.4	78.8	1.75	32.8	0.0305
46	32.6	154	122	49.4	72.3	82.1	1.78	33.8	0.0313
47	34.2	155	120	51.2	69.2	85.4	1.82	34.8	0.0322
48	35.8	155	119	53.0	65.9	88.9	1.85	35.7	0.0331
49	37.5	155	117	54.9	62.6	92.4	1.89	36.7	0.0340
50	39.3	155	116	56.8	59.2	96.0	1.92	37.7	0.0349
51	41.1	155	114	58.7	55.6	99.8	1.96	38.7	0.0359
52	43.0	156	113	60.6	52.0	104	1.99	39.7	0.0368
53	44.9	156	111	62.6	48.2	108	2.03	40.8	0.0378
54	46.9	156	109	64.7	44.4	112	2.07	41.8	0.0388
55	49.0	156	107	66.7	40.4	116	2.10	42.9	0.0398
56	51.1	156	105	68.8	36.4	120	2.14	43.9	0.0408

Table 3-A9 (cont'd)

57	53.2	157	103	71.0	32.4	124	2.18	45.0	0.0418
58	55.3	157	101	73.1	28.2	128	2.22	46.1	0.0428
59	57.5	157	99.3	75.4	24.0	133	2.25	47.1	0.0438
60	59.8	157	97.2	77.6	19.6	137	2.29	48.2	0.0448
61	62.1	157	95.1	79.9	15.2	142	2.33	49.3	0.0458
62	64.4	157	93.0	82.2	10.8	147	2.36	50.4	0.0468
63	66.7	158	90.8	84.6	6.2	151	2.40	51.5	0.0478
64	69.1	158	88.6	87.0	1.6	156	2.44	52.6	0.0488
65	71.5	158	86.4	89.4	-3.1	161	2.48	53.6	0.0498
66	73.9	158	84.1	91.9	-7.8	166	2.51	54.7	0.0508
67	76.3	158	81.8	94.4	-12.6	171	2.55	55.8	0.0517
68	78.8	158	79.4	97.0	-17.5	176	2.59	56.9	0.0527
69	81.3	158	77.1	99.6	-22.5	181	2.62	57.9	0.0537
70	83.8	159	74.7	102	-27.4	186	2.66	59.0	0.0547
71	86.3	159	72.4	105	-32.5	191	2.69	60.0	0.0556
72	88.8	159	70.0	108	-37.5	196	2.73	61.0	0.0566
73	91.3	159	67.6	110	-42.6	202	2.76	62.0	0.0575
74	93.8	159	65.2	113	-47.8	207	2.80	63.0	0.0584
75	96.4	159	62.8	116	-53.0	212	2.83	64.1	0.0594
76	98.9	159	60.3	119	-58.3	218	2.86	65.0	0.0603
77	101	159	57.9	122	-64	223	2.90	66.0	0.0612
78	104	159	55.5	124	-69	228	2.93	66.9	0.0621
79	106	160	53.2	127	-74	234	2.96	67.8	0.0629
80	109	160	50.8	130	-79	239	2.99	68.7	0.0638

Table 3-A10 Enrollment, environmental and welfare measures for cropping system D

Price/acre	Farmer WTA (million $)	Resident WTP (million $)	Economic surplus (million $)	Farmer Welfare (million $)	Resident Welfare (million $)	Spending (million $)	Enrollment (million acre)	Lake (number)	GHG (% of 2000 emission level)
0	0.000	38.9	38.9	0.0	38.9	0.00	0.846	0	0
1	0.0136	124	124	0.846	123	0.86	0.859	0.321	0.000
2	0.0411	128	128	1.71	126	1.75	0.873	0.646	0.001
3	0.0831	131	130	2.58	128	2.66	0.887	0.98	0.001
4	0.140	132	132	3.47	129	3.61	0.901	1.32	0.001
5	0.212	134	134	4.37	129	4.58	0.916	1.66	0.002
6	0.300	135	135	5.28	130	5.58	0.930	2.02	0.002
7	0.403	136	136	6.21	130	6.62	0.945	2.36	0.002
8	0.521	137	137	7.16	129	7.68	0.960	2.71	0.003
9	0.655	138	137	8.12	129	8.77	0.975	3.06	0.003
10	0.804	139	138	9.09	129	9.90	0.990	3.41	0.003
11	0.970	139	138	10.1	128	11.1	1.00	3.77	0.004
12	1.15	140	139	11.1	128	12.2	1.02	4.13	0.004
13	1.35	140	139	12.1	127	13.5	1.04	4.48	0.004
14	1.56	141	139	13.1	126	14.7	1.05	4.83	0.005
15	1.79	141	140	14.2	125	16.0	1.07	5.19	0.005
16	2.04	142	140	15.3	124	17.3	1.08	5.55	0.005
17	2.31	142	140	16.3	124	18.6	1.10	5.93	0.006
18	2.59	143	140	17.4	123	20.0	1.11	6.31	0.006
19	2.90	143	140	18.5	122	21.4	1.13	6.69	0.006
20	3.22	143	140	19.7	121	22.9	1.15	7.08	0.007
21	3.56	144	140	20.8	119	24.4	1.16	7.47	0.007
22	3.92	144	140	22.0	118	25.9	1.18	7.85	0.007
23	4.29	144	140	23.2	117	27.5	1.19	8.24	0.008
24	4.69	145	140	24.4	116	29.0	1.21	8.63	0.008
25	5.10	145	140	25.6	114	30.7	1.23	9.03	0.009

Table 3-A10 (cont'd)

26	5.55	145	140	26.8	113	32.3	1.24	9.43	0.009
27	6.01	146	140	28.0	112	34.0	1.26	9.84	0.009
28	6.50	146	139	29.3	110	35.8	1.28	10.3	0.010
29	7.01	146	139	30.6	109	37.6	1.30	10.7	0.010
30	7.54	147	139	31.9	107	39.4	1.31	11.1	0.010
31	8.10	147	139	33.2	106	41.3	1.33	11.5	0.011
32	8.68	147	138	34.5	104	43.2	1.35	12.0	0.011
33	9.29	147	138	35.9	102	45.2	1.37	12.4	0.012
34	9.93	148	138	37.2	100	47.2	1.39	12.9	0.012
35	10.6	148	137	38.6	98.6	49.2	1.41	13.4	0.013
36	11.3	148	137	40.0	96.7	51.3	1.42	13.8	0.013
37	12.0	148	136	41.5	94.9	53.4	1.44	14.3	0.013
38	12.7	148	136	42.9	92.9	55.6	1.46	14.7	0.014
39	13.4	149	135	44.4	90.9	57.8	1.48	15.2	0.014
40	14.2	149	135	45.8	88.9	60.0	1.50	15.7	0.015
41	15.0	149	134	47.3	86.8	62.3	1.52	16.1	0.015
42	15.8	149	134	48.9	84.7	64.6	1.54	16.6	0.016
43	16.6	150	133	50.4	82.5	67.0	1.56	17.1	0.016
44	17.5	150	132	52.0	80.3	69.4	1.58	17.6	0.017
45	18.3	150	132	53.5	78.1	71.9	1.60	18.1	0.017
46	19.2	150	131	55.1	75.8	74.4	1.62	18.5	0.017
47	20.1	150	130	56.7	73.4	76.9	1.64	19.0	0.018
48	21.1	150	129	58.4	71.0	79.5	1.66	19.5	0.018
49	22.0	151	129	60.0	68.6	82.1	1.67	20.0	0.019
50	23.0	151	128	61.7	66.1	84.7	1.69	20.5	0.019
51	24.0	151	127	63.4	63.6	87.4	1.71	21.0	0.020
52	25.0	151	126	65.1	60.99	90.2	1.73	21.5	0.020
53	26.1	151	125	66.9	58.37	92.9	1.75	22.0	0.021
54	27.2	151	124	68.6	55.71	95.8	1.77	22.5	0.021
55	28.2	152	123	70.4	53.01	98.6	1.79	22.9	0.022
56	29.3	152	122	72.2	50.26	102	1.81	23.4	0.022

