What Drives the Adoption of Clean Agricultural Technologies? An Ex Ante Assessment of Sustainable Biofuel Production in Southwestern Wisconsin

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Abstract

This paper explores the farmer's general decision to adopt a clean agricultural production technology and the particular role of pro-social behavior. We hypothesize that pro-social behavior may influence farmers' individual valuation of clean technologies through two channels, their beliefs about the technology's public benefits and their preferences for environmental quality. A linear characteristics model is developed to illustrate how a pro-social preference structure may lead to different adoption outcomes as compared to the standard profit-maximization framework. We test this possibility using mail survey data on *ex ante* bioenergy crop adoption in southwestern Wisconsin. The contingent valuation empirical strategy estimates farmers' distribution of willingness-to-accept values (i.e., minimum biomass reservation prices) as a function of expected pro-social behavior, factors that constrain short-run technological change, and other standard adoption influences. We find that the observed heterogeneity in WTA values is partially and significantly explained by expected pro-social behavior.

Key words: bioenergy, contingent valuation, corn stover, linear characteristics, switchgrass, technology adoption and diffusion

1. Introduction

This paper contributes to recent literature on the adoption of clean agricultural production technologies, with a particular focus on the role of pro-social behavior in farmers' individual start-up or *conversion* decision. Here, we consider 'clean' production technologies to be distinct in the sense that they impart or are perceived to impart some social or environmental benefit to

the adopting farmer, other nearby residents, and/or society more generally. Pfaff, Chadhuri and Nye (2004) define one class of clean agricultural production technologies as those that are less environmentally-degrading as compared to a conventional or 'dirty' technology (i.e., they produce fewer harmful emissions and thus improve the quality of some amenity stock). Another class may be broadly conceptualized as those that aid in the achievement of some social objective such as clean energy goals, regardless of whether the technology itself has any environmental effect at the local level.

Previous research by Lewis, Barham and Zimmerman (2011) treats the clean technology conversion decision in a real options context involving sunk costs, uncertainty and learning. In this case, the optimal conversion decision depends on the clean technology satisfying an expected 'reservation' return whose net present value (NPV) exceeds that for the simple 'breakeven' return at which it first becomes profitable. The authors show that spatial spillovers allow for reductions in transaction and learning costs and drive the agglomerated patterns of organic dairy adoption in southwestern Wisconsin. In this respect, the findings by Lewis, Barham and Zimmerman (2011) fit into the classical diffusion literature which shows that dynamic economic factors may delay or constrain farmer's adoption of seemingly profitable technologies (e.g., Feder, Just and Zilberman, 1985; Dixit and Pindyck, 1994; Foster and Rosenzweig, 2010).

Our contribution in this paper is to suggest that farmers' individual valuation of clean technologies may be influenced by pro-social behaviors, and that this behavior may partially offset the return 'premium' that appears as a wedge between the farmers' reservation and breakeven decision thresholds. In doing so, we seek to answer the question, "Does pro-social behavior drive the early adoption of clean agricultural technologies?" Our model assumes that

farmers behave as utility-maximizing agents whose preferences are represented by a multi-attribute utility function that contains a private composite good (i.e., profit) and a composite environmental public good (e.g., fulfillment of a clean energy goal or enhancement of a local natural resource stock). Casting the problem in terms of a linear characteristics model, we analyze the comparative static effect of introducing the clean technology among the landowners' portfolio of land use choices. This setup provides useful insight into clean technology adoption decision by illustrating how pro-social preference structures can lead to different predictions about adoption outcomes as compared to the standard profit-maximization framework.

For an empirical application, we apply this framework to the case of farmer bioenergy crop adoption in southwestern Wisconsin. The contingent valuation empirical strategy we employ allows us (1) to estimate the distribution of farmers' individual willingness-to-accept (WTA) values (i.e., reservation prices) for conversion to a bioenergy cropping system, and (2) to explain the observed variation as a function of expected pro-social behaviors and traditional adoption variables. In this manner, we are able to develop explicit empirical tests of the theoretical predictions of the farmer's choice model, and to demonstrate how they improve the performance of the estimations and deepen our understanding of the likely patterns of clean technology diffusion across heterogeneous farms and pro-social behavioral preferences.

Bioenergy crops fit the notion of a clean agricultural production technology in two ways. First, they are grown and harvested as a source of renewable fuel. As a result, the farmers who produce these crops may view themselves as contributing directly to regional or national energy goals or indirectly to other related public benefits of bioenergy development such as rural economic growth or reductions in greenhouse gas emissions. Second, bioenergy crops such as perennial grasses or trees may enhance the quality of agricultural resource stocks (e.g., soil,

water, biotic resources) that may directly improve the well-being of the farmer though yield gains or indirectly thorough enhancement of some on-farm or nearby amenity (e.g., improved wildlife habitat, recreational opportunities or scenic vistas). If farmers attach values to these social outcomes (e.g., via altruism or the less pure "warm glow" effect) then pro-social behavior with respect to these attributes may play a central role in early phases of the diffusion process. In addition, transitions to bioenergy cropping systems involve potentially major changes to land management practices (e.g., crop/livestock mix, contractual arrangements, feed purchasing and storage, new investments and equipment purchases) and are thus also expected to be influenced by the previously discussed dynamic economic factors such as sunk costs, uncertainty, and learning (Song, Zhao and Swinton, 2011; Bocquého and Jacquet, 2010).

Data are from an *ex ante* survey on bioenergy crop adoption mailed to farm landowners in 2011, which contains rich information on biophysical land attributes, land management activities, demographic and social indicators. One unique feature of the questionnaire is a CV module designed to elicit landowners' reservation prices for land conversion to corn stover and switchgrass as bioenergy crop technologies. The specific CV elicitation approach implemented is the well-developed double-bounded dichotomous choice (DB-DC) format popularized by environmental economists for non-market valuation purposes. A second unique feature are two sets of questions that gauge respondents' beliefs about the social benefits of alternative energy development and environmental preferences, respectively. Our econometric analysis exploits these data to estimate the role of current land use, enterprise activity, and proxy variables for expected pro-social behavior on farmers' individual valuation of these technologies.

