The Economics of Perennial Bioenergy Crop Production Under Risk and Uncertainty: Understanding Economic and Policy Incentives

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Abstract

In order to reduce economic and national security risks, U.S. energy policy, in 2005 and 2007, mandated production of renewable biofuels. By 2014, the renewable biofuel industry was consuming approximately one-third of domestic corn and soybean production. To meet this growing demand, conservation and pastureland has been cultivated with corn and soybean, resulting in a reduction in ecosystem services, such as carbon storage, wildlife habitat and water quality. Perennial bioenergy crops (e.g., switchgrass) offer a more sustainable alternative. However, unlike annual crops, farmers and landowners have little experience with perennial bioenergy crop production. Uncertainty in production and prices will impact the supply of these novel crops into an emerging market. Using a stated preference method, I show that agricultural landowners are willing to produce perennial bioenergy crops, given competitive returns, but only on a portion of their land. These results suggest that risk and uncertainty are important considerations in perennial bioenergy crop supply. Next, using a state-contingent approach to choice under uncertainty, I characterize the comparative static effects of government incentives to promote perennial bioenergy crop production. I show that uncertainty can dampen the impact of these incentives and in some cases even decrease perennial bioenergy acreage. Finally, I estimate the magnitude of the relative risks and the fixed cost hurdle using a discrete/continuous structural model. I show that agricultural landowners perceive a relatively high level of risk from perennial bioenergy crop production and are less willing to produce short rotation woody crops than perennial grasses.

Contents

List of Tables

List of Figures

Chapter 1

Introduction

1.1 US Ethanol Policy

Following the energy crisis of the 1970s, the objective of United States (U.S.) energy policy largely focused on increasing energy independence to reduce economic and national security risks. The Energy Tax Act (ETA) of 1978 created an alternative energy subsidy in the form of a federal excise tax exemption on gasoline blends containing at least ten percent ethanol[1]. This exemption, along with tax benefits and loan guarantees to ethanol producers and blenders and tariffs on foreign-produced ethanol, spurred growth in ethanol production of nearly thirty percent per year in the U.S. between 1981 and 1990 (U. S. Energy Information Administration, 2011).

In order to reduce economic and national security risks, recent energy policy has included provisions to increase energy independence. These policies promote using the U.S.'s large natural resource endowments of agricultural land and forests to produce energy as part of the strategy to increase domestic energy production. Federal policies (e.g., Energy Policy Act of 2005[2]) and state policies (e.g., renewable portfolio standards), have been effective at increasing domestic bioenergy production. U.S. production of renewable liquid fuels (i.e., ethanol and biodiesel) increased from 3.4 billion gallons in 2004, before the passage of the Energy Policy Act, to 14.9 billion gallons in 2011 (U. S. Energy Information Administration, 2011). Today bioenergy is a small fraction of domestic production but, nonetheless, it has contributed to an increase in U.S. energy independence. Net oil imports peaked in 2005 at 210 billion gallons and have continued to decline at an average rate of 7.4 billion gallons per year, even with the continued economic recovery (U. S. Energy Information Administration, 2015).

[1] Forty cents per gallon (1978), 50 cents per gallon (1982) and 60 cents per gallon (1984).
[2] Later amended with the Energy Independence and security Act of 2007.

The Energy Policy Act does include provisions for advanced biofuels from cellulosic (i.e., structural material of plants) biomass but the lack of commercial production has resulted in a mandate that is much lower than the original policy goals. Before 2014, commercial scale production was largely absent. Commercial scale production began in 2014 (i.e., 33 million gallons), with most of the feedstock coming from annual crop residues. Removal of crop residues will further increase the environmental impacts of annual crop production (Lal, 2005).

1.2 Land Use Impacts

Renewable liquid fuel has been primarily produced using corn and soybeans, resulting in major changes to the agricultural sector. While the impact of biofuels on food prices and the carbon emissions is debated, research has shown that land use has changed as a result of biofuel policies (Barrows, Sexton, and Zilberman, 2014; U. S. Environmental Protection Agency, 2010; Searchinger et al., 2008; Tyner et al., 2010). Between 2006 and 2014, annual field crop acreage increased 2.2 million per year on average (U. S. Department of Agriculture National Agricultural Statistics Service, 2014). Over this period, environmentally sensitive cropland, including highly erodible land that had been enrolled in the Conservation Reserve Program (CRP), has been cultivated to meet the increasing demand for corn and soybeans. The land has come primarily from cultivating land in the CRP (U. S. Department of Agriculture, 2013b), resulting in a decline in CRP enrollment of 1.3 million acres per year on average between 2006 and 2014 (U. S. Department of Agriculture Farm Service Agency, 2014). This change in land use can have significant detrimental environmental implications (Fargione et al., 2008; Rajagopal et al., 2007), including decreases in water quality. Total nutrient delivery to the

Gulf of Mexico from the Mississippi River Basin, which contains seventy four percent of U. S. Cropland,[3] has risen with this increase in annual crop acreage (U. S. Geological Survey, 2014).

Perennial energy crops can produce conservation benefits through the presence of a live crop year round and the reduction in annual cultivation. Perennial crops conserve soil and water resources through the perennial presence of deep live root structures that are not found in annual crop systems. Perennial systems result in a reduction in cultivation associated with annual replanting of conventional crops.

1.3 Biomass from Perennial Crops

Emerging markets for biomass led the U.S. Department of Energy to evaluate the potential availability of one billion dry tons of biomass (U. S. Department of Energy, 2005). The most recent update to this analysis, published in August of 2011, estimates that dedicated energy crops will provide the largest and fastest growing single source of biomass beyond 2022 (U. S. Department of Energy, 2011). However, dedicated energy crops are the only source not currently supplying any biomass into the market. Supply will depend upon economic conditions in the agricultural sector and the willingness of farmers to adopt dedicated energy crops into their food and feed cropping systems.

Perennial grasses and woody crops are an alternative source of feedstock for cellulosic biofuel, bioheat, and biopower. These crops are high yielding and can produce uniform and consistent feedstocks. New production systems and emerging markets, especially those dependent on continued government intervention, can

[3]There is 240.3 million acres of cropland in the Mississippi River Basin (U. S. Department of Agriculture, 2013a) and 324.8 million acres of cropland in the U.S. (U. S. Department of Agriculture National Agricultural Statistics Service, 2014).

have significant risks. Risks and uncertainty can reduce a farmer's willingness to adopt perennial bioenergy crops.

Annual energy crops share a similar production regime to their grain and forage counterparts. Some annual energy crops that are currently produced in agriculture (e.g., sorghum), have long established production histories and well developed markets. Producing annual crops for cellulosic ethanol will require limited agronomic modifications. Perennial bioenergy crops on the other hand, have production regimes that differ from current annual production of conventional agricultural commodities and lack well-developed markets. The agronomic differences create a barrier to adoption. These barriers include the need to invest in capital (e.g., equipment and education), the risk and uncertainty in returns, and other non-financial barriers to adoption (e.g., cultural, perceptions and lack of information).

Prices in emerging perennial markets can be highly volatile relative to annual crop markets due to several factors including the limited number of buyers and sellers. Emerging markets face uncertainty in output and input prices that can further limit participation by potential producers. In addition, perennial energy crops may have high yield risks in new environments due to the limited development of a variety of cultivars. Farmers likely perceive substantial risks in entering emerging markets, and their aversion to these risks may limit their willingness to participate unless compensated.

