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PRODUCER PARTICIPATION IN BIOMASS MARKETS: FARM FACTORS, MARKET FACTORS, AND CORRELATED CHOICES

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Abstract. This study evaluates attitudes toward production of three major types of biomass—corncobs, corn stover, and dedicated energy grass—using responses to a mail survey of 2,250 Iowa farmers. We examine how factors influencing willingness to supply biomass vary across biomass types and analyze the presence of potential correlations across interest in growing various types of biomass. We find that correlation in choices across biomass types is strong and statistically significant. Farmers consider corn stover and corncobs as complementary, but dedicated energy grasses and corncobs or stover as substitutes. Factors affecting farmer choices also vary significantly by type of biomass.

Keywords. biomass, cellulosic ethanol, corn stover, corncobs, energy grass

JEL Classifications. Q12, Q13, Q15

1. Introduction

Renewable biofuel production is at the forefront of current U.S. agricultural and energy policy due to its promise for attaining energy security and independence, promoting rural economic development, and mitigating anthropogenic climate impacts. Although the renewable biofuel production movement started with

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first-generation biofuels, mainly from corn and sugarcane, attention has shifted to advanced biofuels from nonfood sources over time due to the "food versus fuel" debate as well as the environmental benefits of these biofuels relative to fossil fuel (Zilberman et al., 2013). The Renewable Fuels Standard mandate under the Energy Independence and Security Act of 2007 requires that biofuel production reach 36 billion gallons by 2022, with at least 16 billion gallons coming from cellulosic biomass sources.[1] However, the progress toward fulfilling the mandated target has been very slow and as a result, the U.S. Environmental Protection Agency has reset the 2014 target of 1.75 billion gallons of cellulosic biofuel to a significantly lower level of 14 million gallons. Markets for agricultural biomass are still developing, and as such, much uncertainty remains at all stages of the supply chain. Sustainable production of cellulosic biofuels depends on a continuous, consistent supply of biomass, which relies critically on farmer interest and participation in biomass production.

Recent studies analyzing farmer perceptions and attitudes about biomass have tended to focus on one specific type of biomass crop—for example, corn stover or switchgrass (Altman and Sanders, 2012; Altman et al., 2011; Bergtold, Fewell, and Williams, 2011; Caldas et al., 2014; Jensen et al., 2007; Paulrud and Laitila, 2010; Qualls et al., 2012; Smith et al., 2011; Tyndall, Berg, and Colletti, 2011). However, given seasonality in the availability of biomass and the large volumes of biomass required to operate at an economic scale, many biofuel plants propose to rely on multiple feedstocks (Coyle, 2010). To economize on transportation costs, processors may rely on producers located within a certain radius of their processing facility and, thus, may demand that farmers supply multiple types of biomass. From the grower's perspective, choosing to engage in multiple biomass enterprises may be advantageous as well. A farmer's land may vary significantly in terms of soil quality, land slope and contour, and other factors that determine suitability for conventional crops such as corn and soybeans. The knowledge and perceptions each farmer has may vary by type of biomass as well. Some farmers may be willing to produce different types of biomass, whereas others will prefer to specialize in one specific type. Willingness to grow various biomass types might be simultaneously based on farmer perceptions, farm characteristics, and available information. Unobserved individual characteristics may result in preferences for one combination of biomass types over another; for example, if farmers have strong concerns for the environment, they might prefer the combination of corncobs and energy grasses over the combination of corn stover and energy grasses. This suggests a potential for contemporaneous correlation among individual decisions across biomass types and makes a strong case for applying a modeling technique suitable for correlated choice—for example, a

1 Per the U.S. Environmental Protection Agency (http://www.epa.gov/otaq/fuels/renewablefuels/index.htm).

multivariate probit technique.[2] This study includes a set of biomass crop options and, to our knowledge, is the first to examine potential correlation across choices when analyzing farmers' interest in supplying biomass.

Using responses to a mail survey of Iowa farmers, we examine farmer attitudes toward production of three major types of biomass—corncobs, corn stover, and dedicated energy grass.[3] Corncobs and corn stover are both coproducts of corn production but differ somewhat in terms of agronomic consequences, harvesting process, and other logistics. Energy grasses, many of which are perennial, require very different production practices and may have environmental benefits not characteristic of residue crops like stover and corncobs. The main objectives of this study are (1) to understand the general interest of Iowa farmers in supplying various types of biomass, (2) to determine the most critical elements for producer participation in biomass markets and to explore how these may vary by type of biomass, and (3) to analyze the implications of appropriate modeling techniques in the presence of potential correlations across farmer interest in growing various types of biomass.

This study focuses exclusively on Iowa farmers. Iowa is currently the largest corn ethanol–producing state in the United States and has huge potential for crop residue–based biomass production, but the attitudes and willingness of Iowa farmers to grow biomass remain uncertain. Tyndall, Berg, and Colletti (2011) argue that Iowa alone could produce 1.53 billion gallons of cellulosic ethanol per year if its share of the nation's collectible corn stover could be brought into production. This potential has induced two large biofuel manufacturers to build commercial-scale plants in the state: POET in Emmetsburg, Iowa, and DuPont Cellulosic Energy in Nevada, Iowa. Both of these plants are currently expected to operate at commercial-scale production (20 billion gallons/year or more) starting

2 Gillespie, Davis, and Rahelizatovo (2004) utilized a multivariate probit approach to identify factors affecting adoption of four different breeding technologies for hog production and argued that in the case of simultaneous adoption, the multivariate probit technique increases the efficiency in estimation. For similar reasons, Huffman and Lange (1989) modeled spousal off-farm labor supply decision under a multivariate framework.

3 Corn stover (stalks, leaves, husks, and corncobs), corncobs, and energy grasses were selected as biomass categories for the project due to several factors. DuPont Danisco Cellulosic Ethanol LLC (now DuPont Biofuel Solutions), which constructed a pilot plant in Vonore, Tennessee, in partnership with the University of Tennessee and Genera Energy, was working on its supply chain in central Iowa and intended to use corncobs and switchgrass (an energy grass) as feedstocks (University of Tennessee, 2010). POET's (now POET-DSM Advanced Biofuels) planned facility in Emmetsburg, Iowa, expected to use corncobs (POET, 2009). Corn stover was identified by the Billion Ton Biomass Study as a major biomass feedstock source (Perlack et al., 2005), placing Iowa, the leading U.S. corn producer in acres planted and grain harvested (U.S. Department of Agriculture, National Agricultural Statistics Service, 2010), at the center of corn stover production. Therefore, corn stover, corncobs, and energy grasses were selected as the biomass categories for the producer survey. As the companies developed their supply chains, both the DuPont Biofuel Solutions facility at Nevada, Iowa, and the POET-DSM facility at Emmetsburg determined corn stover would be the primary feedstock for their cellulosic ethanol plants (DuPont Biofuel Solutions, 2014; POET, 2014).

in 2014.[4] A rigorous study of farmer attitudes toward biomass production can provide these processors and future market entrants useful insights for biomass procurement.

The remainder of this article proceeds as follows. The next section reviews recent studies of farmers' biomass adoption. The "Study Methods" section elaborates on the data, the factor analysis procedures followed to condense the data, and econometric methodology adopted for the analysis. The "Results" section reports the estimation results and findings. We conclude with a discussion of the findings and suggestions for future research.