The estimation results lend support for a theory of pro-social motivations in farmers' bioenergy crop adoption decisions. In addition to the standard set of static and dynamic factors

that are typically used to explain farmers' adoption decisions, we find that farmers' social beliefs and environmental attitudes also influence their valuation of 'clean' bioenergy crop technologies. The findings are nuanced in that they provide empirical insights on pro-social behaviors that are relatively pure (or altruistic) like climate change and more impure like water quality or soil quality outcomes (that affect both the farm and the surrounding environment). Remaining questions for future work are to determine the extent to which they might influence expected bioenergy crop diffusion patterns, and whether these insights might be leveraged to improve policy design as it relates to the environmental management of farm landscapes.

2. Background

Here we focus our discussion of relevant literature to economic models that incorporate pro-social behavior into individual decision-making but it is important to note that other disciplines such as social psychology have also made substantial progress in this realm (e.g., value-belief-norm theory [Stern et al., 1999], theory of planned behavior [Ajzen, 1991]). Turaga, Howarth and Borsuk (2010) provide a review of literature in both the economic and social psychology fields and discuss the considerable degree of integration occurring between them in recent years. This literature distinguishes among several broad motivations for engaging in pro-social behavior. One is altruism, or moral concern for the well-being of others without the expectation of compensation or personal benefit (direct or indirect). This contrasts with egoism where the individual strictly behaves according to selfish interests. Another is impure altruism where the individual appears to engage in altruistic behavior but only because they derive some direct or indirect egoistic benefit as a derivative of their action.

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Most economic models of pro-social behavior build upon the notion of private provision of public goods (Bergstrom, Blume and Varian, 1986). In this now classic work, the consumer chooses how to allocate its income between a private good and donations to a pure public good. Utility is gained via consumption of the private good and the overall level of provision for the public good. In a related article, Andreoni (1990) develops an economic theory of impure altruism called "warm glow" giving. Here, individual's preference structures contain a taste for warm glow they feel due to the social recognition or personal satisfaction they get from doing the right thing. As reviewed by Turaga, Howarth and Borsuk (2010) other economic models exist that explain similar impure altruistic benefits such as prestige, social approval and self-image (e.g., Hollander, 1990; Rege, 2004; Brekke, Kvernkokk and Nyborg, 2003).

In recent years, these models have spawned a growing amount of literature in the applied areas of clean energy consumption (e.g., Ek and Soderholm, 2008; Kahn, 2007; Kotchen and Moore, 2007) and the environment/agriculture interface (e.g. Bonnieux et al., 1998; Chouinard et al, 2008; Dupraz et al., 2003; Ma et al., 2011; Sheeder and Lynne, 2011; and Weaver, 2006). Some of these studies utilize a linear characteristics framework in order to incorporate the notion of 'tastes' for impure public characteristics of certain goods into models of private decision making. The impure public good is typically defined as a private consumption good with public characteristics. Consumption of the impure good generates utility both directly via increased consumption of private market goods and indirectly from its contribution to the public good.

Our model is developed in a similar vein and is closely related to two previous studies. Kotchen (2006) investigates the case of 'green' markets in which items such as fair-trade coffee or green electricity are modeled as the impure public good. In another study, Pfaff, Chaudhuri, and Nye (2004) explored the effects of introducing a clean technology on household production

decisions. Our model is most similar to Pfaff, Chaudhuri and Nye (2004) in that clean

technology adoption enhances some amenity stock.

3. The Clean Technology Adoption Model

Our model considers the simple case of an individual farm household's private adoption

decision, and is developed in three parts. We first introduce the clean production technology and

define the household land constraint. Next we describe how farmers may integrate pro-social

behavior into the traditional profit-maximizing model of farm decision making. The third section

characterizes the model and explores its implications.

3.1. Household Production Technology and Land Constraint

Let the farm household's total land holdings L be fixed. Each unit of L may be allocated to an

agricultural use A or non-agricultural use M, such that the farm faces the constraint $L = A + M$.

For each agricultural land unit A, the farm household also faces the choice over production

technology $j \in \{c, d\}$ where c represents the new *clean* technology and d is the conventional or

dirty technology. The household is thus bound by the land constraint $A = a_c + a_d$ where a_c and

a_d represent the acres of land devoted to the clean and dirty technologies, respectively.

Agricultural production using either technology provides a joint-output that includes a vector of

private market goods y (e.g., contains crops and animal products as its elements) and a vector of

non-market externalities e (e.g., contains normalized coefficients for soil loss, nutrient runoff,

habitat depreciation as elements). The household's agricultural profit is thus given by $R = $

$r_d a_d + r_c a_c$ where r_j is the net return (\$/acre) to technology j defined as the product $r_j = p_j y_j - $

c_j for a given output price vector p_j and cost c_j. Similarly, aggregate emissions are $E = e_d a_d + $

$e_c a_c$ where $e_j \in (0,1)$ is the normalized per-acre level of externality. To lend 'clean' technology with a practical interpretation we maintain the assumption $e_d > e_c$.

3.2. Landowner Preferences

The landowner is assumed to derive utility from characteristics of the land use rather than from land use itself. For simplicity let such preferences be represented by the concave and strictly increasing utility function $U(\pi, z)$ where π is household income (i.e., a composite market good) and z is a public or environmental (i.e., non-market) amenity service flow. Here, we define $\pi = R + I$ where R is as described and I is off-farm income. We also allow for z to vary depending on an initial endowment level and the external effects of agricultural production e. For the purpose of this analysis we normalize the household's initial environmental endowment to equal total landholdings $Z = L - E$. In this sense, z relates the degree to which the household's land holdings are degraded from their natural state.