It is worth keeping in mind that agricultural production is subject to return risk no matter which crop is produced. Diversifying production by growing more than a single crop is a common way to manage risk. Currently, this is accomplished by offsetting the timing of rotations and growing different crops in different fields across the farm.

The purpose of this research is to quantify the willingness of agricultural landowners to produce perennial bioenergy crops at varying relative net returns by using a stated crop choice approach (Chapter 2). Then, using a crop choice under uncertainty conceptual model, we characterize the comparative static effects of three policy levers (i.e., establishment cost-share, per acre payments, and price matching) on perennial acreage. We develop a set of sufficiency conditions for each directional effect of the policy levers (Chapter 3). Next, we estimate the magnitude of the relative risks of perennial bioenergy crop production using a structural model of crop choice under risk (Chapter 4). A summary and concluding remarks are presented in the final chapter (chapter 5).

Chapter 2

Perennial Bioenergy Supply: A Stated Choice Approach

2.1 Introduction

In order to reduce economic and national security risks, recent United States (U.S.) energy policy has included provisions to increase energy independence. Federal policies such as the Energy Policy Act of 2005[1] and state policies such as renewable portfolio standards have been effective at increasing domestic bioenergy production. Renewable liquid fuel has been primarily produced using corn and soybeans, resulting in major changes to the agricultural sector. While the impact of biofuels on food prices and the carbon emissions is debated, research has shown that land use has changed as a result of biofuel policies (Barrows, Sexton, and Zilberman, 2014; U. S. Environmental Protection Agency, 2010; Searchinger et al., 2008; Tyner et al., 2010). The land has come primarily from cultivating land in the CRP (U. S. Department of Agriculture, 2013b), resulting in a decline in CRP enrollment of 1.3 million acres per year on average between 2006 and 2014 (U. S. Department of Agriculture Farm Service Agency, 2014). This change in land use can have significant environmental implications (Fargione et al., 2008; Rajagopal et al., 2007) including decreases in water quality.

Perennial crops such as perennial grasses (e.g., switchgrass) and woody crops are an alternative source of feedstock for bioenergy. These crops pose fewer negative environmental impacts than corn and soybean, including reductions in soil erosion, greenhouse gas emissions, and nutrient delivery (Lemus and Lal, 2005; McLaughlin and Walsh, 1998). Land-use changes, in which perennial vegetation is replaced by annual crops, further degrade water quality and make meeting water pollution limits even more of a challenge. In regions that are dominated by annual crops, some reversion to perennial vegetation is necessary to meet water pollution limits, even with wide adoption of annual crop conservation practices (Minnesota

[1] Later amended with the Energy Independence and Security Act of 2007

Pollution Control Agency, 2012).

In order for perennial bioenergy crops to contribute to energy independence and environmental goals, the cellulosic industry must overcome several challenges. One challenge is the efficient operation of ethanol production plants in order to lower production costs. Another is a constant supply of low cost cellulosic biomass from agricultural land (Gold and Seuring, 2011). Unlike crop residue, which comes from well established production systems and is readily available in large quantities, perennial bioenergy cropping systems are largely unknown to farmers and landowners. Given this uncertainty, the production of perennial bioenergy crops is dependent on the willingness of farmers to produce these crops.

This study evaluates the willingness of agricultural landowners to produce two major types of perennial bioenergy crops. Much of the previous work has specified generic perennial bioenergy crops[2] or a particular type, usually switchgrass. This study looks at two major types of generic perennial bioenergy crops — grasses and woody crops. These two major types have been selected because of the major differences in the agronomics, harvest frequency, stand life, and machinery between the two. Grasses can be harvested annually using common harvesting equipment. SRWC can be harvested every three or four years and require novel machinery. The optimal stand life of perennial bioenergy crops can be as long as 10-20 years. Not only must farmers be willing to produce these crops, but agricultural landowners must be willing to agree to longer rental contracts if renters are to produce them. In addition, the lower management requirements of perennial bioenergy crops may encourage non-farming landowners to produce bioenergy crops themselves.

[2] In many cases the examples given are switchgrass or miscanthus.

With the lack of an existing market and revealed preference data for perennial bioenergy crops, this study uses a stated crop choice approach that randomly varies net income assumptions regarding perennial grasses and SRWC. Previous perennial bioenergy crop choice approaches used randomly assigned absolute and relative net incomes (Paulrud and Laitila, 2010; Bergtold, Fewell, and Williams, 2014) to understand the value of other randomly assigned bioenergy crop characteristics. Our approach is consistent with this research. The data was collected using a mail survey of farmers in nine counties in the Upper Mississippi River Basin.

2.2 Methods

Given the lack of revealed preference data on perennial bioenergy production, this study uses a stated preference method to estimate the willingness of agricultural landowners to supply perennial bioenergy crops at varying levels of net incomes relative to the landowner's current net income. If they were willing to grow perennial grasses, they were then asked how many acres they would be willing to devote to grass production. The same set of questions was also asked regrading woody crop production, resulting in four responses (i.e., two yes/no and two acreage) and two factors (i.e., relative net income of woody crops and grasses) for each respondent. The relative income amounts ranged from \$-100 to \$250 per acre for grasses and \$-50 to \$300 per acre for woody crops in \$50 increments, for a total of eight treatment levels for each factor. This results in sixty-four different versions of the survey.

2.2.1 Survey

The survey targeted agricultural landowners in nine counties in the lower Minnesota River Valley. The counties include Blue Earth, Brown, Carver, Le Sueur, Martin, Nicollet, Scott, Sibley, and Watonwan. This population was chosen for two major reasons. First, these counties have a majority of their land in the lower Minnesota River watershed. Second, they are adjacent to the Koda Energy bioheat and biopower plant and a potential biomass plant site in Madelia, MN. Most of the agricultural land in this region is used to grow corn and soybeans.

Addresses for the agricultural landowners were obtained through each county tax assessors office. Records for parcels zoned for agriculture, with greater than 20 acres, were included in the final study population. This prevents land zoned for agriculture but used for other purposes, such as a homestead, from being included. Duplicate addresses were deleted. The final study population is 13,850 agricultural landowners in the nine counties.

Sample

After determining the study population, the next step was to randomly draw a sample size that was large enough for the anticipated results to be statistically significant at the 95% confidence level.[3] With a population of 13,850 (N_p) and an unknown proportion (p) choosing a response category, we use the proportion (50%) with the most conservative estimate of the sample size. The final sample size needed to be at least 374 agricultural landowners[4] (Dillman, Smyth, and Christian, 2008). Given that survey response rates can vary widely and depend on the successful design of the survey, 1000 surveys were mailed anticipating at

[3] This is a margin of error (B) of 5% and a Z-score (C) of 1.96.

[4] The minimum final sample size is $N_s = \frac{(N_p)p(1-p)}{(N_p-1)(B/C)^2+p(1-p)}$.

least a forty percent response rate to achieve the maximum sample size.