2. Literature on Biomass Adoption

Several recent studies have analyzed factors important for farmers' willingness to grow biomass. These studies focus on either midwestern or southeastern U.S. states because these areas offer the most potential for growing biomass crops. The majority of the studies include only one type of biomass crop. Given that the markets for biomass energy crops are still emerging, the existing research uses survey methods incorporating biomass-specific issues and concerns to elicit farmers' interest in growing biomass crops rather than data on actual adoption of crops. The studies apply different quantitative and qualitative techniques to analyze farmers' perceptions and attitudes toward development of biomass enterprises. Besides identifying various demographic and farm-specific factors affecting farmers' biomass production decisions, these studies have also argued that various agronomic and environmental concerns arising from biomass harvesting (soil quality issues, reduced fertility, soil carbon loss, loss of wildlife habitat, environmental stewardship, etc.), asset specificity, storage and transportation issues, high capital investment requirements, lack of access to finance, and lack of existing markets for biomass are all factors inhibiting the farmers' willingness to adopt commercial biomass production.

2.1. Demographics

Age, experience, and education have been identified as individual characteristics affecting farmers' technology adoption decisions. In addition, demographic factors, if included in technology adoption models, may capture individual-level heterogeneity in preferences and risk attitudes. Older farmers may be less willing to adopt uncertain technologies or invest in long-term enterprises as they would have less time to recoup the benefit. Qualls et al. (2012) found a statistically significant lack of interest among older farmers to adopt switchgrass production

4 DuPont's plant in Nevada, Iowa, is expected to produce 30 million gallons of cellulosic biofuel from corn stover residue annually (http://biofuels.dupont.com/cellulosic-ethanol/). POET's Project Liberty plant opened on September 3, 2014, and plans to ramp up to 25 million gallons per year (http://www.projectliberty.com/).

in several southeastern U.S. states, but note that other recent studies fail to find any significant effect of age on adoption decisions (Altman et al., 2011; Bergtold, Fewell, and Williams, 2011; Jensen et al., 2007; Paulrud and Laitila, 2010; Smith et al., 2011). Education tends to increase agricultural technological adoption among farmers (Abdulai and Huffman, 2005; Foster and Rosenzweig, 1995). If technological innovation is relatively new, more educated farmers adopt it faster because they are better equipped to acquire and process information, as well as to judge risk and profitability associated with an investment in new technology. Education increases labor productivity and improves technical efficiency. Information directly affects individual's technology choice by reducing uncertainty. Though Qualls et al. (2012) did not find any evidence in favor of more highly educated farmers being more interested in switchgrass production in northeastern Tennessee, there is evidence of finding a positive impact of education on agricultural technology adoption (Jensen et al., 2007). Altman et al. (2011) noted a counterintuitive behavior among Illinois corn farmers; college-educated corn farmers with experience in selling biomass were less willing to supply corn stover.

2.2. Farm Characteristics

Income from farm and nonfarm sources have different impacts on farmers' technology adoption choices. Farmers with both on- and off-farm income may be more willing to try a new technology compared with farmers who derive all their income from farming because their off-farm income can offset some risk. Similarly, farmers with higher levels of farm income may have greater capability for diversifying their crop portfolio and may show more interest in trying new technologies than low farm-income farmers. The empirical evidence is mixed. Smith et al. (2011) found positive impacts of farm income on adoption. Qualls et al. (2012) found that southeastern U.S. farmers with moderate farm income were less likely to adopt switchgrass compared with the high and low farm-income group, which they explain by arguing that farmers in the high-income group may have enough resources to risk trying new technologies, and farmers in the low-income group would always try new things to increase profit. Jensen et al. (2007) found significantly negative impacts of farm income per acre on farmers' willingness to grow switchgrass.

Farm size impacts farmers' technology adoption decisions. Paulrud and Laitila (2010) found a positive relationship between farm acreage and adoption, whereas the findings of Altman et al. (2011) were mixed. Farmers in mid-Missouri with more acres were more likely to be interested in supplying wheat straw, whereas farmers with more acres in Illinois expressed less interest in supplying biomass. Jensen et al. (2007) found a negative relationship between farm size and willingness to grow switchgrass among farmers in Tennessee. Smith et al. (2011) found that landowner-farmers who leased a larger numbers of acres were more likely to supply higher amounts of perennial biomass. Having more idle land sometimes induces farmers to try new things: although Paulrud and Laitila (2010) did not find any significant relationship, Qualls et al. (2012) noted that having more idle land influences the number of acres on which one would try biomass production.

Current and future land use plans also play a role in how farmers may allocate their land under different cropping systems. Smith et al. (2011) found that farmers using the land for recreational use were less likely to convert those acres to energy biomass production compared with those who had plans for conventional crop production. Similarly, if current land use is for grasses and hay for feed supply of cattle production, the land is less likely to be used for bio-energy crops in the near future. Qualls et al. (2012) found that farmers with a higher proportion of land in grazing cattle or hay production for cattle were least interested in converting land for biomass. At the same time, they found that individuals' ownership of hay equipment had a positive impact on adoption. Altman et al. (2011) examined the influence of having a large number of hay acres on biomass adoption decisions but did not find any statistically significant relationship.

2.3. Environmental and Agronomic Concerns

Soil quality and land type of the farm enterprise are important factors in the bioenergy crop decision. The use of conservation practices in the current farm operation also determines future land use options. If farmers are currently practicing conservation tillage in farming, it indicates that they have more concern with agronomic and environmental issues, which suggests that this group of farmers is less likely to adopt any kind of new enterprise or technology that requires more intensive use of the land. If the soil quality of the farm land is poor, energy grasses may be a good choice for soil protection because of the associated environmental and agronomic benefits. This is reflected in the findings of Smith et al. (2011): farmers who were interested in growing biomass allocated more poor-quality land to perennial grasses and sloped-land acres to short-term woody biomass.

The literature on biomass technology adoption argues that farmers' environmental stewardship efforts are a key indicator of farmers' environmental concern. One such indicator is the percentage of farm land enrolled in the Conservation Reserve Program (CRP). Altman et al. (2011) and Smith et al. (2011) found that farmers with more CRP acres were less willing to supply residue crops such as corn stover or wheat straw. Qualls et al. (2012) found that farmers who had more land under CRP, were willing to use less fertilizer for environmental reasons, and had a strong preference for attaining energy security were more interested in switchgrass production. Jensen et al. (2007) found that no-till farmers in Tennessee were more willing to supply switchgrass. Farmers practicing no till are concerned about soil erosion, and switchgrass is believed to have soil-preserving qualities.

2.4. Market Uncertainty

Currently, there exists only a thin market for some crop-based biomasses. Market-determined prices are not readily available to help farmers make decisions about adoption. The lack of markets is considered to be one of the key barriers to farmer adoption of biomass production. However, Qualls et al. (2012) showed that farmers with greater concern for underdeveloped markets expressed more interest in switchgrass production. This may be because only farmers interested in biomass production are concerned about market conditions.

There are several barriers and concerns surrounding biomass supply chain components as well as sustainability of the venture. Because energy crops are a relatively new enterprise compared with conventional crops, the equipment and capital expenditure requirements are still uncertain. If farmers have some experience or familiarity with something similar to cellulosic biomass, they express more interest in willingness to adopt biomass production. In southeastern U.S. states, Qualls et al. (2012) found that farmers owning hay equipment were more interested in adopting switchgrass production. The equipment used in hay production and switchgrass production is similar. Due to various kinds of risks involved in the business, loans or credit from the financial system may not be available in the early stages. Smith et al. (2011) showed that the stronger farmers' perceptions of lack of access to equipment and loss of loan eligibility were, the lower was their willingness to supply. Paulrud and Laitila (2010) showed that Swedish farmers were concerned about the risks associated with energy-crop farming in the absence of insurance, and they argue that government incentive payments can reduce this risk to some extent by playing an insurance-like role.