This normalization lends a useful 'ecological' interpretation that amenity services are maximized when there is no agricultural production and land is in its most natural state $Z^{\max} = L$. In this case $R = 0$ and all utility is derived via the environmental amenity and off-farm income. By contrast, amenity services are minimized when all land is allocated to agriculture under the dirty technology $Z^{\min} = L(1 - \alpha_d)$. In this case agricultural profits are maximized (assuming $r_d > r_c$). Notice that $z^{\min} > 0$ implies the farm household always enjoys some positive level of amenity services regardless of their land allocation. Note also that this framework is just one example of the way in pro-social preferences may operate and that the preference structure may vary for different behaviors.

3.3 The Farm Household's Decision Problem

The farm household's decision problem becomes that of choosing A and (a_d, a_c) to maximize

utility subject to the constraints,

$$\max_{A,(a_d,a_c)} U(\pi, Z)$$

subject to,

(1) Land constraints: $L = A + M$ where $A = a_d + a_c$

(2) Profit equation: $\pi = R + I$ where $R = r_d a_d + r_c a_c$

(3) Damage function: $E = e_d a_d + e_c a_c$

(4) Amenity service: $Z = L - E$

where L is exogenously determined and the clean technology assumption $\alpha_d > \alpha_c$ is imposed.

To further explore how farmers' combined land use and technology decision affects their

environmental milieu, we can first recast this problem in terms of the production scale A and

technique φ where $\varphi = a_c/(a_d + a_c)$ (i.e., the share of agricultural land devoted to the clean

technology). Combining constraints (1), (3) and (4) and using the definition of φ, we obtain the

following expression for the level of environmental amenities,

(5) $$Z = M + A[1 - e_d - \varphi(e_c - e_d)]$$

which has the desired scale effect, $\frac{\partial Z}{\partial A} < 0$, and technique effect: $\frac{\partial Z}{\partial \varphi} > 0$. Holding the proportion

of land allocated to the clean technology, the scale effect shows that any expansion in

agricultural land area degrades environmental quality. By contrast, the technique effect shows

that the amenity is enhanced by increasing the share of land allocated to the clean technology

holding the total amount of land constant. Similar results were also obtained by Pfaff, Chaudhuri

and Nye (2004) but in a different context.

3.4 The Problem in (π, Z) Characteristic Space

Relying on the earlier notions of the private provision of public goods and the linear

characteristics model, we can recast the farmers' maximization problem as a choice over

characteristics of land use rather than land use itself. Figure 1 illustrates the static comparative

effect of introducing a clean technology among the portfolio of land use choices enjoyed by the

private landowner. Initially, the option of a clean technology is not available to the landowner.

Rather, they are faced only with the choice of allocating land to the conventional technology. In

this case, the constraint set is linear along the segment $\overline{wx}$. At point *w*, the landowner allocates

all of their land to agriculture under the dirty technology (i.e., A = L, φ = 0). The landowner still

enjoys a positive level of the environmental amenity albeit at its minimum level. At point *x*, the

landowner allocates all of their land to open space (A = 0). Both interior and corner solutions are

possible. If the landowner derives no utility from the environmental amenity, the indifference

curve will be vertical and the only solution is the corner solution at point *w*. In this case, the

landowner behaves as a profit maximizing firm. Alternatively, an interior solution along

segment $\overline{wx}$ may arise if the landowner's strength of preferences for the environmental amenity

is sufficient to equate the MRS and slope of the constraint set.

Introduction of the clean technology expands the landowner's constraint set. Here, the

point *y* represents the case where the landowner allocates all of their land to agriculture but under

the clean technology (A = L, φ = 1). The landowner now obtains an intermediate level of the

environmental amenity and profits. The solution in this case again could take the form of an

interior solution or a corner solution depending on the strength of the landowners preferences.

Note that this figure as illustrated maintains several implicit assumptions, such as the assumption

that the clean technology is less profitable than the dirty technology. The point *y* could appear in different locations relative to *w* under different circumstances.

4. Bioenergy Crop Adoption in Southwestern Wisconsin

In the empirical application below, we apply the model to the case of *ex ante* bioenergy crop adoption in southwestern Wisconsin. Bioenergy crops are defined here to be plant residues, perennial grasses or short-rotation trees that are grown and harvested specifically for sale as raw material or 'biomass' for the bioenergy sector. In most cases this biomass is expected to be combusted for heat and electricity generation or converted into a transportation fuel. These crops are often viewed as socially-beneficial in the sense that they represent a source of domestic renewable energy yet avoid several of the major social and environmental pitfalls associated with the use of corn grain for ethanol production (e.g., food versus fuel and indirect land use change concerns). In addition, perennial bioenergy crop technologies are viewed as sustainable or conservation-friendly in that they provide a range of environmental benefits such as soil conservation, reduced runoff, wildlife habitat and aesthetic appeal.

Southwestern Wisconsin's diverse agricultural resource base and varied physical geography make it a possible center of bioenergy crop production (U.S. DOE, 2011; Gelfand et al., 2013). Principal farming activities in the region include grain and forage crops and livestock production. Cultural practices vary widely, with many growers practicing long term crop rotations and reduced rather than conventional tillage. Much of the region lies in the un-glaciated Driftless Area, and is thus comprised of many winding ridges, steeply sloped ravines, and sandstone bluffs. As a result, a significant proportion of the land area is enrolled in USDA-Conservation Reserve Program (CRP). The presence of a well-developed transportation

infrastructure with highways, rail lines, and river ways adds to the region's potential as a center of bioenergy crop production.

However, farmer adoption of bioenergy crops in this region is uncertain. The majority of farms in the area operate integrated crop-livestock enterprises, such as dairies, and have large investments and other on-going commitments to competing activities. To the extent that they are present on a given farm, these sunk costs and economies of scope are expected to act as a short-run (or perhaps more binding) constraint on bioenergy crop adoption. In addition, markets for agricultural biomass do not currently exist in the area, nor have they in the recent past. Bioenergy crops require different management and marketing approaches than food and feed crops, and are thus outside the current range of experience for most farmers. Nor do they have neighbors from whom they might obtain information to reduce this uncertainty. Finally, pro-social behaviors are expected to play a role. Some farmers may view bioenergy crops as major step toward meeting the challenges of energy independence or environmental sustainability and attach related values to them.