Mail Survey Administration

The survey used the standard five-contact Dillman mail survey method (Dillman, Smyth, and Christian, 2008). The survey was conducted in late 2010 and early 2011. First, a pre-notice letter was mailed to the respondents, approximately one week before the mailing of the first questionnaire, to prepare them to receive the survey. Then, the survey was mailed with a cover letter explaining the purpose of the survey and a prepaid envelope to return the survey. One week later, a reminder postcard was sent that reiterated the importance of filling out the survey and reminded respondents to return it. When the number of returned surveys slowed to zero to two per day, approximately four weeks after the first survey, a second replacement survey was sent. This survey was mailed in an envelope with a different size and color from that of the first survey and only to addresses that had not yet responded. The final contact involved a reminder postcard about one week after the last survey was mailed.

2.2.2 Model

Each landowner in our sample received a randomized set of relative net incomes. The farmland owners were asked to answer four questions related to their willingness to grow perennial bioenergy crops. Two of the questions were follow-up questions, and answering the questions was conditional on the response to the previous question. With more than one response variable, multivariate multiple regression (MMR)[5] techniques are preferred to estimating four independent

[5]Multivariate multiple regression is known as multivariate analysis of covariance (MANCOVA) when there are two or more continuous response variables.

regressions. Given that MMR is a special case of seemingly unrelated regression (SUR) in which all equations share a comment set of independent variables, MMR has many of the same advantages as SUR. The advantages include increases in estimation efficiency without loss of consistency, limits in type I errors by consolidating hypotheses testing, and the ability to test hypotheses across response models (Zellner, 1962). MMR is commonly used for analysis when one of the variables is randomly assigned.

Regression

Based on the design of our stated choice appraoch, we use a sample selection mixed-process multivariate multiple regression estimated by simulated maximum likelihood. The acreage responses are only observed for those respondents who are willing to grow perennial bioenergy crops. Due to this self selection, it would not be reasonable to assume that the sample of acreage responses that we received is a random sample of the population. The binary response equations (y_G, y_T) are the selection equations for the acreage response equations (y_g, y_t). Using the Heckman selection model requires that the independent variables (x) in the acreage equation (x^1) be a subset of the selection equation independent variables (x^1, x^2) (Wooldridge, 2002). In multivariate analysis, all equations share a common set of independent variables (x). Reducing the number of variables in the acreage equations to allow for the use of Heckman selection is a trade-off between additional information that the omitted variables would have provided and the bias estimates of the coefficients in the acreage equations (β_g^1, β_t^1) if the sample selection was not corrected. Using a set of additional explanatory variables in the binary response questions that are highly correlated with the binary response, and not the acreage response, will limit the loss of information.

The grass and woody crop sets of equations with Heckman selection could be estimated independently from one another. It is likely that our error in predicting outcomes for woody crops are correlated to our error in predicting outcomes for grasses. The two binary equation errors (ϵ_G,ϵ_T) and two acreage equation errors (ϵ_g,ϵ_t) seem most likely to be correlated given that they are the same response type. The binary and acreage equation errors across grasses and woody crops may also be correlated. The independent equation model is a special case of the error correlation model and so the independence of equations can be tested. Based on our survey approach and the response selection, we use a mixed-process multivariate multiple regression. The four equations that we estimate are

$$y_G = \beta_G^1 x^1 + \beta_G^2 x^2 + \epsilon_G \tag{2.1a}$$

$$y_g = \beta_g^1 x^1 + \epsilon_g \tag{2.1b}$$

$$y_T = \beta_T^1 x^1 + \beta_T^2 x^2 + \epsilon_T \tag{2.1c}$$

$$y_t = \beta_t^1 x^1 + \epsilon_t \tag{2.1d}$$

where ϵ is the error term. Our model is then,

$$\begin{aligned} \boldsymbol{Y} &= f(\boldsymbol{y}) \\ &= (1\{y_G > 0\}, y_g, 1\{y_T > 0\}, y_t)'. \end{aligned} \tag{2.2}$$

We assume that the error term has a joint normal distribution,

$$\boldsymbol{\epsilon} = (\epsilon_G, \epsilon_g, \epsilon_T, \epsilon_t)' \sim \mathcal{N}(\mathbf{0}, \boldsymbol{\Sigma}). \tag{2.3}$$

The co-variance matrix is

$$\boldsymbol{\Sigma} = \begin{bmatrix} 1 & \sigma_{Gg} & \sigma_{GT} & \sigma_{Gt} \\ \sigma_{Gg} & \sigma_{gg} & \sigma_{gT} & \sigma_{gt} \\ \sigma_{GT} & \sigma_{gT} & 1 & \sigma_{Tt} \\ \sigma_{Gt} & \sigma_{gt} & \sigma_{Tt} & \sigma_{tt} \end{bmatrix} \tag{2.4}$$

where the variance of the discrete equations is equal to one, σ is the co-variance, and σ_{gg}, σ_{tt} are the variances of the acreage equations.[6] The above regression model is estimated in Stata with the user written command `cmp` (Roodman, 2011).

2.3 Results and Discussion

2.3.1 Responses

Survey Response

The survey had a relatively high response rate given its length. Five hundred forty eight surveys were returned of which fifty-two were blank and four hundred and nineteen had responses to all the questions used in this study. This is comparable to the 2007 study of corn and soybean farmers' willingness to adopt environmental practices in Michigan by Jolejole, Swinton, and Lupi (2009) (56% response rate) and significantly higher than the Jensen et al. (2007) survey of the willingness of Tennessee farmers to grow switchgrass (24% response rate).

Non-Response

As discussed in the previous section, the response rate was relatively high compared to similar studies on perennial bioenergy crops and academic surveys of farmers in general. If the respondents are a random subsample of the population, then there should not be any concern regarding nonresponse bias. The challenge, of course, is that we know very little about the nonrespondents. One common technique to test for nonresponse bias is to follow up with a random sample of the nonrespondents and find out why they did not respond (Lindner, Murphy, and

[6] The error correlation ρ is equal to $\frac{\sigma_{12}}{\sigma_1 \sigma_2}$.

Briers, 2001). Studies that follow up with nonrespondent farmers, when asking about interest in perennial bioenergy crops, find that the nonresponse is largely unrelated to their interest in perennial bioenergy crops. Paulrud and Laitila (2010) found that 56% of the nonrespondents "had no time to answer the questionnaire" and 27% "generally do not like to answer surveys." If these reasons are uncorrelated with perennial bioenergy crop interest then nonresponse bias will be limited. Some of the nonrespondents (13%) in their study "had no interest in growing energy crops." This would likely bias estimates of the percentage of farmers willing to produce perennial bioenergy crops upwards. The nonresponse rate for their study was 50% thus the estimates of the percentage of farmers would be biased upwards 6.5%.

To examine the nonresponse bias, we first compared the characteristics of the respondents to the population to determine if our sample is representative in terms of the responses to questions that we asked. We then examined differences in responses to our outcome variables for respondents that required a second round of surveys to respond and those respondents that indicated that they had no interest in grasses or woody crops for energy production. The full analysis of nonresponse can be found in the Appendix.

The comparison of the respondent's characteristics to those in the study population was limited due to the lack of population data on agricultural landowners. The United States Department of Agriculture (USDA) Census of Agriculture reports on all farms and while this does include landowners, it is difficult to separate landowners from farmers for the study region with publicly available data.[7] We evaluate the crops grown in our study region with the results of our survey. We find that our sample is similar to the population in terms of share of cropland

[7] A custom data request would be required to obtain census data from only landowners.

used to grow crops (see Table A.1 in the Appendix). Our survey appeared to over-sample landowners with soybean fields and under-sample landowners with hay fields.