Table 3-A10 (cont'd)

57	30.5	152	121	74.0	47.46	104	1.83	23.9	0.022
58	31.6	152	120	75.8	44.62	107	1.85	24.4	0.023
59	32.8	152	119	77.7	41.73	110	1.87	24.9	0.023
60	34.0	152	118	79.5	38.8	114	1.89	25.4	0.024
61	35.2	153	117	81.4	35.8	117	1.91	25.9	0.024
62	36.5	153	116	83.4	32.8	120	1.93	26.4	0.025
63	37.8	153	115	85.3	29.7	123	1.95	26.9	0.025
64	39.1	153	114	87.2	26.6	126	1.97	27.4	0.026
65	40.4	153	113	89.2	23.4	130	1.99	27.9	0.026
66	41.8	153	111	91.2	20.2	133	2.02	28.5	0.027
67	43.2	153	110	93.2	16.9	136	2.04	29.0	0.027
68	44.6	153	109	95.3	13.6	140	2.06	29.5	0.028
69	46.0	154	108	97.3	10.2	143	2.08	30.1	0.028
70	47.5	154	106	99.4	6.8	147	2.10	30.6	0.029
71	49.0	154	105	101	3.4	150	2.12	31.1	0.029
72	50.5	154	104	104	-0.1	154	2.14	31.6	0.030
73	52.0	154	102	106	-3.6	158	2.16	32.2	0.030
74	53.5	154	101	108	-7.2	161	2.18	32.7	0.031
75	55.1	154	99.3	110	-10.8	165	2.20	33.3	0.031
76	56.6	154	97.8	112	-14.5	169	2.22	33.8	0.032
77	58.2	155	96.3	115	-18.2	173	2.24	34.4	0.032
78	59.9	155	94.8	117	-22.0	177	2.26	34.9	0.033
79	61.5	155	93.3	119	-25.8	181	2.29	35.4	0.033
80	63.2	155	91.7	121	-29.6	185	2.31	36.0	0.034

Table 3-A11 Enrollment, environmental and welfare measures for mixed-choice cropping system alternative

Price/acre	Farmer WTA (million $)	Resident WTP (million $)	Economic surplus (million $)	Farmer Welfare (million $)	Resident Welfare (million $)	Spending (million $)	Enrollment (million acre)	Lake (number)	GHG (% of 2000 emission level)
0	0.000	39	38.9	0.0	38.9	0.00	0.68	0	0
1	0.133	140	140	0.7	139	0.82	0.82	4.17	0.0043
2	0.175	141	141	1.5	139	1.67	0.84	4.62	0.0048
3	0.240	142	141	2.3	139	2.58	0.86	5.07	0.0054
4	0.295	142	141	3.2	138	3.49	0.87	5.22	0.0054
5	0.451	143	142	4.1	138	4.52	0.90	6.01	0.0063
6	0.467	142	142	5.0	137	5.44	0.91	5.73	0.0055
7	0.769	143	142	5.9	136	6.65	0.95	6.56	0.0064
8	0.820	143	142	6.8	136	7.65	0.96	6.81	0.0064
9	0.928	143	142	7.8	134	8.71	0.97	6.52	0.0062
10	1.242	144	142	8.8	134	9.99	1.00	7.45	0.0065
11	1.611	144	142	9.8	133	11.4	1.03	7.81	0.0070
12	1.81	145	143	10.8	132	12.6	1.05	8.43	0.0077
13	2.07	144	142	11.8	131	13.9	1.07	8.35	0.0076
14	2.87	145	142	12.9	129	15.8	1.13	9.90	0.0082
15	3.29	145	142	14.0	128	17.3	1.15	9.80	0.0082
16	3.27	145	142	15.2	127	18.5	1.15	10.0	0.0082
17	4.93	146	141	16.3	125	21.3	1.25	11.5	0.0092
18	4.47	146	142	17.6	124	22.1	1.23	11.3	0.0093
19	5.47	147	141	18.8	122	24.3	1.28	12.2	0.0098
20	5.62	147	141	20.1	121	25.7	1.29	12.8	0.0098
21	6.76	147	140	21.4	119	28.1	1.34	13.3	0.0100
22	6.74	147	140	22.7	118	29.5	1.34	13.7	0.0102
23	8.01	148	140	24.1	116	32.1	1.39	14.8	0.0109
24	7.92	147	140	25.5	114	33.4	1.39	14.7	0.0105
25	9.35	148	139	26.8	112	36.2	1.45	15.8	0.0111
26	9.54	148	138	28.3	110	37.8	1.46	16.1	0.0110

Table 3-A11 (cont'd)

27	12.7	149	136	29.7	106	42.4	1.57	18.1	0.0126
28	12.5	149	137	31.3	105	43.8	1.56	18.8	0.0128
29	13.4	149	136	32.9	103	46.3	1.60	19.2	0.0127
30	16.3	150	133	34.5	98.9	50.8	1.69	21.2	0.0138
31	17.2	150	133	36.2	96.6	53.4	1.72	22.0	0.0143
32	16.6	150	133	37.9	95.5	54.5	1.70	22.2	0.0141
33	17.6	150	132	39.6	92.7	57.2	1.73	22.7	0.0140
34	21.4	150	129	41.3	87.7	62.7	1.84	24.3	0.0146
35	21.5	150	129	43.2	85.7	64.7	1.85	24.6	0.0147
36	21.7	151	129	45.0	83.8	66.7	1.85	25.3	0.0148
37	24.4	151	127	46.9	79.7	71.3	1.93	26.8	0.0157
38	25.8	151	125	48.8	76.6	74.6	1.96	27.6	0.0160
39	26.7	151	125	50.8	73.9	77.5	1.99	28.7	0.0163
40	27.2	152	124	52.7	71.6	79.9	2.00	29.4	0.0168
41	29.4	152	122	54.7	67.6	84.1	2.05	30.4	0.0171
42	31.9	152	120	56.8	63.2	88.7	2.11	31.5	0.0172
43	32.3	152	120	58.9	60.9	91.2	2.12	32.3	0.0176
44	33.8	152	118	61.0	57.3	94.8	2.15	33.0	0.0176
45	35.9	152	116	63.2	53.2	99.1	2.20	34.0	0.0181
46	36.5	152	116	65.4	50.4	102	2.21	34.4	0.0179
47	37.6	153	115	67.6	47.4	105	2.24	35.4	0.0187
48	38.5	153	114	69.8	44.4	108	2.26	36.0	0.0193
49	39.3	153	113	72.1	41.2	111	2.27	36.4	0.0183
50	41.7	153	111	74.4	36.8	116	2.32	37.5	0.0192
51	42.5	153	110	76.7	33.7	119	2.34	38.5	0.0191
52	45.1	153	108	79.0	29.0	124	2.39	39.8	0.0197
53	47.1	153	106	81.4	24.9	128	2.42	40.9	0.0200
54	51.7	153	102	83.8	17.9	136	2.51	42.4	0.0203
55	51.6	153	102	86.3	15.6	138	2.51	42.8	0.0200
56	54.2	154	99.5	88.9	10.6	143	2.55	44.4	0.0205
57	60.0	154	94.0	91.4	2.58	151	2.66	46.3	0.0211

Table 3-A11 (cont'd)