5. Survey Data

Data used in the analysis are from the 2011 Wisconsin Bioenergy Crop Production Study, a mail survey of 1,543 prospective farm operations in Iowa, La Crosse, Richland and Sauk Counties (Mooney et al., 2013). Unique features of the study questionnaire include (1) a contingent valuation module designed to elicit farmers' *ex ante* participation rates in bioenergy markets for corn stover and switchgrass, and (2) two questions that summarize respondents' beliefs about the social benefits of alternative energy development and attitudes towards the environmental land

stewardship, respectively. We describe each of these features in more detail below, but first provide background on the farm selection and mailing process.

5.1 Farm Selection and Sample Returns

The study targeted active farm landowners who raised grain crops, forage, or livestock during the 2010 growing season. These farms manage the majority of cultivable land in the area, and are thus the most important in terms of understanding the overall impact of bioenergy crops at a regional scale. This leaves out some active farmers who exclusively raise vegetables, fruit crops, or other products but there are relatively fewer of them and they tend to operate smaller farms. Thus, their management decisions affect only a small portion of the total land in farms.

Farm selection process followed a clustered, stratified sampling design. First, a selected set of townships within each county (i.e., clusters) were selected based on the relative abundance of marginal cropland and marginal non-crop land, and proximity to transportation corridors. This step relied on a geographic information system (GIS), and data layers from the USDA-NRCS soil survey (SSURGO) and the USDA-NASS Cropland Data Layer. Second, individual farms within these townships were stratified according to CRP participation based on a list frame maintained by the Wisconsin Agricultural Statistics Service (WASS) at the Wisconsin Department of Agriculture, Trade and Consumer Protection. All farms enrolled in the CRP as of 2007 (most recent year for which data are available) were automatically included in the study. An additional set of farms was then drawn at random from the remaining population.

The final sample comprised a total of 1,543 farms, including 348 in Iowa County, 249 in La Crosse County, 397 in Sauk County, and 449 in Richland County. Questionnaires were mailed in April 2011, with a reminder post card and two follow-up mailings conducted in May

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and June of the same year. Slightly over half of those contacted (n = 784) returned their

questionnaire. Among the returns, a large share were unusable due to a change in farming status

from active to inactive (n = 302), non-eligibility of the farm due to the type of farming activity

pursued (n = 32), partially incomplete (n = 51) or because the respondent declined to participate

(n = 121). The primary factor behind the large number of inactive and non-eligible responses is

likely the amount of time that elapsed between compilation of the WASS mailing list (in 2007)

and the time of this survey mailing (in 2011). This report summarizes data from 253 returned and

completed questionnaires by active farm landowners, for a useable response rate of 21% after

removing the inactive an ineligible responses from the population frame.

5.2 CV Module

The module asked respondents if they would be willing to participate in a hypothetical market

program for different sustainable biofuel crop technologies—including corn stover and

switchgrass—and to report on how much, if any, land they would convert from its current use to

biofuels production. The module followed a DB-DC format, with separate series of questions for

each of the crops considered. The first question asked, "At $[biomass purchase offer]/dry ton,

would you enroll any acres in this program?" If they responded *yes* to the initial offer, the

biomass purchase offer in the second question decreased. Similarly, if they responded *no* then the

follow-up offer increased. It asked, "If the price increased (decreased) to $[biomass purchase

offer]/dry ton and all other contract provisions remain the same, would you now (still) enroll in

the corn stover program, albeit with fewer acres?"

Three sets of biomass purchase offer prices were used (Table 1). Low version prices were

determined by reviewing existing literature on production costs (e.g., extension crop budgets,

academic studies) and then setting the lowest price to fall just below the average cost of production. High version prices were based on input from knowledgeable professionals in the field, at prices slightly greater than what a bioenergy facility would be able to pay and still breakeven relative to sourcing from other fuels (e.g., coal or petroleum). Upon agreeing to enroll, respondents also indicated how many acres they would convert to the new technology and the location where it would be planted. The location options given were: (i) land currently in a short-term grain rotation, (ii) land currently in a long-term forage rotation, (iii) land currently in a CRP contract, (iv) land that is newly rented-in (i.e., expand cropland operated without replacing a current activity), (v) land currently in permanent pasture, and (vi) land that is cultivable but not currently farmed (i.e., unfarmed open space). The acreage and location questions helped ensure that responses were consistent with existing land constraints and are hypothesized to minimize incentive compatibility issues associated with the DB-DC format (Haab and McConnell, 2003).

Finally, the CV module provided a basic introduction, background on the market program (e.g., enrollment, compensation), and a description of each crop. The crop description included agronomic information (e.g., yields, management practices), a description of expected environmental outcomes, and a photograph. This allowed the farmer respondents to form an expectation of the profitability and associated environmental benefits/costs for each biofuels crop technology, to use when weighing each option against their portfolio of current land uses. To provide a reference point for the opportunity cost of land, respondents were asked to make their allocation decisions based on a corn grain price of $5.20 per bushel.

5.3 Questions to Proxy Pro-Social Behavior

Here we proxy for farmers' expected pro-social behavior in the empirical analysis that follows using two distinct but similarly constructed sets of index variables. The first set of indices seeks to capture respondents' beliefs about the social or 'public' benefits of alternative energy development. Variable construction is based on whether respondents agreed to the following statements: "*Meeting our renewable energy goals is key to rural economic growth*," "*Meeting our renewable energy goals is key to slowing climate change*," and "*Meeting our renewable fuel standards is key to reducing our dependence on foreign energy sources*."