Examining the response round is a common technique in social science research to better understand the nonrespondents (Lindner, Murphy, and Briers, 2001). Respondents to survey rounds two and above are non-respondents to the previous rounds. In our survey, 37% of the respondents were from the second round of surveys. We found no significant difference in response to our four outcome variables between respondents from round 2 and round 1 (see Table A.2 in the Appendix).

Previous research has shown that some of the nonrespondents may not be interested in perennial bioenergy. We are able to identify differences between respondents that have no interest in either grasses or woody crops and those that have at least some interest in either by including questions to gauge their level of interest. Not surprisingly, we found a significantly greater willingness (41%) to produce both grasses and woody crops among landowners with at least some interest (see Table A.3 in the Appendix). When we estimate this difference at the treatment amounts, we see that the magnitude of this difference is highest at the $50 and $100 per acre relative net income amounts. This low difference is due to the low willingness of interested landowners at the negative relative net income amounts and the high willingness of uninterested landowners at high relative net incomes. We found no significant difference in the amount of acres for perennial bioenergy production between the landowners that were interested versus those that were not.

2.3.2 Summary Statistics

In order to better understand the willingness of landowners to supply perennial bioenergy crops, we report on the effect of a variety of variables on adoption. This includes land tenure, land use, income, conservation experience and demographics.

Treatments

Table 2.1a summarizes the frequency of the grass and woody crop amounts. The sample received a balanced set of treatments with a 1 in 8 probability (p) of receiving a particular grass (g) or woody crop (t) amount and a 1 in 64 probability ($p_g p_t$) of receiving a particular set of grass and woody crop amounts. With a response rate (n) of 419, the expected frequency ($p_g p_t n$) of a set of grass and woody crop amounts is 6.55. The response rates ($n_{g,t}$) are unbalanced but do not have any statistical relationship to the treatment amount. We also conducted the Pearson's chi-squared test[8] of the independence of the woody crop response rate to the grass response rate. We failed to reject the null hypothesis that the grass and woody crop response rates are independent. Thus, there is no evidence that the response rate was different based on the treatment amounts.

Willingness to Supply

The willingness to supply perennial bioenergy questions asked the respondents if they would grow perennial bioenergy crops if their annual net farm income per acre from growing perennial bioenergy crops was a randomly selected amount greater or lower than their current net farm income per acre. The randomly selected amount ranged from -\$ 100 to \$ 250 for perennial grasses and -\$ 50 to \$ 300 for

[8]The Pearson's chi-squared test is $\chi^2 = n \sum_{g,t} p_g p_t \left(\frac{\frac{n_{g,t}}{n} - p_g p_t}{p_g p_t} \right)^2$.

Table 2.1a: Summary Statistics: Number of Responses by Treatment

	Woody Crop Relative Net Income acre^{-1} (RNI)								
Grass RNI	-$50	$0	$50	$100	$150	$200	$250	$300	Total
-$100	6	5	7	8	6	6	9	4	51
-$50	5	3	11	6	5	9	5	5	49
$0	10	9	8	6	7	1	7	8	56
$50	7	5	6	6	7	8	8	3	50
$100	4	6	8	10	11	7	5	7	58
$150	4	6	4	8	9	6	6	8	51
$200	12	7	4	7	4	8	6	8	56
$250	2	5	9	4	6	6	9	7	48
Total	50	46	57	55	55	51	55	50	419
	Pearson $\chi^2(49) = 44.750$ Pr = 0.646								

woody crops at $ 50 increments.

Some (17%) of the respondents were willing to supply perennial grasses at negative relative net incomes (RNI) per acre (Table 2.1b). The willingness to supply jumped 45% at the RNI equal to their current net income ($ 0). In most studies that ask farmers directly, less than half (25-45%) indicate that they would be willing to produce perennial bioenergy crops (Fewell and Lynes, 2013; Caldas et al., 2014; Wen et al., 2009; Jensen et al., 2007). The percentage of respondents and the acreage was non-decreasing in relative net incomes. The variation in the acreage between studies was surprisingly low, with most studies between 60-70 acres (Jensen et al., 2007; Wen et al., 2009; Qualls et al., 2012). Given the different study populations and average farm sizes, this acreage translates to 16-24% of farmed acres. Almost no respondents (4%) were willing to supply woody crops at net incomes less than their current net income. The percentage of respondents and the acreage was non-decreasing in relative net incomes for tress as well. At all amounts, the percentage of respondents willing to supply perennials was lower

Table 2.1b: Summary Statistics: Willingness to Produce Grasses

	Yes		Acres|Yes†			Acres†		
RNI	Mean	Grp.‡	Mean	SD	Grp.‡	Mean	SD	Grp.‡
-$100	0.16	a	30	17	a	4	12	a
-$50	0.18	a	36	32	ab	5	17	a
$0	0.63	b	76	68	ab	42	63	b
$50	0.70	bc	69	64	ab	44	61	bc
$100	0.72	bc	66	53	a	44	53	bc
$150	0.69	bc	74	69	ab	48	65	bc
$200	0.79	bc	86	92	ab	64	87	bc
$250	0.81	c	113	189	ab	73	161	c
Total	0.59		77	96		41	80	
N	419		222			419		

† Acres|Yes is the average acres for respondents that were willing to produce perennials. Acres is the average acres for all respondents assuming zero acres for respondents unwilling to produce perennials.
‡ The null hypothesis that the means are equal can be rejected for models with different letters

for woody crops than for grasses.

Design: The majority of the respondents responded to the first round of surveys. The second round of surveys included an additional 158 responses. The sampling frame (i.e., county tax record addresses) was constructed by aggregating records by county. The response rates can be found in Table 2.1d. These response rates match with the share of the population in each county.

Land Tenure: Table 2.1e summarizes land tenure for the respondents in the survey. Using the information from the county tax records, we included landowners with parcels 20 acres or larger to limit homesteads that are zoned for agriculture but not used for that purpose. We received nine questionnaires from respondents that owned fewer than 20 acres of land. These responses were removed from

Table 2.1c: Summary Statistics: Willingness to Produce Woody Crops

	Yes		Acres|Yes†			Acres†		
RNI	Mean	Grp.‡	Mean	SD	Grp.‡	Mean	SD	Grp.‡
-$50	0.04	a	12	4	ab	0	3	a
$0	0.39	ab	29	23	a	11	20	ab
$50	0.42	ab	32	31	a	13	25	abc
$100	0.45	ab	44	42	ab	18	34	bc
$150	0.53	ab	48	35	ab	22	33	bc
$200	0.47	ab	68	66	b	27	53	cd
$250	0.55	ab	43	52	ab	20	41	bc
$300	0.60	b	70	76	b	40	67	d
Total	0.43		48	52		19	40	
N	419		163			419		

† Acres|Yes is the average acres for respondents that were willing to produce perennials. Acres is the average acres for all respondents assuming zero acres for respondents unwilling to produce perennials.
‡ The null hypothesis that the means are equal can be rejected for models with different letters