58	59.8	154	94.3	94.1	0.26	154	2.65	47.0	0.0219
59	63.5	154	90.6	96.7	-6.14	160	2.72	48.2	0.0211
60	64.8	154	89.6	99.4	-9.9	164	2.74	49.2	0.0223
61	66.8	154	87.6	102	-14.6	169	2.77	50.1	0.0217
62	69.0	155	85.5	105	-19.4	174	2.81	51.2	0.0224
63	74.0	155	80.7	108	-27.1	182	2.89	52.7	0.0228
64	70.5	155	84.2	111	-26.5	181	2.83	52.4	0.0229
65	76.6	155	78.1	113	-35.3	190	2.92	53.9	0.0228
66	76.7	155	78.2	116	-38.2	193	2.92	54.8	0.0230
67	77.9	155	77.1	119	-42.2	197	2.94	55.3	0.0235
68	84.9	155	70.2	122	-52.0	207	3.05	57.4	0.0234
69	83.2	155	72.0	125	-53.3	209	3.02	57.7	0.0240
70	88.6	155	66.7	128	-61.6	217	3.10	59.1	0.0243
71	87.5	155	67.8	131	-63.7	219	3.08	58.9	0.0241
72	90.4	155	65.1	135	-69.4	225	3.12	60.6	0.0246
73	94.4	156	61.1	138	-76.5	232	3.18	61.9	0.0243
74	94.0	155	61.4	141	-79.4	235	3.17	61.9	0.0239
75	95.4	156	60.2	144	-83.8	239	3.19	62.6	0.0247
76	100.8	156	54.9	147	-92.2	248	3.26	64.1	0.0254
77	101.2	156	54.6	150	-95.9	252	3.27	64.5	0.0252
78	101.8	156	54.0	154	-99.7	255	3.28	65.1	0.0249
79	108.1	156	47.8	157	-109.2	265	3.36	66.7	0.0251
80	105.8	156	50.3	160	-110.1	266	3.33	66.8	0.0259

APPENDIX 3-8: DETAILED RESULTS FOR BENEFIT AND COST SIMULATION (PAYMENT FOR ADDITIONALITY)

Table 3-A12 Enrollment, environmental and welfare measures for cropping system A (payment for additionality)

Price/acre	Farmer WTA (million $)	Resident WTP (million $)	Economic surplus (million $)	Farmer Welfare (million $)	Resident Welfare (million $)	Spending (million $)	Enrollment (million acre)	Lake (number)	GHG (% of 2000 emission level)
0									
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15	0.525	125	14.4	0.00	124	0.525	0.0350	0.382	0.000304
16	0.718	126	15.4	0.0350	125	0.753	0.0471	0.467	0.000408
17	0.980	127	16.3	0.0821	126	1.06	0.0625	0.556	0.000542
18	1.18	128	17.5	0.145	127	1.33	0.0738	0.674	0.000641
19	1.46	130	18.7	0.218	128	1.68	0.0883	0.823	0.000766
20	1.73	131	20.1	0.307	129	2.03	0.102	1.01	0.000883
21	2.13	132	21.3	0.408	129	2.54	0.121	1.20	0.00105

Table 3-A12 (cont'd)

22	2.53	133	22.4	0.529	130	3.05	0.139	1.41	0.00120
23	2.88	133	23.4	0.668	130	3.55	0.154	1.61	0.00134
24	3.31	134	24.4	0.823	130	4.13	0.172	1.84	0.00149
25	3.60	135	25.4	0.995	130	4.59	0.184	2.07	0.00159
26	4.25	135	25.9	1.18	130	5.42	0.209	2.28	0.00181
27	4.66	136	26.6	1.39	130	6.05	0.224	2.49	0.00194
28	5.20	136	27.1	1.61	130	6.81	0.243	2.71	0.00211
29	5.47	137	27.7	1.85	129	7.32	0.253	2.90	0.00219
30	6.03	137	27.9	2.11	129	8.13	0.271	3.07	0.00235
31	6.87	138	28.0	2.38	128	9.25	0.298	3.30	0.00257
32	7.37	138	28.3	2.68	128	10.0	0.314	3.49	0.00270
33	7.94	138	28.6	2.99	127	10.9	0.331	3.71	0.00286
34	8.44	139	28.9	3.32	127	11.8	0.346	3.92	0.00298
35	9.00	139	29.1	3.67	126	12.7	0.362	4.13	0.00312
36	10.3	140	28.6	4.03	125	14.4	0.399	4.35	0.00345
37	11.1	140	28.4	4.43	124	15.6	0.420	4.52	0.00363
38	11.7	140	28.5	4.85	124	16.6	0.436	4.74	0.00377
39	12.1	140	28.8	5.28	123	17.4	0.447	4.94	0.00386
40	12.6	141	28.9	5.73	122	18.4	0.459	5.13	0.00396
41	13.6	141	28.4	6.19	121	19.8	0.483	5.29	0.00417
42	14.2	141	28.4	6.67	120	20.9	0.497	5.48	0.00428
43	14.9	141	28.3	7.17	119	22.0	0.513	5.66	0.00441
44	15.8	141	27.9	7.68	118	23.5	0.534	5.83	0.00460
45	16.7	142	27.5	8.22	117	24.9	0.553	5.98	0.00476
46	17.0	142	27.5	8.77	116	25.8	0.561	6.10	0.00483
47	17.9	142	27.0	9.33	115	27.2	0.579	6.25	0.00498
48	18.4	142	26.9	9.91	114	28.3	0.590	6.40	0.00508
49	20.0	142	25.8	10.5	112	30.5	0.622	6.56	0.00536
50	20.6	143	25.6	11.1	111	31.7	0.635	6.72	0.00547
51	21.8	143	24.9	11.8	109	33.6	0.659	6.90	0.00563
52	22.4	143	24.8	12.4	108	34.8	0.669	7.06	0.00570

Table 3-A12 (cont'd)

53	23.3	143	24.2	13.1	107	36.4	0.687	7.22	0.00586
54	23.8	143	24.2	13.8	106	37.5	0.695	7.37	0.00593
55	24.4	143	23.9	14.5	104	38.8	0.706	7.51	0.00602
56	25.7	143	23.0	15.2	103	40.9	0.730	7.69	0.00619
57	26.5	144	22.6	15.9	101	42.4	0.743	7.82	0.00630
58	26.8	144	22.5	16.6	100	43.5	0.749	7.94	0.00636
59	27.9	144	21.7	17.4	98.45	45.3	0.768	8.04	0.00652
60	28.4	144	21.5	18.2	97.26	46.6	0.776	8.15	0.00659
61	29.3	144	20.8	18.9	95.73	48.2	0.790	8.25	0.00671
62	30.1	144	20.2	19.7	94.17	49.9	0.804	8.36	0.00683
63	31.0	144	19.6	20.5	92.58	51.6	0.819	8.48	0.00696
64	32.0	144	18.9	21.4	90.92	53.3	0.833	8.59	0.00708
65	32.7	144	18.6	22.2	89.51	54.8	0.844	8.71	0.00717
66	33.1	144	18.4	23.0	88.34	56.1	0.850	8.83	0.00723
67	33.4	144	18.3	23.9	87.18	57.3	0.855	8.94	0.00727
68	33.8	145	18.2	24.7	86.03	58.5	0.861	9.04	0.00732
69	34.9	145	17.3	25.6	84.19	60.5	0.876	9.15	0.00746
70	35.8	145	16.6	26.5	82.4	62.3	0.890	9.24	0.00758
71	36.9	145	15.7	27.4	80.5	64.3	0.905	9.33	0.00765
72	37.3	145	15.5	28.3	79.3	65.6	0.911	9.43	0.00770
73	37.7	145	15.4	29.2	78.1	66.8	0.916	9.53	0.00774
74	38.0	145	15.2	30.1	76.9	68.1	0.921	9.63	0.00778
75	38.3	145	15.1	31.0	75.7	69.3	0.924	9.70	0.00782
76	38.9	145	14.7	31.9	74.2	70.9	0.932	9.77	0.00789
77	39.1	145	14.5	32.9	73.1	72.0	0.935	9.83	0.00791
78	39.4	145	14.4	33.8	71.9	73.2	0.938	9.88	0.00794
79	39.6	145	14.3	34.7	70.8	74.3	0.941	9.94	0.00796
80	39.7	145	14.3	35.7	69.7	75.4	0.943	10.0	0.00798