The second set of index variables gauges respondent's environmental preferences. In particular, they serve to identify farmers who behave according to land stewardship principals. Here, we follow the notion developed by Chouinard et al. that a stewardship farmer is willing to trade profits for improvements to environmental quality. The statements used are: "*I would accept increased uncertainty in net return if local wildlife populations increase*," "*I would accept increased uncertainty in net returns if soil quality on my farm increased*," and "*I would accept increased uncertainty in net returns if water quality improves in nearby lakes or streams*."

For both sets, we construct individual indices for each statement that take on a value of one if the respondent agreed with the statement and zero, otherwise. In addition, we construct an aggregate index equal to the sum of the individual indices. Thus, these aggregate indices may range in value from zero to three.

6. Empirical Strategy

One empirical challenge to implementing the model arises because the implicit costs imposed by the dynamic factors at play in farmers' technology adoption decisions may more than offset the

utility gains from engaging in pro-social behavior as illustrated in the static framework above. To overcome this challenge, we employ a CV approach that estimates farmers' individual valuation of bioenergy crop technologies as a function of these factors in addition to pro-social behavior.

6.1 Proxy Variables for Expected Pro-Social Behavior

Before describing the CV model and estimation approach, we first explore our proxy measures for expected pro-social behavior to demonstrate their 'independence' from the other observed variables. Table 2 provides sample means for the proxy variables. Overall, respondents agreed with the statements about the social benefits of alternative energy development than the statements regarding environmental preferences. Notably, over two thirds of respondents agreed with the statements that alternative energy development is important for rural economic growth and energy security. In contrast, only half though it was important for slowing climate change. For the environmental preferences, only one-third of respondents indicated a willingness to trade economic returns for soil and water quality. The exception here is wildlife habitat where just under half of respondents agreed. To explore these proxy variables further, we specified probit and poisson regression models for the individual and aggregate indexes, respectively. The results are shown in Table 3. The main observation from this table is that only two variables (education and livestock ownership) are found to be significant, and even here only for environmental preferences. This suggests that expected pro-social behavior is explained largely by unobserved factors and thus 'independent' from other observed variables.

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6.2 Reservation price estimation

Data from the contingent valuation survey module allow for direct estimation of landowners' *ex ante* WTA. The specific elicitation question format employed in the module followed the double-bounded dichotomous choice (DB-DC) format described by Hanemann, Loomis and Kanninen (1991). This approach treats farmers' WTA as a random variable and uses maximum likelihood estimation to obtain the mean and variance as a function of explanatory variables. An advantage of this approach is that the regression coefficients are directly interpreted as marginal effects on landowners' reservation prices.

The DB-DC approach allows the analyst to recover the mean and variance of farmers' reservation price, or distribution of *WTA* values. It is obtained by mapping individuals' responses to the dichotomous choice survey questions into a probability density function. Let $F(B^j; \theta)$ be some statistical distribution function with parameter vector θ and let p denote the associated probability. Then, for a given biomass offer price j, utility maximization implies,

$$Pr\{no \text{ to } B^j\} \Longleftrightarrow Pr\{WTA > B^j\} \Longleftrightarrow p^n(B) = 1 - F(B^j; \theta)$$

$$Pr\{yes \text{ to } B^j\} \Longleftrightarrow Pr\{WTA \leq B^j\} \Longleftrightarrow p^y(B^j) = F(B^j; \theta)$$

Extending this logic to the case of a two-question response sequence as follows and letting $j = \{L, 0, H\}$ as described above, the probability of a *yes-yes* response is then given as,

$$p^{yy} = Pr\{WTA \leq B^0 \text{ and } WTA \leq B^L\}$$

Applying the definition of conditional probability gives,

$$p^{yy} = Pr\{WTA \leq B^0 | WTA \leq B^L\}Pr\{WTA \leq B^L\}$$

Next, note that $Pr\{WTA \leq B^0 | WTA \leq B^L\} = 1$ because $B^L < B^0$, which leads to the simplified expression,

$$p^{yy} = Pr\{WTA \leq B^L\} = F(B^L; \theta)$$

Furthermore, we assume for this analysis that farmers' WTA follows a lognormal distribution. This appears reasonable in that it is bounded at zero and allows for a varying proportion of density in the upper tail. In addition, this distribution is attractive from an analytical perspective because the mean and variance are sufficient to recover the probability density function. Letting $b^j = \ln(B^j)$ and $\theta = \{\mu, \sigma\}$, and imposing the assumption and standardizing, we get,

$$p^{yy} = \Phi\left(\frac{b^L - E[WTA]}{\sigma[WTA]}\right)$$

Finally, assuming a constant variance and conditional mean $E[WTA|\boldsymbol{x}] = \beta'\boldsymbol{x}$, the expression may be simplified to,

$$p^{yy} = \Phi\left(\frac{b^L - \beta'\boldsymbol{x}}{\sigma}\right).$$

Following the same arguments, the probability of a *no-no* response sequence is given by,

$$p^{nn} = Pr\{P^R \geq B^0 \text{ and } P^R \geq B^H\}$$

$$= Pr\{P^R \geq B^0 | P^R \geq B^H\} Pr\{P^R \geq B^H\}$$

$$= Pr\{P^R \geq B^H\} = 1 - \Phi\left(\frac{b^H - \beta'\boldsymbol{x}}{\sigma}\right).$$

In the case of a *yes-no* response, we have the interval,

$$p^{yn} = Pr\{B^L \leq WTA \leq B^0\} = F(B^0; \theta) - F(B^L; \theta) = \Phi\left(\frac{b^0 - \beta'\boldsymbol{x}}{\sigma}\right) - \Phi\left(\frac{b^L - \beta'\boldsymbol{x}}{\sigma}\right).$$

Similarly, for a *no-yes* response,

$$p^{ny} = Pr\{B^0 \leq WTA \leq B^H\} = F(B^H; \theta) - F(B^0; \theta) = \Phi\left(\frac{b^H - \beta'\boldsymbol{x}}{\sigma}\right) - \Phi\left(\frac{b^0 - \beta'\boldsymbol{x}}{\sigma}\right).$$