2.5. Knowledge about Biomass Production and Previous Experience

Lack of knowledge is likely to have a negative impact on farmers' willingness to adopt new technology and innovation. Previous experience in biomass production augments individuals' knowledge and information and may increase interest in providing biomass in the future. Among the surveyed farmers in Illinois, Altman et al. (2011) found a positive relationship between experience in selling wheat straw and willingness to supply in the future; however, the opposite relationship was found for corn stover. Qualls et al. (2012) and Smith et al. (2011) found no relationship between previous exposure to biomass growing and trading and future interest in supplying biomass.

2.6. Contractual Issues

In the absence of established markets and risk management mechanisms for energy crop–type biomass, it is likely that farmers will supply cellulosic biofuel feedstocks only if a contract is offered by processors to supply the feedstock (Rajagopal et al., 2007). Profit-maximizing producers will accept such a contract if the payoff from the enterprise is greater than any other possible land use. Contractual arrangements will be affected by many factors, such as contract pricing, time frame, acreage commitments, risk, timing of harvest, yield variability, feedstock quality, harvest responsibilities (e.g., custom harvesting), nutrient replacement, location of biorefineries, available cropping choices, technology, and conservation considerations (Epplin et al., 2007). Landowners willing to supply more acreage for perennial crops in Smith et al. (2011) preferred long-term financial agreements if planting, maintenance, and harvesting were offered by the contract service provider. Similarly, in Bergtold, Fewell, and Williams (2011), farmers expressed greater interest in biomass production contracts if harvest and storage options were included.

3. Study Methods

3.1. Conceptual Framework and Empirical Specification

Following the literature on the adoption of agricultural technology and practices, we model a farmer's decision to adopt biomass production in a random utility framework. Assume the producer can choose between two alternatives: produce biomass type j or do not produce biomass. If producer i chooses to supply biomass type j, the producer's expected profit is

$$\pi_{ij}^{B} = E\left(P_{ij}^{B} \times Y_{ij}^{B}\right) - \mathrm{E}\left[\sum_{k=1.}^{N} \left(w_{ijk}^{B}\right) \times X_{ijk}^{B}\right] - f_{ij}^{B}, \quad (1)$$

which is a function of biomass output per acre Y_{ij}^{B}, biomass selling price P_{ij}^{B}, and the costs of producing the biomass crop, which includes a fixed cost f_{ij}^{B} that is assumed not to vary across biomass types (e.g., land rent) and variable costs $\sum_{k=1.}^{N}\left(w_{ijk}^{B}\right) \times X_{ijk}^{B}$, where w_{ijN}^{B} indicates prices and X_{ijN}^{B} indicates quantities of N variable inputs required for biomass production. If the producer does not produce biomass, then the expected profit is π_{i0}^{NB}, which is presumed to derive from the next best use of the land. This might be growing an alternative nonbiomass crop, keeping the land in pasture, or enrolling the land in the CRP.

The profit-maximizing farmer will adopt a biomass enterprise if[5]

$$\pi_{ij}^{B}\left(P_{ij}^{B}, \boldsymbol{w}_{ij}^{B}\right) > \pi_{i0}^{NB}\left(P_{i0}^{NB}, \boldsymbol{w}_{i0}^{NB}\right) \quad (2)$$

or

$$E\left(P_{ij}^{B} \times Y_{ij}^{B} - P_{i0}^{NB} \times Y_{i0}^{NB}\right) > E\left\{\left[\sum_{k=1,2\ldots}^{N}\left(w_{ijk}^{B}\right) \times X_{ijk}^{B}\right] - \left[\sum_{k=1,2\ldots}^{M}\left(w_{i0k}^{NB}\right) \times X_{i0k}^{NB}\right]\right\}. \quad (3)$$

5 The vector $\boldsymbol{w}$ is an input vector with N possible arguments for inputs in biomass production and M possible arguments for the case of no biomass production.

Equation (3) implies that if the expected revenue differential between biomass adoption and nonadoption is high enough to cover the expected additional cost of the biomass enterprise, farmers would adopt biomass. The profit-maximizing framework is limited, however, for analyzing adoption of biomass production because of the potential environmental benefits of biomass crops that may be nonpecuniary in nature. Producers may care about multiple objectives in making adoption decisions, not only profit maximization but also environmental protection (e.g., Gedikoglu and McCann, 2012). This broader view of the adoption decision is better captured in a random utility framework (Greene, 2008; Train, 2003). An individual producer's utility is specified as a linear function of the attributes of the choice of biomass types, including expected profit and any perceived environmental benefits associated with producing the biomass crop, as well as individual and farm characteristics and a stochastic component.

Let V_{ij} denotes farmer i's utility from adopting production of biomass type "j," and V_{i0} be utility from nonadoption. Let X_{ij} be a vector of biomass j's attributes including expected profit, Z_i be a vector of individual and farm characteristics that affect the biomass adoption decision, and $\in_{ij}$ be the vector of unobservable factors. Producer i's utility when biomass type j is adopted is linearly approximated as $V_{ij} = f\left(X_{ij}, Z_i\right) + \in_{ij}$. If the producer does not adopt biomass, utility is $V_{i0} = f\left(X_{i0}, Z_i\right) + \in_{i0}$. A producer will choose to adopt production of a particular biomass type if the utility from that alternative is greater than or equal to the utility from any other alternatives in the choice set, including the option to not produce any biomass crop. Thus, producer i will adopt the biomass type j if $V_{ij} > V_{i0}$. The probability of adoption is stated as follows:

$$\begin{aligned} Pr(B_{ij} = 1|X_{ij}, Z_i) &= \Pr[f(X_{ij}, Z_i) + \in_{ij} > f(X_{i0}, Z_i) + \in_{i0}] \\ &= Pr[f(X_{ij}, Z_i) - f(X_{i0}, Z_i) > (\in_{i0} - \in_{ij})]. \end{aligned} \tag{4}$$

Because we only observe the farmer's willingness to adopt a particular biomass type, we have the following latent structure for adoption of each biomass type:

$$B^*_{ij} = X'_{ij}\beta_j + Z_i\gamma + \in_{ij}, i = 1, 2, \ldots, n; j = 1, 2, 3 \tag{5}$$

$$B_{ij} = \begin{cases} 1, B^*_{ij} > 0 \\ 0, B^*_{ij} < 0 \end{cases},$$

where the dependent variable B_{ij} assumes a value of either 1 in the case of the farmer's willingness to adopt or 0 for reluctance to adopt. The binary dependent variable for the general adoption decision, where we do not distinguish across biomass types "j," is the following:

$$B_i = \begin{cases} 1, \textit{ if a farmer is willing to produce/sell biomass for biofuel production} \\ 0, \textit{ otherwise.} \end{cases}$$

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We first estimate equation (5) utilizing a simple probit model, where B_i assumes binary responses, to examine the essential factors differentiating biomass adopters from nonadopters. This simple probit model does not differentiate farmers' attitudes across biomass type "j." The density for $(B_i|X_i, Z_i)$ is

$$F\left(B_i|X_i, Z_i; \beta, \gamma\right) = \left[\Phi\left(X_i, Z_i; \beta, \gamma\right)\right]^{B_i}\left[1 - \Phi\left(X_i, Z_i; \beta, \gamma\right)\right]^{(1-B_i)}, B_i = 0, 1.$$

The corresponding log likelihood function is

$$\mathcal{L}_N(\beta) = \sum_{i=1}^{N} B_i \log\left[\Phi\left(X_i, Z_i; \beta, \gamma\right)\right] + \left(1 - B_i\right)\log\left[1 - \Phi\left(X_i Z_i; \beta, \gamma\right)\right].$$