Table 3-A13 Enrollment, environmental and welfare measures for cropping system B (payment for additionality)

price/acre	Farmer WTA (million $)	Resident WTP (million $)	Economic surplus (million $)	Farmer Welfare (million $)	Resident Welfare (million $)	Spending (million $)	Enrollment (million acre)	Lake (number)	GHG (% of 2000 emission level)
0	0.000	39	69.8	0.00	38.9	0.00	0.746	0	0
1	0.0119	121	70.2	0.746	120	0.758	0.758	0.28	0.00013
2	0.0386	125	70.6	1.50	124	1.54	0.771	0.58	0.00028
3	0.0834	128	71.0	2.28	126	2.36	0.786	0.89	0.00044
4	0.137	130	71.4	3.06	127	3.20	0.800	1.23	0.00060
5	0.211	131	71.8	3.86	127	4.07	0.814	1.59	0.00077
6	0.305	133	72.3	4.68	128	4.98	0.830	1.96	0.00095
7	0.415	134	72.7	5.51	128	5.92	0.846	2.36	0.00113
8	0.554	135	73.1	6.35	128	6.91	0.863	2.78	0.00133
9	0.717	136	73.5	7.21	128	7.93	0.881	3.21	0.00153
10	0.896	137	73.9	8.10	128	8.99	0.899	3.66	0.0017
11	1.10	137	74.3	9.00	127	10.1	0.918	4.13	0.0020
12	1.41	138	74.6	9.91	127	11.3	0.944	4.62	0.0022
13	1.68	139	75.0	10.9	126	12.5	0.965	5.13	0.0025
14	1.98	140	75.4	11.8	126	13.8	0.986	5.65	0.0027
15	2.28	140	75.7	12.8	125	15.1	1.01	6.15	0.0030
16	2.63	141	76.0	13.8	124	16.4	1.03	6.68	0.0032
17	3.02	141	76.3	14.8	123	17.9	1.05	7.25	0.0035
18	3.50	142	76.5	15.9	122	19.4	1.08	7.85	0.0038
19	3.98	142	76.7	17.0	121	20.9	1.10	8.47	0.0041
20	4.49	143	77.0	18.1	120	22.6	1.13	9.11	0.0044
21	5.14	143	77.1	19.2	119	24.3	1.16	9.79	0.0047
22	5.77	144	77.2	20.4	118	26.1	1.19	10.5	0.0050
23	6.48	144	77.4	21.5	116	28.0	1.22	11.2	0.0054
24	7.33	145	77.3	22.8	115	30.1	1.25	12.0	0.0058
25	8.14	145	77.4	24.0	113	32.2	1.29	12.8	0.0062
26	9.04	145	77.4	25.3	111	34.3	1.32	13.7	0.0066

Table 3-A13 (cont'd)

27	10.1	146	77.3	26.6	109	36.7	1.36	14.6	0.0070
28	11.1	146	77.2	28.0	107	39.1	1.40	15.5	0.0074
29	12.2	147	77.0	29.4	105	41.6	1.43	16.4	0.0079
30	13.6	147	76.6	30.8	103	44.4	1.48	17.4	0.0084
31	14.8	148	76.4	32.3	100	47.1	1.52	18.4	0.0088
32	16.1	148	76.0	33.8	98.0	49.9	1.56	19.4	0.0093
33	17.5	148	75.6	35.4	95.4	52.9	1.60	20.5	0.0098
34	19.0	149	75.1	37.0	92.7	56.0	1.65	21.5	0.0103
35	20.4	149	74.6	38.6	89.9	59.0	1.69	22.6	0.0108
36	21.9	149	74.1	40.3	87.1	62.2	1.73	23.6	0.0113
37	23.5	150	73.5	42.0	84.1	65.5	1.77	24.7	0.0118
38	25.5	150	72.5	43.8	80.6	69.3	1.82	25.9	0.0124
39	27.3	150	71.7	45.6	77.3	72.9	1.87	27.1	0.0129
40	29.1	151	70.9	47.5	73.9	76.6	1.92	28.3	0.0134
41	31.0	151	70.0	49.4	70.4	80.4	1.96	29.5	0.0140
42	33.0	151	69.0	51.4	66.7	84.4	2.01	30.7	0.0146
43	35.0	151	68.0	53.4	63.0	88.4	2.06	31.9	0.0151
44	37.1	152	67.0	55.4	59.2	92.5	2.10	33.2	0.0156
45	39.3	152	65.7	57.5	55.09	96.8	2.15	34.4	0.0162
46	41.4	152	64.5	59.7	51.03	101	2.20	35.7	0.0168
47	43.8	152	63.1	61.9	46.68	106	2.25	36.9	0.0174
48	46.2	153	61.7	64.1	42.35	110	2.30	38.2	0.0179
49	48.6	153	60.2	66.4	37.82	115	2.35	39.5	0.0185
50	51.2	153	58.7	68.8	33.2	120	2.40	40.9	0.0191
51	54.3	153	56.5	71.2	27.9	126	2.46	42.2	0.0198
52	56.9	154	54.9	73.7	23.1	131	2.51	43.5	0.0204
53	59.5	154	53.2	76.2	18.1	136	2.56	44.8	0.0210
54	62.2	154	51.5	78.7	13.1	141	2.61	46.2	0.0216
55	64.9	154	49.7	81.3	8.0	146	2.66	47.5	0.0222
56	67.7	154	47.8	84.0	2.8	152	2.71	48.9	0.0228
57	70.6	155	45.8	86.7	-2.7	157	2.76	50.3	0.0234

Table 3-A13 (cont'd)

58	73.5	155	43.8	89.5	-8.2	163	2.81	51.7	0.0240
59	76.4	155	41.8	92.3	-13.6	169	2.86	53.0	0.0245
60	79.2	155	39.8	95.1	-19.2	174	2.91	54.3	0.0251
61	82.1	155	37.8	98.0	-24.8	180	2.95	55.5	0.0257
62	85.0	156	35.7	101	-30.5	186	3.00	56.8	0.0262
63	87.8	156	33.6	104	-36.2	192	3.04	58.0	0.0268
64	90.7	156	31.5	107	-41.9	198	3.09	59.3	0.0273
65	93.5	156	29.4	110	-47.7	204	3.13	60.5	0.0278
66	96.5	156	27.2	113	-53.7	210	3.18	61.6	0.0284
67	99.2	156	25.1	116	-59.4	216	3.22	62.8	0.0288
68	102	156	23.0	120	-65.3	222	3.26	63.8	0.0293
69	105	156	21.0	123	-71	228	3.30	64.9	0.0298
70	107	157	19.0	126	-77	233	3.34	65.9	0.0302
71	110	157	16.8	130	-83	240	3.37	66.9	0.0307
72	113	157	14.7	133	-89	246	3.41	67.9	0.0311
73	115	157	12.7	136	-95	252	3.45	68.8	0.0315
74	118	157	10.6	140	-101	258	3.48	69.8	0.0320
75	121	157	8.46	143	-107	264	3.52	70.8	0.0324
76	123	157	6.26	147	-113	270	3.55	71.7	0.0328
77	126	157	4.19	150	-119	276	3.59	72.6	0.0332
78	128	157	2.14	154	-125	282	3.62	73.5	0.0336
79	131	157	0.14	158	-131	289	3.65	74.4	0.0340
80	133	158	-1.88	161	-137	295	3.68	75.3	0.0344