Next, considering N respondents in the survey sample, the log-likelihood to estimate the mean and variance of the probability density function is,

$$\ln L(\theta) = \sum_{i=1}^{N} \{d_i^{yy} \ln p^{yy}(b_i^0, b_i^L) + d_i^{nn} \ln p^{nn}(b_i^0, b_i^H)$$

$$+ d_i^{yn} \ln p^{yn}(b_i^0, b_i^L) + d_i^{ny} \ln p^{ny}(b_i^0, b_i^L)\}$$

where d_i^{yy}, d_i^{nn}, d_i^{yn}, d_i^{ny} are binary indicator variables equal to one if the respective response

sequence holds and zero otherwise. An advantage of this specification is that the model allows

for the mean *WTA* to be estimated as a linear function of the explanatory variables,

(1) $$WTA = \beta' \boldsymbol{x} + e$$

where β is the parameter vector to be estimated and e is a normally distributed error term. The

estimated coefficients β in this model are interpreted directly as the marginal effect of the

explanatory factor on the farm's *WTA* in dollar terms. This contrasts with a regular probit

assessment, which yields parameter estimates only up to a factor of proportionality (Haab and

McConnell, 2002).

6.3 Variables

For the CV estimation, Table 4 reports the specific explanatory variables that are used in

unrestricted and restricted versions of the WTA model. The restricted version relies on a smaller

and more parsimonious set of explanatory variables. The key sets of variables are the bioenergy

attitudes and environmental preference questions to proxy for expected pro-social behavior. The

unrestricted model includes a separate variable for each individual attitude and preference

statement. The restricted model uses the aggregate index values representing the total number of

statements with which the respondent agreed.

Other explanatory variables include those hypothesized in the technology adoption

literature to constrain spatial and temporal diffusion. Smaller farms and farms with less land area

devoted to agricultural production are expected to have less flexibility in terms of land use.

Livestock may similarly constrain bioenergy crop adoption because these farms typically have a

high degree of integration among the crop and animal enterprises. In addition, they may

represent a source of large investments (particularly for dairies) and thus constrain transitions to other enterprises in the short-run. Previous experience growing a crop similar to the candidate bioenergy crop and/or a high degree of integration within the farming operation is likewise expected to be a factor excluding some farms from adopting biofuels in the short run. Finally, age and a lack of current awareness about biofuels is expected to limit the consideration given to biofuels.

7. Preliminary Results

Maximum likelihood results for the willingness-to-accept reservation price estimation are presented in Table 5. For corn stover, the full model has one or more variables that are statistically significant in each conceptual category of the estimation, except animal operations. Farm size has a negative effect on WTA, indicating that larger farm operations have a lower reservation price for participation. Age is found to increase WTA but education is found to lower it, both of which are consistent with many other technology adoption estimations. In addition, farms with poor soils and sloped farmland are found to have a lower WTA, or, that is, demand a lower price to adopt. One possible explanation for this finding is that corn production on low quality soils is less productive, and earning the additional revenue for stover may be appealing to those farmers. However, this result also suggests that markets for stover could adversely impact the on-farm environment if more stover is removed from these environmentally-sensitive parcels.

In relation to the main hypothesis of the paper, both environmental tastes and political attitudes are found to significantly influence landowners' WTA for corn stover. In particular, a preference for better water quality outcomes is found to lower WTA and a similar one for wildlife is found to increase WTA. The former is somewhat counter intuitive, because corn

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stover removal potentially increases the amount of soil and other runoff that filters into local waterways. Perhaps it is explained by the idea that biomass production might be viewed as better for the overall environment, and the water quality question reflects a broader preference for environmental outcomes. By comparison, the positive coefficient on wildlife habitat is not surprising because landowners may view stover as complementary to wildlife if it provides feed to wildlife or pockets of shelter to hide from prey for wildlife during the winter months. In terms of the political attitudes, positive views of government support for bioenergy and the sector's likely effect on rural economic development prospects also lowered farmers' WTA. Combined, these two sets of results suggest that to the extent that environmental and political attitudes might be socially and spatially concentrated, biomass adoption might be targeted effectively based on finding 'hot spots' of support from farmers and landowners in certain regions of the state.

Next examining the full switchgrass model, some notable differences arise relative to the corn stover model. First, farm size and cropland area are significant in explaining WTA. All else equal, larger farms have a lower WTA but those with a greater emphasis on crop production have a higher WTA. This contrast with corn stover is understandable, as a larger farm size may indicate greater availability land for experimentation with a new crop whereas an increased concentration in crop activity may indicate less land for a perennial crop such as switchgrass. The number of livestock is found to be positive and significant, indicating a potential conflict between the on-farm use of agricultural outputs and the possible production of bioenergy crops for cash sales. Combined, these two sets of results on agricultural land and livestock operations both cut severely against the prospects for switchgrass in these regions, which are dominated by dairy and cattle operations that have a strong emphasis on both crop and forage production for feed. While corn stover can potentially be complementary in some respects to these farms

because it does not require a direct substitution away from feed production, switchgrass does almost regardless unless it were to be encouraged as a substitute for conservation land uses, such as CRP and other non-ag lands.

For the switchgrass WTA estimations using the 'full model', environmental and political attitudes are generally of the same sign as in the corn stover WTA estimations. However, they are considerably smaller and only in one case, a positive view of government policy to support bioenergy, is the coefficient estimate statistically significant. In the reduced form model that uses aggregated indices, both positive preferences for environmental stewardship and policies supporting the bioenergy sector are strongly and statistically correlated with a decreased WTA. Thus, again, there is evidence to suggest that biomass production strategies might be more effective if they can be targeted toward hot spots of support for cultivation. Farmers' willingness to adopt varies significantly based on these types of environmental and social-stewardship values. Whether they are sufficient to overcome some of the structural barriers associated with other farm enterprise choices and farmer characteristics is a topic worthy of deeper exploration.