Table 2.1d: Summary Statistics: Design of Survey

Variable	**Description**	**Mean**
Round 2	Landowner responded to the second round of surveys (0,1)	0.38
County		
Blue Earth	Share of respondents from each county (0,1)	0.19
Sibley		0.15
Le Suer		0.13
Brown		0.12
Carver		0.12
Martin		0.11
Nicollet		0.08
Watonwan		0.07
Scott		0.05

Table 2.1e: Summary Statistics: Land Tenure and Land Use (acres)

Variable	Description	Mean	Std. Dev.
Tenure			
Owned	Total acres owned	217	213
Rented	Acres rented or sharecropped from other landowners	86.1	269
Farmed	Total acres farmed. Equals zero for landowners that do not farm.	199	367
Land Use			
Wildlife	Wildlife habitat acres	5.1	20.0
Alfalfa		5.4	18.0
Pasture	Pasture livestock area	3.4	15.8
Wetland		3.7	14.2
Recreation	Recreation acres, such as hunting or bird watching	2.8	12.1
Woods	Wooded acres	1.4	11.2
Native Prairie		2.1	10.3
Hay	Hay Acres, not including alfalfa	1.8	6.6
Orchards		0.06	0.64
SRWC	Woody Crops	0.03	0.49
CRP	Acres enrolled in the Conservation Reserve Program	0.34	0.47

the sample to match the sampling methodology. Of the 419 landowners that responded, they owned an average of 217 acres of land. About half (51%) leased or sharecropped their land to other farmers and about one-quarter (24%) rented land. Just over half (55%) of the respondents farmed land they owned or rented. The landowners that did farm had an average farm size of 361 acres.

Land Use: Table 2.1e summarizes the current land uses of the respondents. Most of the respondents in these counties had corn (92%) and soybean (84%) being produced on the land they owned. Other common agricultural uses included alfalfa (17%), hay (14%), and pasture (14%). Common non-agricultural land uses are wildlife habitat (19%), recreation (11%), and native prairie (8%). Land leased

Table 2.1f: Summary Statistics: Conservation Programs & Practices

Variable	**Description**	**Mean**
CRP	Has implemented a conservation easement on the land such as Conservation Reserve Program (0,1)	0.34
CSP	Has implemented a government conservation program that conserves resources while farming such as the Conservation Security Program (0,1)	0.09
Soil Conservation	Has implemented soil conservation practices such as no-till/low-till, direct seeding, or nutrient management (0,1)	0.44

to other farmers was collected in the survey but not used in this study because land leased is a linear combination of the other land tenure variables.

Conservation: Table 2.1f summarizes the implementation of conservation programs or practices on the respondent's land. Most of the respondents (61%) indicated that they had implemented one of the three conservation programs or practices. Generic soil conservation practices such as no-till/low-till, direct seeding, or nutrient management was the most common conservation program or practice, with about half of the respondents (44%) indicating they had implemented such a practice. Conservation tillage is becoming a common practice in corn and soybean fields. Just over one-third (34%) of the respondents received a conservation easement such as those available from the Conservation Reserve Program (CRP). Only some of the landowners (9%) had enrolled in a government conservation program that conserves natural resources while farming such as the Conservation Security Program (CSP).

Demographics: Table 2.1g summarizes the demographic characteristics of the respondents. Most of the respondents to the survey are male. Our estimates of

Table 2.1g: Summary Statistics: Demographics

Variable	**Description**	**Mean**
Male	Gender of landowner is male (0,1)	0.79
Age	Age of landowner	59.75 (18.45)
Work Off Farm	Someone in the landowner's household works off-the-farm (0,1)	0.55
Education	Highest level of formal education landowner has completed	
Some high school	Some high school or less (0,1)	0.06
High School	High school/GED (0,1)	0.33
Some College	Some College (0,1)	0.14
2 year degree	Technical/Community college degree (0,1)	0.18
Bachelor's	Bachelor's degree (0,1)	0.16
Graduate	Graduate/Professional degree (0,1)	0.11
No answer	Did not answer the question (0,1)	0.03

the share of female respondents is higher than other similar research that surveyed farm operators. The average age (60) of the respondents and the share that has someone in the household working off the farm (55%) matches closely to other research. Just under half of our respondents (45%) had completed a college degree.

Income: Table 2.1h summarizes the household and farm incomes of the survey respondents. Just under half of the respondents had household incomes under $75,000. Median net farm income was in the range of $10,000-25,000. Net cash farm income in the United States in 2009 was the lowest in the years 2008 and 2014.

Interest: Table 2.2 summarizes interest of the respondents in perennial crops, assuming that they were financially competitive with current land usage, using a Likert Scale. Most of the respondents (68%) had at least some interest in growing grasses for perennial bioenergy. This matches closely with other research where

Table 2.1h: Summary Statistics: Income

Variable	**Description**	**Mean**†
Household Income	Total household income from all sources, before taxes, in 2009.	
less than $25,000	(0,1)	0.06
$25,000-50,000	(0,1)	0.22
$50,000-75,000	(0,1)	0.19
$75,000-100,000	(0,1)	0.15
$100,000-150,000	(0,1)	0.14
more than $150,000	(0,1)	0.12
No answer	Did not answer this question (0,1)	0.11
Farm Income	Net cash farm income from farm operations in 2009, including rental income	
Net Loss	Less than $0, Net Loss (0,1)	0.05
$0-5,000	(0,1)	0.13
$5,000-10,000	(0,1)	0.13
$10,000-25,000	(0,1)	0.27
$25,000-50,000	(0,1)	0.17
more than $50,000	(0,1)	0.15
No answer	Did not answer this question (0,1)	0.11

Table 2.2: Summary Statistics: Interest in Perennial Bioenergy Crops

Variable	**Description**	**Mean**
Interest Grass		
No	(0,1)	0.11
Little	(0,1)	0.18
Some	(0,1)	0.40
High	(0,1)	0.20
No answer	Did not answer the question (0,1)	0.11
Interest Woody Crop		
No	(0,1)	0.24
Little	(0,1)	0.24
Some	(0,1)	0.32
High	(0,1)	0.14
No answer	Did not answer the question (0,1)	0.06

the majority of farmers (67-75%) indicated that they are interested in converting to dedicated biofuels including switchgrass (Kelsey and Franke, 2009; Qualls et al., 2012). Overall, landowners were less interested in woody crops than grasses.

2.3.3 Estimated Model

This research included primary data collection using a randomized crop choice survey. We collected information on co-variates in addition to the randomized treatments. The collection of co-variates increases the efficiency of our treatment effects, given that an effect exists. It also allows for the estimation of the effect that the observable co-variates have on the willingness to produce perennial bioenergy crops. The variables that are included in this model were chosen based on the types of variables that have been included in similar research. In the reported model, each variable is included in all four equations (see B.1). The one exception is the interest variables, which is only included in the selection equations to allow for Heckman sample selection correction (see 2.2.2 Regression).

Error Correlation

In addition to the variables, mixed-process multivariate regression is flexible enough to allow for various error correlation structures. This includes the error correlation between the acreage and the selection equation which is the simultaneous Heckman correction. The reported model follows the MANCOVA procedure and includes no restrictions on the error correlations. Table 2.3 shows the log-likelihood values for models with various combinations of restrictions on the error correlations. The upper left model is the most restricted, having no error correlation. The lower right model is the unrestricted model. The models without the restrictions on the error correlation between the two willingness to produce equations and the two acreage equations have a better fit than the models with the restrictions. The other two restrictions have mixed results.