Table 3-A14 Enrollment, environmental and welfare measures for cropping system C (payment for additionality)

price/acre	Farmer WTA (million $)	Resident WTP (million $)	Economic surplus (million $)	Farmer Welfare (million $)	Resident Welfare (million $)	Spending (million $)	Enrollment (million acre)	Lake (number)	GHG (% of 2000 emission level)
0	0.00	39	59.8	0.00	38.9	0.00	0.519	0	0
1	0.02	122	60.5	0.52	122	0.54	0.536	0.410	0.0001
2	0.05	126	61.2	1.06	125	1.10	0.551	0.831	0.0003
3	0.10	129	61.9	1.61	127	1.70	0.568	1.27	0.0004
4	0.16	130	62.6	2.17	128	2.34	0.585	1.72	0.0005
5	0.25	132	63.3	2.76	129	3.01	0.602	2.19	0.0007
6	0.36	133	64.0	3.36	129	3.72	0.620	2.67	0.0008
7	0.50	134	64.7	3.98	130	4.49	0.641	3.16	0.0010
8	0.65	135	65.3	4.62	130	5.28	0.660	3.66	0.0011
9	0.83	136	66.0	5.28	130	6.11	0.679	4.18	0.0013
10	1.03	137	66.6	5.96	130	6.99	0.699	4.72	0.0014
11	1.26	138	67.2	6.66	130	7.93	0.720	5.29	0.0016
12	1.53	138	67.8	7.38	129	8.91	0.743	5.87	0.0018
13	1.83	139	68.3	8.12	129	10.0	0.765	6.47	0.0019
14	2.17	139	68.9	8.89	128	11.1	0.790	7.08	0.0021
15	2.57	140	69.4	9.7	128	12.3	0.817	7.72	0.0023
16	2.97	141	69.8	10.5	127	13.5	0.842	8.37	0.0025
17	3.39	141	70.3	11.3	126	14.7	0.867	9.04	0.0027
18	3.84	142	70.8	12.2	125	16.0	0.891	9.73	0.0029
19	4.32	142	71.2	13.1	125	17.4	0.916	10.4	0.0031
20	4.82	142	71.6	14.0	124	18.8	0.942	11.1	0.0033
21	5.39	143	71.9	15.0	122	20.3	0.969	11.9	0.0035
22	6.05	143	72.2	15.9	121	22.0	1.00	12.6	0.0038
23	6.68	144	72.5	16.9	120	23.6	1.03	13.4	0.0040
24	7.35	144	72.7	17.9	119	25.3	1.05	14.1	0.0042
25	8.06	144	72.9	19.0	117	27.1	1.08	15.0	0.0044
26	8.85	145	73.1	20.1	116	28.9	1.11	15.8	0.0047

Table 3-A14 (cont'd)

27	9.65	145	73.2	21.2	114	30.8	1.14	16.6	0.0049
28	10.5	145	73.3	22.3	113	32.8	1.17	17.5	0.0052
29	11.4	146	73.4	23.5	111	34.9	1.20	18.3	0.0054
30	12.3	146	73.3	24.7	109	37.0	1.23	19.2	0.0057
31	13.2	146	73.3	25.9	107	39.2	1.26	20.0	0.0059
32	14.2	147	73.2	27.2	105	41.4	1.29	20.9	0.0061
33	15.3	147	72.9	28.5	103	43.8	1.33	21.7	0.0064
34	16.5	147	72.7	29.8	101	46.3	1.36	22.6	0.0067
35	17.6	147	72.4	31.2	98.7	48.8	1.39	23.5	0.0069
36	18.8	148	72.1	32.6	96.4	51.3	1.43	24.4	0.0072
37	20.0	148	71.7	34.0	93.9	54.0	1.46	25.3	0.0074
38	21.3	148	71.3	35.5	91.4	56.8	1.49	26.2	0.0077
39	22.6	148	70.8	37.0	88.8	59.6	1.53	27.1	0.0080
40	24.0	149	70.3	38.5	86.2	62.5	1.56	28.1	0.0082
41	25.4	149	69.8	40.1	83.5	65.4	1.60	29.0	0.0085
42	26.8	149	69.3	41.7	80.7	68.4	1.63	30.0	0.0088
43	28.2	149	68.7	43.3	77.8	71.5	1.66	30.9	0.0090
44	29.9	150	67.8	45.0	74.7	74.8	1.70	31.9	0.0093
45	31.4	150	67.2	46.7	71.7	78.0	1.73	32.8	0.0096
46	32.9	150	66.4	48.4	68.7	81.3	1.77	33.8	0.0098
47	34.5	150	65.7	50.2	65.5	84.6	1.80	34.8	0.0101
48	36.1	150	64.8	52.0	62.2	88.1	1.84	35.7	0.0104
49	37.9	151	63.9	53.8	58.9	91.7	1.87	36.7	0.0106
50	39.6	151	62.9	55.7	55.5	95.3	1.91	37.7	0.0109
51	41.4	151	61.9	57.6	51.9	99.0	1.94	38.7	0.0112
52	43.3	151	60.9	59.5	48.3	103	1.98	39.7	0.0115
53	45.2	151	59.7	61.5	44.6	107	2.01	40.8	0.0118
54	47.2	151	58.6	63.5	40.7	111	2.05	41.8	0.0120
55	49.3	152	57.3	65.5	36.8	115	2.09	42.9	0.0123
56	51.4	152	55.9	67.6	32.7	119	2.13	43.9	0.0126
57	53.8	152	54.4	69.8	28.5	124	2.17	45.0	0.0129

Table 3-A14 (cont'd)

58	55.9	152	53.1	71.9	24.3	128	2.20	46.1	0.0132
59	58.1	152	51.7	74.1	20.1	132	2.24	47.1	0.0135
60	60.3	152	50.2	76.4	15.8	137	2.28	48.2	0.0138
61	62.6	153	48.7	78.7	11.4	141	2.32	49.3	0.0141
62	64.9	153	47.2	81.0	6.9	146	2.35	50.4	0.0144
63	67.4	153	45.4	83.3	2.2	151	2.39	51.5	0.0147
64	69.8	153	43.8	85.7	-2.5	156	2.43	52.6	0.0150
65	72.2	153	42.1	88.1	-7.2	160	2.47	53.6	0.0153
66	74.6	153	40.4	90.6	-11.9	165	2.50	54.7	0.0156
67	77.1	153	38.7	93.1	-16.7	170	2.54	55.8	0.0159
68	79.5	154	36.9	95.7	-21.6	175	2.58	56.9	0.0161
69	82.2	154	35.0	98.2	-26.7	180	2.61	57.9	0.0164
70	84.7	154	33.1	101	-31.7	186	2.65	59.0	0.0167
71	87.2	154	31.3	103	-36.7	191	2.69	60.0	0.0170
72	89.8	154	29.3	106	-41.9	196	2.72	61.0	0.0173
73	92.3	154	27.5	109	-47.0	201	2.76	62.0	0.0175
74	94.8	154	25.6	112	-52.2	207	2.79	63.0	0.0178
75	97.4	154	23.7	114	-57.4	212	2.82	64.0	0.0181
76	100.0	155	21.7	117	-62.7	217	2.86	65.0	0.0183
77	102	155	19.8	120	-68	223	2.89	66.0	0.0186
78	105	155	17.9	123	-73	228	2.92	66.9	0.0188
79	107	155	16.0	126	-78	233	2.95	67.8	0.0191
80	110	155	14.1	129	-84	239	2.98	68.7	0.0193

Table 3-A15 Enrollment, environmental and welfare measures for cropping system D (payment for additionality)

Price/acre	Farmer WTA (million $)	Resident WTP (million $)	Economic surplus (million $)	Farmer Welfare (million $)	Resident Welfare (million $)	Spending (million $)	Enrollment (million acre)	Lake (number)	GHG (% of 2000 emission level)
0	0.000	39	76.6	0.0	38.9	0.00	0.957	0	0
1	0.0150	125	77.0	0.957	124	0.972	0.972	0.3	0.0004
2	0.0386	129	77.4	1.93	127	1.97	0.984	0.6	0.0007
3	0.0745	131	77.8	2.91	128	2.99	1.00	1.0	0.0010
4	0.124	133	78.1	3.91	129	4.03	1.01	1.3	0.0013
5	0.186	134	78.5	4.92	129	5.10	1.02	1.7	0.0016
6	0.264	135	78.8	5.94	129	6.20	1.03	2.0	0.0020
7	0.351	136	79.2	6.97	129	7.32	1.05	2.4	0.0023
8	0.455	137	79.5	8.02	129	8.47	1.06	2.7	0.0026
9	0.571	138	79.8	9.07	128	9.65	1.07	3.1	0.0030
10	0.700	139	80.1	10.1	128	10.85	1.08	3.4	0.0033
11	0.844	139	80.3	11.2	127	12.1	1.10	3.8	0.0036
12	1.00	140	80.6	12.3	127	13.3	1.11	4.1	0.0040
13	1.17	140	80.8	13.4	126	14.6	1.12	4.5	0.0043
14	1.36	141	81.0	14.6	125	15.9	1.14	4.8	0.0047
15	1.56	141	81.2	15.7	124	17.3	1.15	5.2	0.0050
16	1.78	142	81.4	16.9	123	18.6	1.16	5.6	0.0054
17	2.10	142	81.5	18.0	122	20.1	1.18	5.9	0.0059
18	2.35	143	81.7	19.2	121	21.6	1.20	6.3	0.0062
19	2.62	143	81.8	20.4	120	23.0	1.21	6.7	0.0066
20	2.92	144	82.0	21.6	119	24.5	1.23	7.1	0.0070
21	3.22	144	82.1	22.8	118	26.1	1.24	7.5	0.0074
22	3.54	144	82.2	24.1	117	27.6	1.26	7.8	0.0077
23	3.89	145	82.2	25.3	115	29.2	1.27	8.2	0.0082
24	4.24	145	82.3	26.6	114	30.8	1.29	8.6	0.0085
25	4.61	145	82.3	27.9	113	32.5	1.30	9.0	0.0089
26	5.13	146	82.2	29.2	111	34.3	1.32	9.4	0.0094