Because we consider willingness to adopt three types of biomass, which may be correlated for a given producer, we want to allow for the possibility of correlation across unobservable factors $\in_{ij}$ for each of the j biomass types in a discrete choice modeling framework. Willingness to grow various biomass types might be simultaneously based on farmers' perceptions, farm characteristics, and information. If farmers consider some biomass types to be complements—such as corn stover and corncobs—they might prefer joint adoption, whereas they would trade off among biomass types if they view them as substitutes. For example, if the harvesting equipment and storage procedures for two biomass types are similar, farmers may express willingness to grow both of them simultaneously. If farmers have strong concerns for the environment, they might perceive the combination of corncobs and energy grasses as environmentally complementary and prefer it over the combination of corn stover and energy grasses.[6] The potential for contemporaneous correlation across biomass types suggests that an empirical model allowing for correlated choices is appropriate. In the presence of correlation among unobserved factors across biomass types, the simple probit or logit will produce biased estimates of choice probabilities as well as incorrect standard error for β_j, and inferences based on those for determining critical factors for farmer biomass adoption will lead to inconsistent results (Greene, 2008; Marenya and Barrett, 2007). Multivariate probit modeling techniques are appropriate for correcting such biases generated from correlation across choices (Greene, 2008; Train, 2003) because they allow for possible contemporaneous correlation across elements in choice sets.[7] Other studies have used this technique

6 Recent research states that removal of corncobs neither affects soil sediment loss nor causes major soil nutrient loss (Wienhold and Gilley, 2010). For corn stover, removal of 40%–50% of crop residue is allowable depending on crop rotation, tillage practice, and erodible condition for maintaining soil quality. However, recent studies find that corn stover removal might increase greenhouse gas emission and sediment loading in the nearby watershed (Gramig et al., 2013).

7 Following a reviewer's suggestion, we estimated the model using trivariate ordered probit in two ways: (1) with seven ranked categories, exactly following the reported responses on a Likert scale; and (2) collapsing the Likert scale responses into three categories (1–3 as "not-interested," 4–5 as "moderately interested," and 6–7 as "highly interested"). No matter how many categories we used in the ranked dependent variables, the estimated cutoff points in the trivariate ordered probit model were statistically

for modeling agricultural technology adoption and farmers' perception (e.g., see Fernandez-Cornejo, Hendricks, and Mishra, 2005; Gillespie, Davis, and Rahelizatovo, 2004; Huffman and Lange, 1989; Marenya and Barrett, 2007; Rejesus et al., 2013; Velandia et al., 2009).

We jointly estimate equation (5) for the three different biomass types allowing the errors to be correlated across biomass types. We assume the error terms in equation (5) are jointly standard normally distributed with mean zero and covariance vector ρ:

$$\begin{pmatrix} \in_{i1} \\ \in_{i2} \\ \in_{i3} \end{pmatrix} \sim N\left[\begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}, \begin{pmatrix} 1 & \rho_{12} & \rho_{13} \\ \rho_{21} & 1 & \rho_{23} \\ \rho_{31} & \rho_{32} & 1 \end{pmatrix}\right], \quad (6)$$

where

$$E\left[\in_{ij}\in_{ik}\right] = \begin{cases} \rho_{jk}, \forall j \neq k \\ 1, \forall j = k \end{cases}.$$

The off diagonal elements (ρ_{jk}) in ρ reflect the correlation across choices of biomass types, which is of particular interest to us. A statistically significant ρ_{jk} provides evidence of correlation, either positive or negative, among the choices of biomass types. The joint adoption decision for three different biomass types would involve eight different choice probabilities for each individual.[8] Combining these joint probabilities gives us the log likelihood function for the multivariate model. The likelihood function is estimated by exploiting Stata routines based on Cappellari and Jenkins (2003), which follows the Geweke-Hajivassiliou-Keane simulator approach to numerically compute the multidimensional integral.

insignificant. We interpret the insignificance of cutoff values as an indication that the finer division of our choice variables does not provide additional information. In addition, the basic story of the results remains the same as with the multivariate probit model. As a result, we chose to keep the simpler multivariate probit model. Other studies that have used multivariate ordered probit are Yu and Orazem (2014) and Pandit et al. (2011). Rejesus et al. (2013) argues that the limited used of this model is likely due to the difficulty in the estimation procedure and interpretability of parameters.

8 The joint adoption decision for three different biomass types would involve eight different choice probabilities for each individual: (1)$Pr(B_{i1} = 1, B_{i2} = 0, B_{i3} = 0)$; (2)$Pr(B_{i1} = 1, B_{i2} = 1, B_{i3} = 0)$; (3)$Pr(B_{i1} = 1, B_{i2} = 0, B_{i3} = 1)$; (4)$Pr(B_{i1} = 0, B_{i2} = 0, B_{i3} = 1)$; (5)$Pr(B_{i1} = 0, B_{i2} = 1, B_{i3} = 0)$; (6)$Pr(B_{i1} = 1, B_{i2} = 1, B_{i3} = 1)$; (7) $Pr(B_{i1} = 0, B_{i2} = 1, B_{i3} = 1)$; and (8)$Pr(B_{i1} = 0, B_{i2} = 0, B_{i3} = 0)$. Combining these joint probabilities gives us the following log likelihood equation:

$$L(B_{i1}, B_{i2}, B_{i3}|X_{ij}, \beta_j, \rho) = \sum_{i=1}^{n} \log\left[\Phi_3\left(q_{i1}X'_{i1}\beta_1, q_{i2}X'_{i2}\beta_2, q_{i3}X'_{i3}\beta_3, q_{i1}q_{i2}q_{i3}\rho\right)\right].$$

In the previous equation,Φ_3 is the standard normal cumulative distribution function, and $q_{ij} = 2B_{ij} - 1$, where B_{ij} assumes a value of either 0 or 1.

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3.2. Data

Data for this analysis were gathered by a mail survey sent to 2,250 Iowa producers with 50 or more acres of land in February 2011. The sample was evenly divided among five regions in Iowa: northwest, southwest, north central, south central, and eastern. The survey asked farmers to convey their interest in several biomass production types; farm and farmer characteristics; previous exposure to biofuel markets; general knowledge and perceptions about biomass production and operation; concerns regarding biomass production, harvest, transport, financing of capital expenditures, government policies, and contract issues; and importance of various public and private information sources for advancing biomass production. After exclusion of ineligible farmers and 89 partially completed surveys, a total of 784 completed surveys were returned for a response rate of approximately 35%.[9] The response rate varies across regions, ranging from 21.77% in south-central Iowa to 41.77% in eastern Iowa.[10] Sampling weights were assigned to account for the variation in response rates across regions. Table 1 provides descriptions of key variables used in the analysis.

The choice variables include farmer willingness to adopt corncobs, corn stover, and energy grasses. Farmers expressed their interest in growing these biomass types on a Likert scale of 1 to 7, in which 1 indicates "uninterested" and 7 indicates "very interested." For each biomass type, if a farmer's response lies between 4 (moderate interest) and 7, we considered the farmer interested in growing that biomass; otherwise, we labeled the farmer as uninterested. Drawing on previous studies, the explanatory variables in the model include producer demographics, farm characteristics, and prior exposure to biofuel markets.

In the current context, we do not observe an individual farmer's expected profit from producing a particular biomass. Markets for cellulosic biomass are not developed, and there exists widespread uncertainty surrounding biomass prices. The price of biomass might depend on yield risk (in the cases of dedicated energy grasses) or relevant crop yield risk (in the case of crop-residue biomass), price volatility for crude oil, and opportunity cost of land for alternative use. In a recent study based on simulated data across the United States, Miao and Khanna (2014) found that land rent comprises a significant component of break-even prices of biomass from energy crops. Because land is a key input in biomass production, and land rent varies by quality of land and crop yield, we incorporate county average cash rental rates for land and county average CRP payments as a proxy for biomass prices.