Table 2.4 is the variance and error correlation matrix for the errors. The errors for the willingness to produce grass and woody crop are positively correlated as are the errors for grass and woody crop acreage. This suggests that there are unobservable variables that are correlated with both grass and woody crop willingness and another set of unobservable variables that are correlated with both grass and woody crop acreage. The willingness to produce grasses and woody crop acreage are negatively correlated.

Treatment Effects

Using the unrestricted model, we report the marginal effects of the treatments on the dependent variables. The marginal effects for the variables in the acres equations is the marginal effect with the Heckman correction. The estimated coefficients can be found in Table B.1 in the Appendix. We also test the joint significance of the treatments on the model using the log-likelihood ratio test.

Table 2.3: Log-Likelihood Values with Various Restrictions on the Error Correlation

	$\rho_{Gt} = \rho_{Tg} = 0$			
	$\rho_{Gg} = \rho_{Tt} = 0$		$\rho_{Gg} = \rho_{Tt} = 0$	
$\rho_{GT} = \rho_{gt} = 0$	-2401.46 a	-2398.02 c	-2399.61 a	
	-2385.89 b	-2384.52 b	-2383.81 bd	**-2381.31** d

† The null hypothesis that the models are equal can be rejected at the 95% level (likelihood ratio test) for models that have different letters; the likelihood ratio test is only valid for models in which one model can be nested within the other.

Table 2.4: Variance & Error Correlation for Unrestricted Model

		Grasses		Woody Crops	
		Yes	Acres	Yes	Acres
Grass	Yes	1.00			
		(.)			
	Acres	−0.55	63 ***		
		(0.51)	(11)		
Woody Crop	Yes	0.60***	−0.16	1.00	
		(0.09)	(0.17)	(.)	
	Acres	−0.37**	0.29*	−0.44	39.7***
		(0.13)	(0.14)	(0.24)	(4.8)

Note: Standard errors in parentheses; * $p < 0.1$, ** $p < 0.01$, *** $p < 0.001$

The RNI for grasses is jointly significant at the 0.001 level. It has a significant effect on the probability of producing grasses and the grass acreage. For each $100 increase in the relative net income from grasses, the probability of planting grasses increases by 15% and the grass acreage increases by 21 acres.

The RNI for woody crops is jointly significant at the 0.001 level. RNI has a significant effect on the probability of producing woody crops and the woody crop acreage. For each $100 increase in the relative net income from woody crops the probability of planting woody crops increases by 12% and the woody crop acreage increases by 14 acres.

The interaction between the grass and woody crop RNIs is not statistically significant. This suggests that the marginal effects of the treatments do not depend on the level of the other treatments. However, we do see a significant and negative effect of the grass net income on the probability of producing woody crops. The sum of the marginal effect of the grass and woody crop net income on the probability of producing woody crops is not significantly different from zero. What this suggests is that an increase in only the woody crop amount increases the probability of producing woody crops. However, the same marginal increase in relative net income for grass and woody crops or a decrease in the net income for their current crop does not increase the probability of producing woody crops. This suggests that landowners are also evaluating the relative returns between grasses and woody crops.

Co-Variates

Design: The design of the survey had some effect on the outcome. The counties were jointly significant. The sampling frame was obtained by aggregating county tax records obtained county by county. The difference in the records from county

Table 2.5a: Marginal Effects of the Treatments and Design

	Grasses		Woody Crops		Joint LRT	
Variable	Yes	Acres	Yes	Acres	*df*	χ^2
Treatments						
Grass net income‡	0.15***	21.0*	−0.085**	−0.8	4	51.40***
	(0.026)	(8.8)	(0.030)	(5.9)		
Woody Crop net income‡	0.02	3.4	0.12***	14.0**	4	37.68***
	(0.021)	(6.2)	(0.022)	(5.3)		
Interaction‡	0.007	−0.5	0.029*	1.6	4	2.99
	(0.017)	(4.4)	(0.017)	(3.1)		
Design						
Round 2	−0.017	−2.8	0.018	−13.9*	4	4.34†
	(0.043)	(9.2)	(0.043)	(7.1)		
County	Yes	Yes	Yes	Yes	32	60.83**

Note: Standard errors in parentheses; * $p < 0.1$, ** $p < 0.01$, *** $p < 0.001$
† Joint t-test reported due to lack of convergence of restricted model
‡ Treatments have been scaled by dividing the relative net income amounts by $100.

to county and any unobserved county level effect is controlled by including the county fixed effects. The round of the survey response was not jointly significant suggesting that later respondents did not differ from earlier respondents.

Land Tenure: Three tenure variables – area owned, rented, and farmed – are included as co-variates. Area leased is not included because it is a linear combination of the three included variables.[9] All three tenure co-variates are significant at the 0.001 level. Tenure had no significant effect on the probability of producing grass. It did have an effect on the probability of producing woody crops. Agricultural landowners that own or rent more land are more likely to produce woody crops while those that farm more acres are less likely to do so. Tenure acreage had a significant impact on grass and woody crop acres. This effect was not significantly different for owned versus rented land. There was a significant

[9] Area leased equals area owned plus area rented minus area farmed.

difference in the marginal effect of area owned and rented on grass and woody crop acres. Landowners are willing to have 17% more land in grass than woody crops production.

Land Use: Current land uses may affect the willingness of landowners to produce perennial bioenergy crops. Landowners that already have perennial land uses may be more willing to produce perennial bioenergy crops or they maybe willing to produce more acres. Farmers that own haying equipment or produce hay were more interested in producing switchgrass (Qualls et al., 2012; Fewell and Lynes, 2013). However, those that raised beef or dairy cattle were less interested (Qualls et al., 2012). The current area of SRWC is a jointly significant co-variate. Landowners that have SRWC are willing to expand the area 14-fold (current area is very small). Landowners with pasture are willing to produce more woody crop acreage. Landowners with wetlands are more willing to produce woody crops and more grass acreage. This is likely because of non-productive nature of wetlands and high water table near wetlands making annual crop production a challenge. Landowners are willing to produce fewer acres of grass if they have CRP or wooded areas. Removing land from CRP can have large penalties and CRP provides rental payments. Converting wooded area to grasses can be costly and the wooded areas may be valuable to the landowner. Landowners with recreation areas are more willing to produce woody crops. This may mean that woody crops are more compatible with recreation activities (e.g., hunting, off-road vehicles) or that people that dedicate land to recreation are more interested in woody crops.