Table 3-A15 (cont'd)

27	5.54	146	82.3	30.5	110	36.0	1.34	9.8	0.0098
28	6.09	146	82.1	31.8	108	37.9	1.35	10.3	0.0103
29	6.55	146	82.1	33.2	107	39.7	1.37	10.7	0.0107
30	7.02	147	82.1	34.6	105	41.6	1.39	11.1	0.0111
31	7.52	147	82.0	36.0	104	43.5	1.40	11.5	0.0115
32	8.11	147	81.9	37.4	102	45.5	1.42	12.0	0.0120
33	8.66	148	81.8	38.8	100	47.4	1.44	12.4	0.0125
34	9.24	148	81.6	40.2	98.3	49.4	1.45	12.9	0.0129
35	9.8	148	81.5	41.7	96.5	51.5	1.47	13.4	0.0134
36	10.4	148	81.3	43.1	94.7	53.6	1.49	13.8	0.0138
37	11.1	148	81.1	44.6	92.8	55.7	1.51	14.3	0.0143
38	11.8	149	80.9	46.1	90.8	57.9	1.52	14.7	0.0147
39	12.6	149	80.5	47.7	88.6	60.3	1.55	15.2	0.0152
40	13.3	149	80.2	49.2	86.6	62.5	1.56	15.7	0.0157
41	14.2	149	79.8	50.8	84.4	65.0	1.58	16.1	0.0162
42	15.0	150	79.4	52.4	82.2	67.4	1.60	16.6	0.0167
43	15.8	150	79.1	54.0	80.0	69.7	1.62	17.1	0.0172
44	16.5	150	78.8	55.6	77.8	72.1	1.64	17.6	0.0176
45	17.3	150	78.4	57.2	75.6	74.6	1.66	18.1	0.0181
46	18.2	150	78.0	58.9	73.3	77.0	1.67	18.5	0.0186
47	19.0	151	77.6	60.5	71.0	79.6	1.69	19.0	0.0190
48	19.9	151	77.2	62.2	68.6	82.1	1.71	19.5	0.0195
49	20.8	151	76.8	63.9	66.2	84.7	1.73	20.0	0.0200
50	21.8	151	76.2	65.7	63.6	87.4	1.75	20.5	0.0205
51	22.7	151	75.7	67.4	61.1	90.1	1.77	21.0	0.0210
52	23.7	151	75.1	69.2	58.49	92.9	1.79	21.5	0.0215
53	24.7	152	74.6	71.0	55.92	95.6	1.80	22.0	0.0220
54	25.6	152	74.0	72.8	53.30	98.4	1.82	22.5	0.0224
55	26.6	152	73.5	74.6	50.66	101.2	1.84	22.9	0.0229
56	27.6	152	72.8	76.4	47.94	104	1.86	23.4	0.0234
57	28.6	152	72.2	78.3	45.21	107	1.88	23.9	0.0239

Table 3-A15 (cont'd)

58	29.9	152	71.3	80.2	42.20	110	1.90	24.4	0.0245
59	31.1	152	70.6	82.1	39.29	113	1.92	24.9	0.0250
60	32.2	153	69.9	84.0	36.4	116	1.94	25.4	0.0255
61	33.3	153	69.2	85.9	33.5	119	1.96	25.9	0.0259
62	34.5	153	68.4	87.9	30.5	122	1.97	26.4	0.0264
63	35.7	153	67.6	89.9	27.4	126	1.99	26.9	0.0269
64	36.9	153	66.8	91.9	24.4	129	2.01	27.4	0.0274
65	38.2	153	66.0	93.9	21.3	132	2.03	27.9	0.0279
66	39.4	153	65.2	95.9	18.1	135	2.05	28.5	0.0285
67	40.8	154	64.2	98.0	14.8	139	2.07	29.0	0.0290
68	42.1	154	63.3	100.0	11.6	142	2.09	29.5	0.0295
69	43.4	154	62.4	102.1	8.3	146	2.11	30.1	0.0300
70	44.8	154	61.5	104.2	4.9	149	2.13	30.6	0.0305
71	46.1	154	60.6	106	1.6	152	2.15	31.1	0.0310
72	47.5	154	59.6	109	-1.8	156	2.17	31.6	0.0315
73	48.9	154	58.6	111	-5.3	160	2.19	32.2	0.0320
74	50.4	154	57.5	113	-8.8	163	2.21	32.7	0.0325
75	51.9	155	56.5	115	-12.4	167	2.23	33.3	0.0330
76	53.4	155	55.3	117	-16.0	171	2.25	33.8	0.0336
77	55.0	155	54.2	120	-19.8	175	2.27	34.4	0.0341
78	57.0	155	52.6	122	-23.9	179	2.29	34.9	0.0348
79	58.5	155	51.5	124	-27.6	183	2.31	35.4	0.0353
80	60.1	155	50.3	126	-31.4	187	2.33	36.0	0.0358

Table 3-A16 Enrollment, environmental and welfare measures for mixed-choice cropping system alternative (payment for additionality)

Price/acre	Farmer WTA (million $)	Resident WTP (million $)	Economic surplus (million $)	Farmer Welfare (million $)	Resident Welfare (million $)	Spending (million $)	Enrollment (million acre)	Lake (number)	GHG (% of 2000 emission level)
0	0.000	39	38.9	0.00	38.9	0.00	0.602	0	0
1	0.159	140	140	0.60	139.6	0.76	0.762	4.17	0.0045
2	0.193	141	141	1.36	139.5	1.56	0.778	4.62	0.0050
3	0.249	142	141	2.14	139.3	2.39	0.797	5.07	0.0055
4	0.271	142	141	2.94	138.5	3.21	0.803	5.22	0.0055
5	0.394	143	142	3.74	138.5	4.14	0.827	6.01	0.0063
6	0.373	142	142	4.57	137.1	4.94	0.824	5.73	0.0054
7	0.618	143	142	5.39	137.0	6.01	0.859	6.56	0.0063
8	0.619	143	142	6.25	136.2	6.87	0.859	6.81	0.0063
9	0.612	143	142	7.11	135.0	7.72	0.858	6.51	0.0059
10	0.868	143	142	7.97	134.5	8.84	0.884	7.45	0.0062
11	1.13	144	143	8.85	133.7	10.0	0.907	7.81	0.0066
12	1.25	144	143	9.76	133.3	11.0	0.918	8.42	0.0073
13	1.33	144	143	10.7	132.1	12.0	0.924	8.35	0.0070
14	2.07	145	143	11.6	131.3	13.7	0.976	9.89	0.0076
15	2.15	145	143	12.6	130.1	14.7	0.982	9.79	0.0074
16	2.25	145	143	13.6	129.1	15.8	0.988	10.0	0.0075
17	3.44	146	142	14.5	127.8	18.0	1.06	11.5	0.0083
18	3.13	146	143	15.6	127.0	18.7	1.04	11.3	0.0084
19	3.85	146	142	16.6	125.7	20.5	1.08	12.2	0.0088
20	4.12	146	142	17.7	124.5	21.8	1.09	12.8	0.0089
21	4.76	146	142	18.8	122.9	23.6	1.12	13.2	0.0088
22	5.07	147	142	19.9	121.7	25.0	1.14	13.7	0.0092
23	5.92	147	141	21.1	120.2	27.0	1.17	14.8	0.0097
24	5.86	147	141	22.3	118.9	28.1	1.17	14.7	0.0093