9 In this study, we consider survey respondents ineligible and exclude them from the analysis if (1) the respondent is a farmer, currently owning or managing less than 50 acres of land; (2) the respondent is a landowner but does not make production decisions; (3) the operation is a feedlot only or not a farm; or (4) the respondent is no longer a farmer or landowner.

10 The response rate of this survey is higher compared with some other similar studies. For example, the survey response rate in Caldas et al. (2014) was 25%; in Altman and Sanders (2012), it was 24% in Missouri and 32% in southern Illinois; and in Qualls et al. (2012), it was 19%.

Table 1. List of Dependent Variables for Farm and Farmer Characteristics in the Model

		Mean				
Variable Name	Description of Categories	All	Not Interested	Interested	Relationship with Interest (*P* value)[a,c]	Average Difference (*t* statistic)[b,c]
Dependent Variables						
Interest in corncobs	Yes = 1; no = 0	0.25				
Interest in corn stover	Yes = 1; no = 0	0.25				
Interest in energy grasses	Yes = 1; no = 0	0.21				
Demographics						
Age		62.0	0.64	0.59		5.29***
Education	High school = 0	0.56	0.62	0.47	0.000***	
	Some college = 1	0.22	0.19	0.26		
	College degree = 2	0.22	0.20	0.27		
Farming experience	<30 years = 0	0.27	0.24	0.31	0.054	
	>30 years = 1	0.73	0.77	0.69		
Off-farm income	<50% income from off-farm = 0	0.18	0.60	0.61	0.809	
	>50% income from off-farm = 1	0.82	0.40	0.40		
Prior exposure	Have not sold corn to ethanol plant = 0	0.49	0.56	0.37	0.000***	
	Have sold corn to ethanol plant = 1	0.51	0.44	0.63		
Farm Characteristics						
Farm size	Farm size <2,500 acres = 0	0.96	96.8	93.6	0.037**	
	Farm size >2,500 acres = 1	0.04	3.2	6.4		
% Corn	Percent total farm land in corn	50.3	49.8	51.1		– 1.33
% CRP/pasture	Percent total farm land in CRP/pasture	8.8	5.4	4.6		2.25*
% HEL	Percent total land highly erodible	36.2	36.8	35.3		1.43
% MinTill	Percent total land in minimum tillage	47.9	48.3	47.2		1.08
Beef cattle	No beef cattle = 0	0.60	59.2	61.5	0.820	
	Beef cattle, <55 head = 1	0.19	19.3	18.0		
	Beef cattle, >55 head = 2	0.21	21.5	20.5		

Table 1. Continued

Variable Name	Description of Categories	Mean: All	Mean: Not Interested	Mean: Interested	Relationship with Interest (P value)[a,c]	Average Difference (t statistic)[b,c]
Factors[d]						
Knowledge	Knowledge of biomass industry	2.71	2.45	3.13		0.482***
Policy sustainability	Concern about government policy, farm programs	4.16	3.93	4.54		0.381***
Contract relationship	Concern about land ownership, lease terms	3.63	3.24	4.23		0.728***
Farm operations	Concern about biomass harvesting	3.50	3.02	4.23		0.955***
Agronomic sustainability	Concern about agronomic impacts of biomass	4.70	4.26	5.36		0.818***
Market uncertainty	Concern about pricing, distance to markets	4.40	3.78	5.34		1.27***

[a] Reports the P value from a χ^2 test to test the relationship between categorical variables.
[b] Reports the t statistic from a difference in means test of the averages between the interested and not interested producers.
[c] Asterisks denote significance at the 10% (*), 5% (**), and 1% (***) levels.
[d] All items included in factors are measured on a Likert scale ranging from 1 to 7.

Because farmers do not have complete information on biomass prices, yield, and agronomic sustainability when choosing biomass, the decision is influenced by many individual- and farm-level characteristics besides expected profitability from the adopted biomass enterprise. Individual features include preferences for environmental conservation, risk attitudes, perceptions toward biomass, and knowledge and information about biomass production, operation, and sustainability of biomass production, as well as relevant government policies. The survey contained approximately 60 questions on issues related to farmers' knowledge, perceptions, concerns, and perceived importance of information sources. Survey respondents expressed their subjective evaluation of knowledge, perceptions, and concerns based on a Likert scale of 1 to 7, in which the left (right) extreme number on the scale shows the lowest (highest) knowledge/concern/importance. To condense the amount of information in these data, we used exploratory factor analysis to guide our groupings of important variables following the method outlined in Martens, Crum, and Poist (2011).[11] Factor analysis was performed on items grouped by two major themes: (1) knowledge and information about biomass production and (2) concerns regarding biomass production and operation. The analysis was implemented using the principal-component factors (PCFs) extraction method, and the resulting number of measures was chosen based on Scree tests of the component eigenvalues. Table 2 reports the items for each factor, eigenvalues and Cronbach's alpha, PCF loadings, and item-to total correlation for each factor and its associated items. The following thresholds were used to determine the final factors: 0.30 was used for the minimum PCF loading of an item; 0.40, for item-to-total correlation; and 0.70, for Cronbach's alpha values. We include more detail about the factor analysis methods in the Appendix.

The main objective of the factor analysis was to condense the bulk of the information from the data for use in the regression model. Based on the factors produced, we created eight multi-item constructs on areas related to knowledge, information perceptions, and concerns regarding various stages of biofuel production and marketing. The multi-item scale was constructed for each of these eight measures by taking the simple average of responses for items loaded in that measure.[12] We use these eight multi-items constructs along with farm and farmers' characteristics as control variables in our multivariate probit model to

11 The factor analysis is conducted on responses that identify a willingness to grow at least one type of biomass in our choice set.

12 This study is exploratory in nature, and all variables were standard (Likert scale). The factor loadings, although significant for the factor analysis, may not be an accurate representation of the difference among factors due to the choice of extraction model and/or rotation method. In this case, we have no evidence to say that weighting based on factor loadings is an improvement over summing the scores, as we did.

Table 2. Measures Extracted from Factor Analysis

Items	Eigenvalues (Cronbach's α)	PCF Loading	Item-to-Total Correlation
Knowledge about Biomass Industry Production and Operation			
Knowledge about corn-based ethanol production in Iowa		0.56	0.44
Knowledge about biomass pricing		0.80	0.71
Knowledge about nutrient value or loss		0.85	0.80
Knowledge about land sustainability issues	4.933	0.83	0.78
Knowledge about cost of removing biomass	(0.91)	0.87	0.81
Knowledge about biomass harvest option		0.87	0.81
Knowledge about alternative biomass crops		0.78	0.69
Importance of Public and Private Information Sources			
Importance of extension programs		0.74	0.42
Importance of companies offering biomass contracts	2.996	0.75	0.55
Importance of crop consultants/marketing companies	(0.76)	0.71	0.54
Importance of government sources such as USDA and FSA		0.64	0.59
Importance of legal counsel		0.55	0.54
Importance of Media Information Sources			
Importance of newspapers or magazines	1.322	0.89	0.68
Importance of television/radio	(0.72)	0.88	0.57
Importance of Internet		0.60	0.41
Concern: Policy Sustainability			
Concern regarding land use changes	1.197	0.83	0.57
Concern regarding farm program compliance issues	(0.76)	0.79	0.69
Concern about changing current crop rotations		0.62	0.54
Concern: Farm Operations			
Single-pass harvest systems		0.73	0.74
Dual-pass harvest systems	1.432	0.81	0.76
Labor availability during harvest	(0.86)	0.75	0.70
Custom biomass harvesters on your land or farm		0.71	0.64
Concern: Agronomic Sustainability			
Percent of biomass removed	8.656	0.76	0.77
Nutrient loss	(0.90)	0.76	0.79
Residue management		0.77	0.79
Soil erosion issues		0.83	0.77
Concern: Contract Relationship			
Landlord concerns or perceptions	1.126	0.78	0.57
Concern regarding previous experiences with contract	(0.75)	0.59	0.47
Land ownership constrains/land lease agreements		0.85	0.73
Concern: Market Uncertainty			
Long-term biomass market viability	1.401	0.82	0.79
Biomass price volatility	(0.89)	0.76	0.84
Distance to markets		0.80	0.76
Concern about contract terms		0.62	0.69