Table 2.5b: Marginal Effects of Tenure and Land Use Area (Acres)

	Grasses		Woody Crops		Joint LRT	
Variable	Yes	Acres	Yes	Acres	*df*	χ^2
Tenure						
Area Owned	0.00006	0.28***	0.00025*	0.11**	4	27.19***†
	(0.00015)	(0.032)	(0.00015)	(0.036)		
Area Rented	−0.00001	0.27***	0.00072***	0.10**	4	40.28***†
	(0.00018)	(0.039)	(0.00020)	(0.033)		
Area Farmed	−0.00001	−0.22***	−0.00048**	−0.10***	4	34.20***†
	(0.00015)	(0.031)	(0.00016)	(0.028)		
Land Use						
SRWC	0.0016	6.6	0.047	14.0*	4	17.68**
	(0.073)	(7.9)	(0.21)	(7.5)		
Hay	−0.0027	−1.4	−0.0063	0.04	4	6.94
	(0.0033)	(1.0)	(0.0040)	(0.88)		
Alfalfa	−0.0017	−0.19	−0.0006	−0.04	4	2.08
	(0.0013)	(0.34)	(0.0014)	(0.26)		
Pasture	0.0007	0.20	−0.00085	0.39*	4	11.60*
	(0.0012)	(0.27)	(0.0014)	(0.22)		
Orchards	−0.0014	6.9	0.024	0.6	4	6.41
	(0.041)	(8.8)	(0.040)	(5.6)		
Wetland	−0.0004	1.90***	0.0040**	0.028	4	12.83*
	(0.0020)	(0.31)	(0.0015)	(0.23)		
CRP	0.0046	−0.81*	0.0002	−0.08	4	20.66***
	(0.0057)	(0.43)	(0.0014)	(0.21)		
Woods	−0.0004	−1.38**	−0.0012	−0.08	4	7.88*
	(0.0030)	(0.53)	(0.0018)	(0.46)		
Recreation	0.0005	−0.59	0.0053**	0.12	4	12.99*
	(0.0018)	(0.37)	(0.0020)	(0.27)		
Native Prairie	0.00001	0.45	0.0005	0.14	4	1.70
	(0.0020)	(0.52)	(0.0018)	(0.38)		
Wildlife	0.0003	−0.54**	−0.0022	−0.20	4	6.85
	(0.0011)	(0.19)	(0.0014)	(0.19)		

Standard errors calculated using the delta method and are in parentheses; * $p < 0.10$, ** $p < 0.01$, *** $p < 0.001$

† Joint t-test reported due to lack of convergence of restricted model

Table 2.5c: Marginal Effects of Conservation

	Grasses		Woody Crops		Joint LRT	
Variable	Yes	Acres	Yes	Acres	*df*	χ^2
CRP	0.010	−12.0	−0.028	0.1	4	1.57
	(0.046)	(15.4)	(0.053)	(9.5)		
CSP	−0.010	−10.1	0.13*	−16.0	4	9.21*
	(0.057)	(15.5)	(0.063)	(14.3)		
Soil Conservation	0.006	12.1	−0.059	−10.6	4	5.42
	(0.042)	(9.5)	(0.042)	(8.8)		

Standard errors calculated using the delta method and are in parentheses; * $p < 0.10$, ** $p < 0.01$, *** $p < 0.001$

† Joint t-test reported due to lack of convergence of restricted model

Conservation: Given the conservation benefit of perennial crops, a landowner's conservation experience may affect their willingness to produce perennial bioenergy crops. Based on our results, we find very little evidence of this. Landowners that have participated in the Conservation Stewardship Program (CSP) were more willing to produce woody crops. Woody crops are a common component in the CSP practices. Landowners with woody crops planted through CSP may be more interested in planting additional woody crops on their land or possibly even making productive use out of land in the CSP.

Demographics: Previous research has identified demographic variables that are correlated with the interest and willingness of farmers to produce perennial bioenergy crops. Similar to previous research, we found that males have a higher probability of adopting both grasses and woody crops. Age of the respondent had a negative or no effect in previous research. We found no significant effect of age on willingness to produce perennials or the quantity of perennial acreage. Most extant research has found a positive effect of education on willingness to adopt but does not control for household income (Caldas et al., 2014; Qualls et al., 2012; Jensen et al., 2007). We find that education does not impact landowner willingness to produce. This is consistent with other research that controls for household income level.

Income: Income level of respondents is an important covariate because it affects aversion to risk, liquidity constraints, and the opportunity cost of perennials. In this research, we have included both farm income and household income. Previous research has included off-farm income, net farm income or neither. Qualls et al. (2012) found that interest in perennial bioenergy crops was increasing in off-farm income. Jensen et al. (2007) found that farmers with higher net farm income indicated that they would convert less land to switchgrass. We find a jointly significant effect of both household and farm income on willingness to produce perennial bioenergy crops and acreage. Willingness to produce grasses is non-decreasing in household income. There are two groups of jointly significant incomes: respondents with household income of less than $75,000 and those with a household income of more than $75,000.[10] Agricultural landowners with less than $75,000 in annual household income are less willing to produce perennial bioenergy crops. Farm income has no significant effect on willingness but has a significant and non-decreasing effect on acreage. In other research, higher off-farm income was associated with higher willingness to produce (Caldas et al., 2014). There were five jointly significant farm income groups. Each income level was jointly significantly different from the non-adjacent groups.[11]

[10] Respondents that did not answer were not significantly different than any of the household income levels.

[11] Respondents that did not answer were not significantly different than any of the farm income.

Table 2.5d: Marginal Effects of Demographics

	Grasses		Woody Crops		Joint LRT	
Variable	Yes	Acres	Yes	Acres	*df*	χ^2
Male	0.12*	−0.064	0.16**	−17.2	4	11.23*
	(0.057)	(13.7)	(0.049)	(14.5)		
Age	0.00003	−0.086	−0.0018	−0.35	4	2.44
	(0.0015)	(0.40)	(0.0017)	(0.33)		
Work off farm	−0.050	2.05	0.022	−11.5	4	7.79*
	(0.046)	(12.4)	(0.043)	(7.47)		
Education					24	27.56
						Group[‡]
Some high school	0	0	0	0		a
	(.)	(.)	(.)	(.)		
High School	−0.014	−12.0	0.013	29.3*		a
	(0.082)	(19.0)	(0.096)	(14.7)		
Some College	−0.052	4.8	0.073	30.3		a
	(0.093)	(18.2)	(0.10)	(19.4)		
2 year degree	0.057	−5.5	−0.004	26.0*		a
	(0.084)	(24.1)	(0.10)	(14.8)		
Bachelor's	−0.027	−4.4	0.05	14.4		a
	(0.091)	(24.5)	(0.10)	(15.4)		
Graduate	0.045	−14.7	−0.01	9.9		a
	(0.096)	(24.8)	(0.11)	(16.5)		
No answer	0.11	28.4	−0.10	33.6		a
	(0.20)	(74.5)	(0.18)	(28.4)		

Standard errors calculated using the delta method and are in parentheses; * $p < 0.10$, ** $p < 0.01$, *** $p < 0.001$