8. Concluding Remarks

This paper explores the farm landowner's decision to adopt a 'clean' production technology. In particular, it develops a theoretical model of the landowner's reservation price for converting a parcel of land from its current use to the clean technology. Clean technologies are distinct in that they protect against the degradation of the farmer's surrounding natural environment as compared to a conventional or dirty technology. In this sense, clean technology may be viewed as an impure public good because of its ability to generate profit and enhance natural amenities. The empirical application is to estimating farmers' WTA (i.e., reservation price) for corn stover

and switchgrass adoption in southwestern Wisconsin. An ex ante approach is utilized here, because no markets for these crops exists. As predicted by the model, landowners expected to engage in pro-social behavior based on positive bioenergy attitudes or preferences for environmental quality have a lower WTA reservation price. Future research should explore to what extent these results might affect predicted diffusion patterns and whether they might inform policy design to improve environmental management on private agricultural lands.

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Table 1. Initial and follow-up biomass purchase price offers

Bioenergy crop (price offer)	Questionnaire Version (biomass offer price, $/ton)		
	Low	Middle	High
Corn Stover			
Initial offer	30	60	90
Low follow-up offer	20	50	80
High follow-up offer	45	75	105
Switchgrass			
Initial offer	45	75	105
Low follow-up offer	30	60	90
High follow-up offer	65	95	125

Table 2. Summary of proxy variables representing farmers' expected pro-social behavior

	All	Corn stover		Switchgrass	
		No	Yes	No	Yes
Number of observations	304				
Social beliefs regarding alternative energy development					
Agree that renewable energy development will reduce our dependence on foreign energy (1=yes,0=no)	0.77	0.74	0.89	0.71	0.87
Agree that renewable energy development promotes rural economic growth (1=yes,0=no)	0.64	0.57	0.91	0.54	0.83
Agree that renewable energy development will help slow climate change (1=yes,0=no)	0.49	0.45	0.64	0.40	0.67
Aggregate beliefs index (integer from 0 to 3)					
Environmental/land stewardship attitudes					
Willing to trade economic returns for improved soil quality (1=yes,0=no)	0.35	0.31	0.54	0.26	0.53
Willing to trade economic returns for improved wildlife habitat (1=yes,0=no)	0.49	0.44	0.67	0.36	0.73
Willing to trade economic returns for improved water quality (1=yes,0=no)	0.31	0.27	0.47	0.25	0.42
Aggregate stewardship index (integer from 0 to 3)					

Table 3. Probit and poisson regression results for variables that proxy expected pro-social behavior

	Environmental tastes				Perceived social benefits			
	Probit			Poisson	Probit			Poisson
	SOIL	WILD-LIFE	WATER	ENV INDEX	ECON-OMY	CLIM-ATE	SECUR-ITY	ATT INDEX
Age of household head (years)	0.000	-0.003	-0.001	-0.001	-0.004	-0.005	-0.009	-0.003
	(0.02)	(0.42)	(0.10)	(0.24)	(0.53)	(0.71)	(1.00)	(0.74)
Education of household head (years)	0.151	0.067	0.119	0.080	0.003	0.052	0.027	0.014
	(4.34)**	(2.07)*	(3.64)**	(4.18)**	(0.11)	(1.63)	(0.76)	(0.83)
Off-farm employment (hours/week)	0.004	0.006	0.002	0.003	-0.001	0.004	-0.002	0.000
	(0.98)	(1.31)	(0.41)	(1.11)	(0.14)	(0.92)	(0.34)	(0.18)
Income (categorical, 1 to 6)	0.544	0.283	0.492	0.383	-0.122	0.159	1.104	0.168
	(0.73)	(0.37)	(0.67)	(0.77)	(0.17)	(0.22)	(1.31)	(0.41)
CRP (1=enrolled, 0=otherwise)	0.108	0.319	0.098	0.146	0.095	0.332	0.104	0.098
	(0.51)	(1.49)	(0.47)	(1.09)	(0.45)	(1.60)	(0.44)	(0.85)
Years farm held in family (years)	-0.009	0.003	0.007	0.000	-0.008	0.001	-0.011	-0.004
	(0.41)	(0.14)	(0.31)	(0.01)	(0.39)	(0.06)	(0.50)	(0.31)
Grows forage (1=yes, 0=no)	0.046	0.167	0.027	0.038	0.018	0.279	0.198	0.085
	(0.19)	(0.70)	(0.11)	(0.26)	(0.08)	(1.20)	(0.77)	(0.65)
Grows corn (1=yes, 0=no)	0.367	-0.276	0.105	0.041	0.179	-0.237	-0.110	-0.023
	(1.80)	(1.35)	(0.52)	(0.31)	(0.90)	(1.19)	(0.48)	(0.21)
Has livestock (1=yes, 0=no)	-0.522	-0.625	-0.556	-0.415	-0.244	-0.456	-0.263	-0.169
	(2.28)*	(2.84)**	(2.50)*	(3.11)**	(1.10)	(2.09)*	(1.06)	(1.44)
Constant	-2.704	-1.576	-2.631	-1.385	1.221	-0.663	-0.606	0.512
	(1.26)	(0.72)	(1.25)	(0.98)	(0.58)	(0.32)	(0.25)	(0.44)
Observations	253	253	253	253	253	253	253	253