Note: FSA, Farm Service Agency; PCF, principal-component factor; USDA, U.S. Department of Agriculture.

explain farmers' joint adoption of three different types of biomass.[13] The mean values for each measure are reported in Table 1. We include the measures of knowledge about biomass production, concerns regarding biomass production, operation and contract issues, and perceptions about the importance of various information sources in an expanded version of the model.

4. Results

4.1. Willingness to Grow Biomass

Roughly 37% (292 out of 781) of respondent farmers expressed willingness to grow at least one of the three biomass types included in our analysis.[14] We refer to these as "interested farmers." Of these, 64% were willing to grow more than one type of biomass. One-quarter of the interested farmers were willing to grow both corncobs and corn stover, and slightly more, 27%, were willing to grow all three types of biomass. Clearly, the combination of corncobs and corn stover is logical; if you have one, you have the other.

Table 1 compares mean characteristics of the interested and uninterested groups. When compared with those uninterested in supplying biomass, interested farmers are relatively younger, have less experience in farming, and have higher educational attainment. Interested farmers have more experience selling corn to ethanol plants, control more acres, and on average have a smaller proportion of land in CRP or pasture, although the magnitude of this difference is small. Although the relative proportion of on-farm to off-farm income is larger for interested farmers, the difference is not statistically significant between the two groups.

Farmers interested in biomass production rate themselves higher than uninterested farmers on knowledge about biomass production and operation, although all farmers rate their knowledge about a majority of the biomass production and operation issues as being quite low. Interested farmers also place greater importance on all types of information sources for learning about biomass production than noninterested farmers.

Table 3 reports the mean rankings of both information sources and concerns about biomass production just for the subset of interested farmers. Ranking

13 Although we anticipated that different variables would affect the choice of biomass provision differently (e.g., land erodibility), we wanted to include the same set of regressors in the equation for each biomass type because we did not have strong a priori expectations about how the importance of factors would vary in determining producers' willingness to supply biomass across the various types. In this way, we have not excluded potentially relevant variables, and we are treating this as an empirical question.

14 Although we are analyzing only three biomass choices in this study, our survey includes two additional biomass types—legumes and trees. We exclude those from the analysis to focus on more popular choices, both from the perspective of growers and processors. Considering farmers' willingness to grow legumes and trees, we find that 325 farmers show interest in biomass (i.e., the percentage of farmers interested in biomass is approximately 42%).

Table 3. Rankings for Top 10 Concerns and Information Sources for Interested Farmers

	Stover		Grass		Corncobs	
	Rank	Mean Rating	Rank	Mean Rating	Rank	Mean Rating
Concern						
Biomass price volatility	4	5.26	5	5.44	4	5.38
Contract opt-out clauses	8	4.99	9	5.10	8	5.14
Contract terms (specific deliverables)	-	-	10	5.03	9	5.10
Contract terms of storage	9	4.93	-	-	-	-
Delays due to biomass harvest	-	-	-	-	10	5.10
Distance to markets	2	5.52	2	5.65	3	5.57
In-field transport and compaction	7	5.00	8	5.13	7	5.23
Long-term biomass market viability	3	5.44	3	5.58	2	5.57
Nutrient loss	1	5.55	1	5.80	1	5.73
Percent of biomass removed	6	5.13	6	5.35	5	5.36
Residue management	10	4.92	7	5.31	-	-
Soil erosion issues	5	5.19	4	5.58	6	5.33
Information Source						
Extension	1	4.63	1	4.54	1	4.60
Companies offering biomass contracts	2	4.49	2	4.48	4	4.32
Crop consultants/marketing companies	8	4.08	9	3.89	9	3.83
Government sources (e.g., USDA, FSA)	4	4.39	4	4.34	3	4.38
Cooperatives	5	4.34	6	4.28	5	4.16
Legal counsel	10	3.57	10	3.51	10	3.44
Neighbors or friends	6	4.31	5	4.28	6	4.07
Newspapers or magazines	3	4.44	3	4.45	2	4.42
Television/radio	9	3.99	8	3.99	8	3.91
Internet	7	4.10	7	4.02	7	4.03

Note: FSA, Farm Service Agency; USDA, U.S. Department of Agriculture.

different information sources by the mean response value, we observe that interested farmers believe that government extension programs, magazines and newspapers, companies offering biomass contracts, and government sources such as the U.S. Department of Agriculture, Farm Service Agency might play a significant role in disseminating information regarding biomass.

In general, farmers who were willing to grow biomass reveal more concern about things such as biomass harvesting issues, market uncertainty, and potential agronomic impacts of biomass production compared with those who were unwilling to grow biomass. This finding was expected because farmers interested in supplying biomass are more likely to have considered the potential challenges. Table 3 reports the top 10 concerns of interested farmers across three major biomass types. The mean rating for most of these concern items exceeds 5, which indicates that interested farmers have strong concerns about these issues. Although the order of rankings varies some, the major concern items are nearly identical across all three biomass types. In general, the most salient concerns for producers relate to agronomic sustainability and market uncertainty and contracting. Nutrient loss, distance to markets, and long-term biomass market viability are the top three concerns of interested farmers for all biomass types. The next three most important concerns for all types are biomass price volatility, percent of biomass that can be removed, and soil erosion issues. Farm operations, in-field transport, soil compaction, and contract opt-out clauses were also among the top 10 concerns for all types, while residue management is a concern for stover and grasses, and contract terms on specific deliverables ranks highly for grass and corncobs. Farmers interested in corncobs rated delays due to biomass harvest as a top 10 concern. The contract terms for storage are important to those considering supplying stover.

These descriptive data suggest that there are differences between those producers interested in growing biomass and those who are not. We turn now to the econometric analysis of the factors that affect the choice of biomass production. The regression results are presented in two parts. First, we discuss the probit model that evaluates the critical elements for Iowa producers' interest in supplying cellulosic biomass in general; second, we discuss the results obtained from the multivariate framework to identify differential patterns across biomass types. In the regression models, the knowledge, information, and concern covariates were constructed based on the factor analysis. We exclude the concern items from the univariate probit because it is not clear whether concerns drive interest or interest drives concerns. In the multivariate framework, we restrict the sample to only the interested group of producers. In this way, although the direction of the causation is still unclear, we have less concern that sample selection may bias the results.[15]

Table 4 reports the results from a simple probit model to explain farmers' biomass adoption decisions when farmer demographics, farm characteristics, knowledge, and importance of various information sources are included as explanatory variables. The probit marginal effects, calculated as the average of marginal effects of all individuals in the sample, are also reported.[16] Farmers operating larger farms and having experience in selling corn to ethanol plants

15 We used a Heckman selection approach to investigate whether we found any evidence of selection in our data. For the first stage, we estimated a probit regression in which the dependent variable took a value of 1 if the respondent indicated interest in any of the biomass types (4 or above for corncobs, stover, or grass). From this, we computed the inverse Mills ratio, which we included as a regressor in the second stage, which limited the sample to only the interested farmers. We ran the simplest case, which was a binary interest indicator by type. In all three cases, the inverse Mills ratio is insignificant in the second-stage regressions. Therefore, we conclude that there is no evidence of selection in our data and continue to exclude the noninterested producers in the analysis of factors affecting choice of biomass type.