Table 3-A16 (cont'd)

25	6.92	147	141	23.4	117.1	30.3	1.21	15.8	0.0098
26	7.32	147	140	24.6	115.5	32.0	1.23	16.1	0.0098
27	9.43	148	139	25.9	113.0	35.3	1.31	18.1	0.0111
28	10.07	149	139	27.2	111.4	37.2	1.33	18.7	0.0116
29	10.47	149	138	28.5	109.6	39.0	1.34	19.2	0.0113
30	13.08	149	136	29.8	106.3	42.9	1.43	21.2	0.0124
31	13.96	150	136	31.3	104.3	45.2	1.46	22.0	0.0129
32	13.97	150	136	32.7	102.8	46.7	1.46	22.1	0.0129
33	14.62	150	135	34.2	100.7	48.8	1.48	22.6	0.0126
34	16.98	150	133	35.7	97.2	52.7	1.55	24.3	0.0129
35	17.1	150	133	37.2	95.6	54.3	1.55	24.6	0.0130
36	17.7	150	132	38.8	93.6	56.5	1.57	25.2	0.0132
37	19.9	150	131	40.3	90.3	60.2	1.63	26.7	0.0139
38	21.6	151	129	42.0	87.1	63.6	1.67	27.5	0.0144
39	23.2	151	128	43.6	84.1	66.8	1.71	28.7	0.0148
40	24.2	151	127	45.4	81.6	69.5	1.74	29.4	0.0153
41	25.6	151	126	47.1	78.6	72.7	1.77	30.4	0.0156
42	27.4	151	124	48.9	75.2	76.3	1.82	31.5	0.0156
43	28.6	152	123	50.7	72.4	79.3	1.84	32.3	0.0161
44	29.8	152	122	52.5	69.4	82.3	1.87	33.0	0.0160
45	31.2	152	121	54.4	66.3	85.6	1.90	34.0	0.0164
46	31.5	152	120	56.3	64.0	87.8	1.91	34.4	0.0161
47	33.3	152	119	58.2	60.7	91.5	1.95	35.4	0.0170
48	34.2	152	118	60.2	58.0	94.4	1.97	35.9	0.0175
49	34.7	152	117	62.1	55.3	96.9	1.98	36.4	0.0166
50	36.9	152	116	64.1	51.5	101	2.02	37.5	0.0174
51	38.7	153	114	66.1	47.7	105	2.06	38.5	0.0175
52	41.3	153	112	68.2	43.4	109	2.11	39.8	0.0181
53	43.2	153	110	70.3	39.5	113	2.14	40.9	0.0184
54	46.4	153	107	72.4	34.3	119	2.20	42.4	0.0185
55	46.7	153	106	74.6	31.8	121	2.21	42.8	0.0182

Table 3-A16 (cont'd)

56	49.9	153	103	76.8	26.6	127	2.26	44.4	0.0188
57	54.3	154	99.3	79.1	20.2	133	2.34	46.3	0.0193
58	55.6	154	98.2	81.4	16.8	137	2.36	47.0	0.0203
59	57.9	154	95.9	83.8	12.1	142	2.40	48.2	0.0193
60	59.7	154	94.4	86.2	8.2	146	2.43	49.2	0.0205
61	61.8	154	92.2	88.6	3.6	150	2.47	50.0	0.0200
62	64.0	154	90.2	91.1	-0.9	155	2.50	51.2	0.0206
63	67.8	154	86.6	93.6	-7.0	161	2.56	52.6	0.0210
64	66.3	154	88.1	96.2	-8.1	162	2.54	52.4	0.0213
65	70.3	154	84.2	98.7	-14.5	169	2.60	53.9	0.0209
66	71.8	155	82.8	101	-18.5	173	2.62	54.8	0.0213
67	72.8	155	81.9	104	-22.0	177	2.64	55.2	0.0217
68	77.9	155	76.8	107	-29.7	184	2.71	57.3	0.0214
69	78.4	155	76.5	109	-32.7	188	2.72	57.6	0.0223
70	82.0	155	73.0	112	-39.0	194	2.77	59.1	0.0224
71	81.3	155	73.7	115	-41.1	196	2.76	58.9	0.0223
72	85.2	155	70.0	118	-47.5	203	2.82	60.5	0.0229
73	88.6	155	66.6	120	-53.8	209	2.86	61.8	0.0225
74	88.4	155	66.7	123	-56.5	212	2.86	61.8	0.0221
75	90.3	155	65.0	126	-61.0	216	2.88	62.6	0.0230
76	94.5	155	61.0	129	-67.9	223	2.94	64.0	0.0235
77	95.5	155	60.0	132	-71.9	227	2.95	64.5	0.0234
78	96.5	155	59.0	135	-75.8	231	2.97	65.0	0.0231
79	101	156	54.4	138	-83.4	239	3.03	66.6	0.0232
80	101	156	54.6	141	-86.2	242	3.02	66.7	0.0242

REFERENCES

REFERENCES

Ahlgren, I., T. Frisk, and L. Kamp-Nielsen. 1988. "Empirical and theoretical models of phosphorus loading, retention and concentration vs. lake trophic state." *Hydrobiologia* 170(1):285-303.

Amigues, J.P., C. Boulatoff, B. Desaigues, C. Gauthier, and J.E. Keith. 2002. "The benefits and costs of riparian analysis habitat preservation: A willingness to accept/willingness to pay contingent valuation approach." *Ecological Economics* 43(1):17-31.

Antle, J.M. 2007. "Payments for ecosystem services and US farm policy." *The 2007 Farm Bill and Beyond: Summary for Policymakers*:111–113.

ARMS (2000-2006) Usda agricultural resource management survey: Farm financial and crop production practices. Washington, DC. http://www.ers.usda.gov/Data/ARMS/

Balagtas, J., and S. Kim. 2007. "Measuring the effects of generic dairy advertising in a multi-market equilibrium." *American Journal of Agricultural Economics* 89(4):932-946.

Baylis, K., G. Rausser, and L. Simon. 2004. "Agri-environmental programs in the United States and european union." *Agricultural policy reform and WTO: where are we heading*:210-233.

Carpenter, S., N. Caraco, D. Correll, R. Howarth, A. Sharpley, and V. Smith. 1998. "Nonpoint pollution of surface waters with phosphorus and nitrogen." *Ecological Applications* 8(3):559-568.

Chen, H. 2010. "Ecosystem services from low input cropping systems and public's willingness to pay for them." M.S. Thesis, Michigan State University, Department of Agricultural, Food and Resource Economics. http://www.aec.msu.edu/theses/fulltext/chen_ms.pdf

Correll, D. 1998. "Role of phosphorus in the eutrophication of receiving waters: A review." *Journal of Environmental Quality* 27(2):261-266.

Delgado, J., R. Sparks, R. Follett, J. Sharkoff, and R. Riggenbach. 1999. "Conserve soil and water quality in the San Luis valley of south central Colorado, soil quality and soil erosion." *Soil quality and soil erosion*:125-142.

Environmental Working Group. 2011. Farm subsidy database. Retrieved Aug 9, 2011, from http://farm.ewg.org/region.php?fips=26000

Environmental Working Group. 2011. "Farm subsidy primer ". Environmental Working Group, Washington, DC. http://farm.ewg.org/subsidyprimer.php

Forster, P., V. Ramaswamy, T.B. P. Artaxo, D.W.F. R. Betts, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz, and R.V. Dorland (2007) Changes in atmospheric constituents and in radiative forcing, ed. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor, H.L. Miller, Climate change 2007: The physical science basis. Contribution of working group i to the fourth assessment report of the intergovernmental panel on climate change. Cambridge, United Kingdom and New York, NY, USA, Cambridge University Press.