Absolute value of z statistics in parentheses

* significant at 5%; ** significant at 1%

Table 4. Explanatory variables in the CV willingness-to-accept model

Category (Variable)	Description	Full model	Reduced model
Land resources			
TOTAL_AREA	Farm size (acres)	x	x
CROPLAND	Cropland operated (acres)	x	x
PASTURE	Pasture operated (acres)	x	x
Land with marginal physical land characteristics			
POORSOIL	Cropland with marginal soils (acres)	x	
SLOPE	Cropland with slope >6% (acres)	x	
MARGINAL	Index of marg. cropland area (MARG + SLOPE)		x
Livestock operations			
DAIRY	Number of dairy cows raised on farm (head)	x	
BEEF	Number of beef cows raised on farm (head)	x	
LIVESTOCK	Livestock index (DAIRY + BEEF) (head)		x
Sociodemographic characteristics			
AGE	Age of household head (years)	x	x
EDUC	Education of household head (coded)	x	x
Environmental tastes			
SOIL	Taste for soil quality (1=yes; 0=no)	x	
WATER	Taste for water quality (1=yes; 0=no)	x	
WILDLIFE	Taste for wildlife habitat (1=yes; 0=no)	x	
ENV_INDEX	Environmental index (sum of tastes [1 to 3])		x
Political attitudes			
GOVERNMENT	Believes government should do more to promote bioenergy (1=yes; 0=no)	x	
ECONOMY	Believes biofuels will promote rural economic growth (1=yes; 0=no)	x	
CLIMATE	Believes biofuels will help slow climate change (1=yes; 0=no)	x	
ENERGYINDP	Believes biofuels will help national energy independence (1=yes; 0=no)	x	
ATT_INDEX	Attitude index (sum of attitudes [1 to 4])		x

Table 5. Maximum likelihood estimates for willingness-to-grow corn stover and switchgrass for bioenergy

| Variable	Corn stover						Switchgrass					
	Full model			Reduced model			Full model			Reduced model		
	Coef.	p-value		Coef.	p-value		Coef.	p-value		Coef.	p-value	
Land resources												
FARM_SIZE	-0.074	(0.06)	**	0	(0.99)		-0.054	(0.04)	**	-0.043	(0.15)	
CROPLAND	0.069	(0.23)		-0.008	(0.81)		0.095	(0.03)	**	0.064	(0.08)	*
PASTURE	0.109	(0.35)		-0.01	(0.89)		-0.016	(0.82)		-0.021	(0.76)	
Biophysical land attributes												
POORSOIL	-0.169	(0.02)	**				-0.074	(0.33)				
SLOPED	-0.120	(0.06)	**				-0.022	(0.22)				
MARGINAL				-0.215	(0.02)	**				-0.106	(0.12)	
Animal operations												
DAIRY	0.118	(0.26)					0.090	(0.34)				
BEEF	0.200	(0.33)					0.326	(0.09)	*			
LIVESTOCK				0.047	(0.47)					0.234	(0.02)	**
Sociodemographic factors												
AGE	1.087	(0.02)	**	0.403	(0.24)		0.887	(0.05)	**	0.868	(0.03)	**
EDUC	-7.160	(0.04)	**	-4.732	(0.16)		-7.691	(0.02)	**	-9.311	(0.01)	***
Environmental tastes												
SOIL	11.83	(0.46)					0.68	(0.96)				
WATER	-51.74	(0.01)	***				9.62	(0.52)				
WILDLIFE	30.46	(0.02)	**				-9.59	(0.39)				
ENV_INDEX				-9.415	(0.01)	***				-6.173	(0.06)	*
Political attitudes												
GOVERNMENT	-32.51	(0.03)	**				-23.87	(0.08)	*			
ECONOMY	-40.95	(0.00)	***				-17.62	(0.16)				
CLIMATE	5.77	(0.59)					-15.39	(0.16)				
ENERGYINDP	16.56	(0.29)					21.77	(0.14)				
POL_INDEX				-1.991	(0.52)					-5.59	(0.05)	**
Other												
CONSTANT	115.4	(0.00)	***	112.7	(0.00)	***	109.0	(0.00)	***	136.5	(0.00)	***
SIGMA	24.3	(0.00)	***	29.5	(0.00)	***	37.8	(0.00)	***	46.2	(0.00)	***
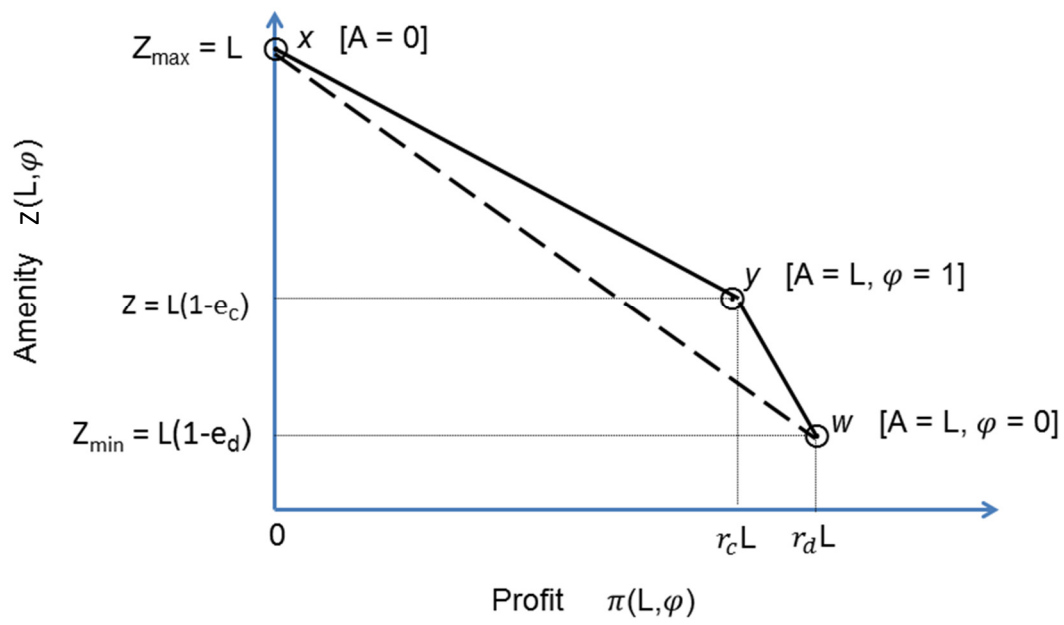
Figure 1. The farmer's constraint set in (Z, π) characteristic space.