16 For various categorical independent variables in the model, the marginal effect is calculated as the discrete change in predicted probabilities from the base level assuming all other explanatory variables remain unchanged.

Table 4. Probit Estimates of Factors Determining Participation in Biomass

Factors	Coefficient	Marginal Effect
Age	– 0.010	– 0.003
	(0.01)	(0.00)
Education: some college	– 0.099	– 0.029
	(0.16)	(0.05)
Education: college degree	0.174	0.053
	(0.15)	(0.05)
Experience in farming >30 years	0.066	0.020
	(0.17)	(0.05)
>50% of income from farming	– 0.083	– 0.025
	(0.17)	(0.05)
Farm size >2,500 acres	0.591**	0.182**
	(0.30)	(0.09)
Have a farming plan next year	– 0.214	– 0.065
	(0.27)	(0.08)
% Land in corn	– 0.006	– 0.002
	(0.00)	(0.00)
% Land in CRP and pasture	– 0.003	– 0.001
	(0.00)	(0.00)
Number of beef cattle <55	0.039	0.012
	(0.17)	(0.05)
Number of beef cattle >55	– 0.225	– 0.067
	(0.15)	(0.05)
% Land erodible	– 0.001	– 0.000
	(0.00)	(0.00)
% Land in minimum tillage	– 0.003	– 0.001
	(0.00)	(0.00)
Previously sold corn to ethanol plant	0.306**	0.093**
	(0.13)	(0.04)
Knowledge about biomass production and operation	0.108**	0.032***
	(0.05)	(0.02)
Importance of information: public and private	0.259***	0.078***
	(0.06)	(0.02)
Importance of information: media	0.259***	0.078***
	(0.06)	(0.02)
Constant	– 1.225	
	(0.68)	
χ^2	125.88	
P	0.000	
N	575	575

Notes: Asterisks denote significance at the 10% (*), 5% (**), and 1% (***) levels. Standard errors in parentheses.

are more likely to express interest in biomass production. All else being equal, a farmer with more than 2,500 acres is 18% more likely to supply biomass compared with farmers with fewer acres. This is consistent with the findings of Paulrud and Laitila (2010) and Smith et al. (2011). Farmers with experience in supplying a corn ethanol plant are 9% more likely to be interested in biomass production, while greater knowledge about biomass production and operation and perceptions about the importance of various information sources have smaller, positive effects on the likelihood that a farmer will be interested in supplying biomass. Interestingly, none of the other producer or farm characteristics, such as land quality, age, or experience, significantly explain general interest in producing biomass for the producers in our sample. However, lumping together interest in the various types of biomass may mask the effect of some factors important for explaining willingness to supply one type of biomass, but not another.

Table 5 reports the multivariate probit model estimates by biomass type. Table 6 reports the estimates for the correlation structure. The factors that significantly affect interest do vary across biomass types. Land quality on the farms appears to matter for interest in biomass type. Farms with a high percentage of erodible land are less likely to express interest in supplying corn stover. Having a large farm (more than 2,500 acres) increases the probability of interest in corncobs but has no significant effect on interest in grass or stover. This could be due to the added cost from the specialized equipment necessary to harvest only corncobs. For large producers (2,500+ acres), the fixed costs would spread across more acres (full utilization) and the equipment paid for more quickly, thus lowering the risk by the producer. Farms with a smaller percentage of off-farm income are somewhat less likely to express interest in corn stover but are more likely to express an interest in producing energy grasses. This is somewhat counterintuitive, as producers with less off-farm income may have less diversified income sources and, therefore, may be less willing to add something in their farming portfolio that is not yet proven. Although there are some alternative markets for stover (e.g., bedding), the alternatives for grass are more limited. Farmers who have a greater proportion of land in CRP or pasture and who have sold corn to an ethanol plant in the past are less likely to show an interest in growing energy grasses. This is expected because farmers with previous experience in selling corn likely have more of their land allocated in corn or soybeans.[17] In the aggregate model for interest in biomass, previous exposure in selling corn is a positive and significant determinant of biomass adoption by farmers. However, the multivariate framework shows that the interested farmers with such previous experience are less likely to supply energy grasses.

Higher cropland values lower producers' interest in supplying energy grasses, presumably because the opportunity cost of growing grass is high when land is more productive. Higher pastureland values increase interest in stover, and higher average CRP payments increase interest in producing energy grasses. These measures may reflect land productivity.

17 The average percent of land in corn for producers in the sample with experience selling corn to an ethanol plant is 74; for those without experience, selling corn to an ethanol plant is 61%. The *t* statistic for the difference in means test is 6.78.

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Table 5. Multivariate Probit Estimates of Factors Determining Adoption across Biomass Types

Factors	Corncobs	Stover	Grass
Age	0.002	0.000	– 0.028*
	(0.013)	(0.013)	(0.014)
Education: some college	0.154	0.675**	– 0.231
	(0.244)	(0.278)	(0.261)
Education: college degree	0.391	– 0.13	– 0.11
	(0.255)	(0.266)	(0.230)
Experience in farming >30 years	– 0.391	0.198	0.102
	(0.257)	(0.274)	(0.250)
>50% of income from farming	– 0.351	– 0.530*	0.455*
	(0.279)	(0.281)	(0.264)
Farm size >2,500 acres	1.049***	– 0.047	– 0.47
	(0.401)	(0.414)	(0.351)
% Land in corn	0.008	– 0.011	– 0.007
	(0.008)	(0.007)	(0.007)
% Land in CRP and pasture	– 0.009	– 0.016*	0.029***
	(0.009)	(0.010)	(0.010)
Beef cattle <55	– 0.176	0.317	0.328
	(0.289)	(0.297)	(0.280)
Beef cattle >55	0.091	0.184	– 0.147
	(0.253)	(0.266)	(0.254)
% Land highly erodible	– 0.002	– 0.011***	– 0.006*
	(0.003)	(0.003)	(0.003)
% Land in minimum tillage	– 0.003	0.001	– 0.001
	(0.003)	(0.003)	(0.002)
Sold corn to ethanol plant	– 0.029	0.198	– 0.381*
	(0.216)	(0.225)	(0.207)
Rental rate of cropland	– 0.002	– 0.016	– 0.026***
	(0.009)	(0.012)	(0.009)
Rental rate of pasture	0.009	0.023***	0.005
	(0.009)	(0.009)	(0.008)
Average county CRP payment	0.000	0.006	0.003***
	(0.001)	(0.007)	(0.001)
Biomass knowledge	0.149	– 0.156	0.053
	(0.097)	0.088	(0.088)
Public and private information	0.197*	(0.107)	– 0.077
	(0.118)	0.203*	(0.117)
Media information	– 0.006	(0.119)	– 0.068
	(0.095)	0.05	(0.097)
Concern: policy sustainability	0.046	– 0.156	0.060
	(0.101)	(0.104)	(0.102)
Concern: farm operation	0.309***	– 0.117	– 0.062
	(0.100)	(0.109)	(0.106)
Concern: agronomic sustainability	– 0.019	– 0.436***	0.172*
	(0.116)	(.0122)	(0.105)
Concern: market uncertainty	– 0.144	0.367***	0.301***
	(0.116)	(0.130)	(0.116)

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Table 5. Continued

Factors	Corncobs	Stover	Grass
Concern: contract relationship	– 0.102	0.102	– 0.140*
	(0.082)	(0.080)	(0.082)
Constant	– 0.700	2.807*	4.562**
	(1.665)	(1.688)	(1.809)
Number of observations	218		
Log pseudo-likelihood/Wald $\chi^2(75)$	– 1,675.14/218.01		

Notes: Estimates from a multivariate probit model with simulated maximum likelihood (500 draws). Asterisks denote significance at the 10% (*), 5% (**), and 1% (***) levels. Standard errors in parentheses.