Fuller, L.M., and Minnerick, R.J. 2008. "State and regional water-quality characteristics and trophic conditions of michigan's inland lakes 2001-2005." Report U.S. Geological Survey, Reston, Virginia.

Gentry, L.E., S.S. Snapp, C.P. McSwiney, G.A. Parker, and R.R. Harwood. 2011. Mineralization and plant available n in rotated and continuous corn systems in a long-term study:Nitrogen credits for crop rotation, cover crops, and composted dairy manure. Working paper. Michigan State University. East Lansing, MI.

Ghidey, F., and E. Alberts. 1998. "Runoff and soil losses as affected by corn and soybean tillage systems." *Journal of Soil and Water Conservation* 53(1):64.

Glotfelty, D.E., J.N. Seiber, and A. Liljedahl. 1987. "Pesticides in fog." *Nature* 325(6105):602-605.

Hoben, J.P., R.J. Gehl, N. Millar, P.R. Grace, and G.P. Robertson. 2011. "Nonlinear nitrous oxide (N_2O) response to nitrogen fertilizer in on-farm corn crops of the US midwest." *Global Change Biology* 17(2):1140-1152.

Janus, L.L., and R. Vollenweider. 1984. "Phosphorus residence time in relation to trophic conditions in lakes." *Verhandlung Internationale Vereinigung Limnologie* 22(1).

Jayne, T., R. Myers, and J. Nyoro. 2008. "The effects of NCPB marketing policies on maize market prices in kenya." *Agricultural Economics* 38(3):313-325.

Jolejole, M.C.B. 2009. "Trade-offs, incentives and the supply of ecosystem services from cropland." M.S. Thesis, Michigan State University, Department of Agricultural, Food and Resource Economics. http://aec3.aec.msu.edu/theses/fulltext/jolejole1_ms.pdf

Joyce, B., W. Wallender, J. Mitchell, L. Huyck, S. Temple, P. Brostrom, and T. Hsiao. 2002. "Infiltration and soil water storage under winter cover cropping in California's Sacramento Valley." *Transactions of the ASAE* 45(2):315-326.

Lal, R., M. Griffin, J. Apt, L. Lave, and M. Morgan. 2004. "Managing soil carbon." *Science* 304(5669):393.

Langdale, G., R. Blevins, D. Karlen, D. McCool, M. Nearing, E. Skidmore, A. Thomas, D. Tyler, and J. Williams (1991) Cover crop effects on soil erosion by wind and water, Cover Crops for Clean Water. Ankeny, IA, Soil and Water Conservation Society, pp. 15–22.

Lipsey, R.G., and K. Lancaster. 1956. "The general theory of second best." *The Review of Economic Studies* 24(1):11-32.

McSwiney, C., S. Bohn, P. Grace, and G. Robertson. 2010. "Greenhouse gas emissions calculator for grain and biofuel farming systems." *Journal of Natural Resources and Life Sciences Education* 39:125-131.

McSwiney, C.P., and G.P. Robertson. 2005. "Nonlinear response of N_2O flux to incremental fertilizer addition in a continuous maize (Zea mays l.) cropping system." *Global Change Biology* 11(10):1712-1719.

McSwiney, C.P., S.S. Snapp, and L.E. Gentry. 2010. "Use of N immobilization to tighten the N cycle in conventional agroecosystems." *Ecological Applications* 20(3):648-662.

Minnerick, R. 2005. "Michigan lakes: An assessment of water quality: U.S. Geological survey fact sheet 2004-3048." USGS Michigan Water Science Center, July 7, 2005. http://pubs.water.usgs.gov/fs2004-3048/

Morgan, R.P.C. 2005. *Soil Erosion and Conservation*: Wiley-Blackwell.

Musser, W.N., J.S. Shortle, K. Kreahling, B. Roach, W.-C. Huang, D.B. Beegle, and R.H. Fox. 1995. "An economic analysis of the pre-sidedress nitrogen test for Pennsylvania corn production." *Review of Agricultural Economics* 17(1):25-35.

Peel, M. 1998. "Crop rotations for increased productivity " Bulletin. North Dakota State University Extension Service, Fargo, ND. http://www.ag.ndsu.edu/pubs/plantsci/crops/eb48-1.htm

Poudel, D., W. Horwath, J. Mitchell, and S. Temple. 2001. "Impacts of cropping systems on soil nitrogen storage and loss." *Agricultural Systems* 68(3):253-268.

Reganold, J.P., L.F. Elliott, and Y.L. Unger. 1987. "Long-term effects of organic and conventional farming on soil-erosion." *Nature* 330(6146):370-372.

Reicosky, D., W. Kemper, G. Langdale, C. Douglas, and P. Rasmussen. 1995. "Soil organic matter changes resulting from tillage and biomass production." *Journal of Soil and Water Conservation* 50(3):253.

Reicosky, D., and M. Lindstrom. 1993. "Fall tillage methods: Effect on short-term carbon dioxide flux from soil." *Agronomy Journal* 85(6):1237-1243.

Robertson, D. 1996. "Sources and transport of phosphorus in the Western Lake Michigan drainages." US Dept. of the Interior, US Geological Survey, Madison, WI. http://wi.water.usgs.gov/pubs/FS-208-96/FS_208-96.pdf

Robertson, G.P., and P.R. Grace. 2004. "Greenhouse gas fluxes in tropical and temperate agriculture: The need for a full-cost accounting of global warming potentials." *Environment, Development and Sustainability* 6(1):51-63.

Silva, G., J. Dahl, and N. Rector. "Initial PSNT results demonstrate nitrogen credit for corn." Michigan State University Extension, June 15. 2011. http://news.msue.msu.edu/news/article/soil_nitrate_n_variability_on_corn_fields_with_high_mineralization_potentia

Soil and Water Conservation Society. 1993. "RUSLE user's guide." Soil and Water Conservation Society, Ankeny, IA. .

Swinton, S.M., F. Lupi, G.P. Robertson, and D.A. Landis. 2006. "Ecosystem services from agriculture: Looking beyond the usual suspects." *American Journal of Agricultural Economics* 88(5):1160-1166.

Thomas, R.H., and F.B. Blakemore. 2007. "Elements of a cost–benefit analysis for improving salmonid spawning habitat in the River Wye." *Journal of Environmental Management* 82(4):471-480.

Tietenberg, T.H., and L. Lewis (2000) Economics of pollution control: An overview, Environmental and natural resource economics. Boston, MA, Addison-Wesley Reading.

USDA-NRCS. 2010. "Conservation stewardship program, final rule." Federal Register Vol. 75, No. 106. June 3, 2010

van den Berg, F., R. Kubiak, W.G. Benjey, M.S. Majewski, S.R. Yates, G.L. Reeves, J.H. Smelt, and A.M.A. van der Linden. 1999. "Emission of pesticides into the air." *Water, Air, & Soil Pollution* 115(1):195-218.

Welsch, B.L., J.H. Dorfman, B. Barnett, and J.C. Bergstrom. 2005. Supply and demand in three proposed farmland preservation markets. Working Paper. Department of Agricultural & Applied Economics, University of Georgia. Athens, GA. http://jdorfman.myweb.uga.edu/farmprsv.pdf

Willett, L., and B. French. 1991. "An econometric model of the US beekeeping industry." *American Journal of Agricultural Economics*:40-54.

Wunder, S. 2005. "Payments for environmental services: Some nuts and bolts." Occasional Paper No. 42. Center for International Forestry Research, Bogor, Indonesia.

Zhang, W., T.H. Ricketts, C. Kremen, K. Carney, and S.M. Swinton. 2007. "Ecosystem services and dis-services to agriculture." *Ecological Economics* 64(2):253-260.