Table 6. Correlation Structure across Biomass Crops

Correlation Between	Coefficient
	0.435***
Corncob and stover	(0.119)
	– 0.536***
Corncob and grass	(0.098)
	– 0.427***
Stover and grass	(0.117)

Notes: Likelihood ratio test of $\rho_{21} = \rho_{31} = \rho_{32} = 0$: $\chi^2(3) = 2671.32$; probability $> \chi^2 = 0.000$. Asterisks denote significance at the 10% (*), 5% (**), and 1% (***) levels.

A number of the concern factors are related to interest in supplying biomass, but which concerns appear to matter varies with biomass type. Consistent with Qualls et al. (2012) who found that farmers with greater concern for underdeveloped markets expressed more interest in switchgrass production, our estimates show a positive relationship between higher levels of concern regarding market uncertainty (biomass price volatility, long-term market viability, distance to market, and market terms) and willingness to supply both grass and corn stover. Three of the concerns ranked in the top 10 by interested producers relate to market uncertainty (Table 3). Although not significant, the coefficient for market uncertainty in the corncobs equation is negative. It may be that of the three choices, producers who have strong concerns about market uncertainty are more interested in stover and grass, which have alternative (if limited) marketing outlets.

Consistent with the rankings in Table 3, agronomic sustainability concerns (what percentage of biomass can be removed, nutrient loss due to stover removal, soil erosion, and residue management) are related to interest in stover and grass, but in opposite directions. Producers are less likely to show interest in supplying corn stover but are more likely to express interest in energy grasses if they are more worried about agronomic impacts. Concerns about farm operations (harvest systems and labor availability during harvest) are positively related to interest in supplying corncobs. This may relate to particular concerns about

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harvesting equipment and harvest delays. In Table 3, only those interested in corncobs ranked concerns about farm operations in the top 10.

The multivariate probit model also estimates the correlation structure across biomass types. Not surprisingly, Table 6 shows that interest in supplying corn stover and corncobs is positively correlated; these two types are complements. In contrast, the correlation between corncobs and energy grass, and corn stover and energy grass is negative, suggesting that the set of producers who are interested in supplying corn residue biomass are different from those willing to produce energy grasses. All the correlation estimates are individually and jointly significant.

5. Conclusions and Implications

This study investigates the critical determinants for the willingness of Iowa farmers to supply three biomass types: corncobs, corn stover, and energy grasses. We find that farm size, previous experience supplying corn to ethanol plants, and land quality attributes each influence the likelihood that farmers would supply certain types of cellulosic biomass. These characteristics suggest that suitable groups of farmers could be targeted for different types of biomass adoption. Furthermore, we find that farmer choices among biomass types are significantly correlated; farmers interested in supplying corncobs are more likely to show interest in supplying stover as well, whereas those expressing interest in producing energy grasses are less likely to be interested in supplying corncobs or stover. The implication for processors is that it may be difficult to procure multiple feedstocks from a given group of farmers, and that they will instead need to seek out different sets of potential producers.

Farmers reported a lack of knowledge about biomass production, yet this analysis finds that those who ranked information sources higher were more likely to express interest in growing biomass. In particular, farmers interested in all three types of biomass rated extension programs as the most valuable source of information, highlighting both the need for information dissemination programs and the role of educational institutions in this regard.

In addition, factors determining farmer biomass choice vary across biomass types. Farmers with greater concerns about agronomic sustainability are less interested in supplying corn stover but are more willing to consider energy grasses. Addressing concerns about market uncertainty related to pricing, market access, and contracting issues also appears to be critical to foster producer participation in biomass markets. For corncobs, harvesting issues were a primary concern for interested farmers, and market uncertainty was the only concern item found to be statistically significant for energy grass producers.

This study also suggests a number of areas for fruitful future research. Of particular interest for market development is a better understanding of the quantity (number of acres) that producers are willing to devote to cellulosic biomass production and the market prices that would be required to induce producers to convert some land to grass production or to harvest crop residue such as stover or corncobs. Producer and processor preferences for contracting terms and methods to compensate for or alleviate agronomic impacts are additional areas in which more and better information could play an important role in the future development of markets for cellulosic biomass.

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Appendix

To condense the amount of information in this data, we use exploratory factor analysis to guide our groupings of important variables following the method outlined in Martens, Crum, and Poist (2011). The factor analysis was conducted only on the set responses that identify a willingness to grow at least one type of biomass in our choice set because a primary objective was to understand the concerns of those who were open to selling biomass. If farmers are not interested in selling biomass, their answers or rankings associated with the questions may be biased (i.e., they are already not interested, so why bother dealing with the issues?).

Factor analysis was performed on items grouped by two major themes: (1) knowledge and information about biomass production and (2) concerns regarding biomass production and operation. The analysis was implemented using the principal-component factors (PCFs) extraction method, and the resulting number of measures was chosen based on Scree tests of the component eigenvalues. To decide on the final factors to include, we relied on both Scree tests and eigenvalues. The Scree test examines a graph of the associated eigenvalues, looking for natural bends or break points where the results flatten. All items were subsequently allowed to load on factors based on their correlations, and the component matrix was rotated using the varimax with Kaiser normalization method (Kaiser, 1958). The items included in each factor-measure and corresponding eigenvalues are reported in Table 2. Steps were taken to validate the measures during the factor analysis process.

Several validation steps were taken to ensure unidimensionality, reliability, and convergent validity. Unidimensionality relates to whether the individual items represent a single measure, and PCF loadings were used to assess unidimensionality. The PCF loadings corresponding to each item are listed in Table 2. Based on Martens, Crum, and Poist (2011), 0.30 was used for the minimum loading of an item in an exploratory study. Although no item in our study had a loading of less than 0.54, 21 out of 55 survey items were removed because the items loaded at 0.30 or higher on at least two factors. Once removed, new factor analysis was performed on the remaining items, until all items were loaded on one factor.

Reliability checks whether measures yield consistent results. To test the reliability, item-to-total correlation and Cronbach's alpha were used. Item-to-total correlation examines how well one item is related to other items in the extracted measure, and Cronbach's alpha represents the proportion of total variance created by a common source and determines the overall internal reliability of each of the extracted measures (Netemeyer et al., 2003). Following Netemeyer et al., the cutoff level 0.40 was chosen for item-to-total correlation. Most of the items included in the eight extracted measures show an item-to-total correlation value much higher than this cutoff level. Cronbach's alpha values for each of the eight measures are greater than the generally accepted threshold value of 0.70, which implies that the reliability is satisfied for all of the measures. Both item-to-total correlations and Cronbach's alpha are reported in Table 2. Finally, convergent validity, which refers to how a factor correlates to the individual items comprising the factor, is evaluated. To evaluate convergent validity, individual factor analysis was performed for each measure (factor) using only the items loaded on that particular measure. When performing the factor analysis, only one factor could be extracted from each measurement set. When individual factor analysis was conducted on items listed under each measure, items were gathered under one factor only. Therefore, evidence of convergent validity exists in all of the final extracted measures.