[†] Joint t-test reported due to lack of convergence of restricted model

Table 2.5e: Marginal Effects of Income

	Grasses		Woody Crops		Joint LRT	
Variable	Yes	Acres	Yes	Acres	*df*	χ^2
Household Income					24	40.97*
						Group‡
less than $25,000	0	0	0	0		a
	(.)	(.)	(.)	(.)		
$25,000-50,000	0.11	−1.9	−0.060	8.3		a
	(0.084)	(16.6)	(0.091)	(13.7)		
$50,000-75,000	0.16*	−8.2	−0.069	19.3		a
	(0.087)	(18.8)	(0.097)	(18.9)		
$75,000-100,000	0.27**	4.5	0.065	6.3		b
	(0.088)	(22.0)	(0.100)	(15.1)		
$100,000-150,000	0.25**	16.4	−0.027	26.1		b
	(0.092)	(24.8)	(0.10)	(19.4)		
more than $150,000	0.22*	44.8*	0.068	28.0*		b
	(0.11)	(21.0)	(0.11)	(15.7)		
No answer	0.23*	15.0	−0.032	−15.4		ab
	(0.11)	(28.1)	(0.12)	(20.1)		
Farm Income					24	45.40**
						Group‡
Net Loss	0	0	0	0		a
	(.)	(.)	(.)	(.)		
$0-5,000	−0.01	40.7	0.026	43.7*		ab
	(0.10)	(28.9)	(0.089)	(19.7)		
$5,000-10,000	0.092	50.6*	0.00	60.6**		bc
	(0.10)	(28.3)	(0.091)	(19.5)		
$10,000-25,000	−0.026	62.1*	0.020	51.2*		cd
	(0.094)	(31.5)	(0.081)	(21.7)		
$25,000-50,000	−0.093	61.8*	0.13	83.8***		de
	(0.094)	(32.6)	(0.092)	(19.9)		
more than $50,000	−0.068	52.1	0.096	58.4**		e
	(0.10)	(38.7)	(0.099)	(21.7)		
No answer	−0.13	39.7	−0.018	49.3		abcde
	(0.12)	(42.3)	(0.12)	(36.0)		

Standard errors calculated using the delta method and are in parentheses; * $p < 0.10$, ** $p < 0.01$, *** $p < 0.001$

† Likelihood-ratio test (LRT)

‡ The joint null hypothesis that the coefficients in all four equations are equal can be rejected for responses with different letters.

Interest: Previous research has used both willingness and interest as dependent variables to estimate the impact of explanatory variables. In this research, we ask respondents to indicate their interest before they are presented with the treatments. We then use interest as an explanatory variable for three reasons. First, willingness to produce is a more direct question and should match closer to revealed preferences. Interest in perennial bioenergy crops (Kelsey and Franke, 2009; Qualls et al., 2012) is usually greater than willingness to produce. Second, previous research, which has examined non-respondents, has found that some of the non-respondents had no interest in perennial bioenergy crops. These non-respondents will bias willingness results upwards. To determine the magnitude of the bias, we need to estimate the effect of no interest on willingness to produce. Third, in order to estimate our model with simultaneous Heckman corrections, we need to include an explanatory variable in our willingness to produce equations that is not in our acreage equations. Interest is highly correlated with willingness to produce but not with acreage and so it is a good candidate for this purpose.

Table 2.5f summarizes the marginal effect of interest on willingness to produce. An increase in the level of interest in each type of perennial bioenergy crop increases the willingness to produce that type of perennial bioenergy crop. A landowner with some interest in grasses (woody crops) would be 32% (32%) more willing to produce grasses (woody crops) and would produce 23.8 (16.1) acres more than a landowner with no interest. Interest levels in grasses has a similar effect on grass willingness to produce as interest levels in woody crops has on woody crop willingness to produce.

Table 2.5f: Marginal Effects of Interest

	Grasses		Woody Crops		Joint LRT	
Variable	Yes	Acres	Yes	Acres	*df*	χ^2
Interest						
Grass					16	47.70***
						Group
No	0	0	0	0		a
	(.)	(.)	(.)	(.)		
Little	0.055	4.8	−0.18*	−9.46*		b
	(0.098)	(8.8)	(0.088)	(4.5)		
Some	0.32***	23.8**	0.060	2.54		c
	(0.092)	(7.7)	(0.083)	(3.6)		
High	0.47***	32.7***	0.13	5.41		c
	(0.14)	(9.3)	(0.10)	(4.3)		
No answer	0.087	7.5	−0.054	−2.49		ab
	(0.11)	(9.0)	(0.093)	(4.3)		
Woody Crop					16	51.1***
						Group
No	0	0	0	0		a
	(.)	(.)	(.)	(.)		
Little	0.14*	10.9*	0.26***	13.9***		b
	(0.063)	(4.9)	(0.063)	(3.5)		
Some	0.12*	9.0*	0.32***	16.1***		b
	(0.056)	(4.4)	(0.058)	(3.3)		
High	0.10	8.2	0.58***	24.7***		c
	(0.18)	(13.3)	(0.071)	(3.4)		
No answer	0.24**	17.5**	0.23*	12.8*		b
	(0.091)	(6.2)	(0.11)	(5.2)		

Standard errors calculated using the delta method and are in parentheses; * $p < 0.10$, ** $p < 0.01$, *** $p < 0.001$

† Joint t-test reported due to lack of convergence of restricted model

2.4 Conclusion

This study utilizes a stated choice approach to examine the willingness of agricultural landowners to produce perennial bioenergy crops at the intensive and extensive margins. With a lack of revealed preference data, we use a stated preference approach and randomly assign relative net returns to agricultural landowners. We also analyze the effect of observable co-variates on willingness to produce perennial bioenergy crops.

The findings show that agricultural landowners would be willing to produce perennial bioenergy crops if financially competitive, but only on a portion of their land.[12] At the same net returns per acre as their current net returns, landowners would supply 22% (5%) of their land for grasses (woody crops). The marginal effect of relative net returns on the fraction of land supply is 0.015% (0.008%) for grasses (woody crops). The implication of these results is that partial and general equilibrium biomass supply models over-estimate biomass supply from perennial crops. Landowner farmers are more willing to produce perennial bioenergy crops but on less land than non-farmer landowners.

Given that agricultural landowners are willing to produce perennial bioenergy crops, such as grasses, but only on a relatively small portion of their land, policies to promote bioenergy must address production at the intensive margins. Future research is needed to understand the underlying reasons why landowners are only interested in production on a small area. One possible explanation for this is the uncertainty and risk in producing a new crop. Policies that include production incentives, such as per acre and price subsidies, will impact perennial bioenergy production in different ways. Per acre subsidies will encourage more perennial

[12] Many models of biomass supply assume that when returns are greater for the bioenergy crop all land is converted.

acreage but will have no effect on the intensity of production. Price subsidies may encourage more acreage and increase the intensity of production.

Chapter 3

A Conceptual Assessment of Policies for Promoting Perennial Bioenergy Crops

3.1 Introduction

The expected utility model has been the primary workhorse in theoretical and empirical research of production under uncertainty. A primary reason for this is its simplicity and mathematical tractability. Additionally, empirical agricultural production models using expected utility foundations provided better fit to observed data than expected profit maximization models (Lin, Dean, and Moore, 1974). Unfortunately, expected utility has theoretical shortcomings as a positive theory and is difficult to reconcile with subsequent empirical evidence (Schoemaker, 1982). For example, a farmer may evaluate a new crop or production technology in reference to their current crop and production regime. In expected utility, farmers reevaluate all options independent of the current regime.

Evidence also suggests that individuals seem to over-weight low probability states and under-weight high probability states (Kahneman and Tversky, 1979). Furthermore, probability may be an ambiguous concept for individuals. In the case of a novel crop or production technology, farmers may have no basis to form the probabilities of outcomes in different states of the world. Studies on perennial bioenergy which allowed farmers to respond with uncertainty (i.e., "not sure" and "don't know"), show that farmers are uncertain (25%; 47%) regarding producing perennial bioenergy crops (Wen et al., 2009; Jensen et al., 2007).

The state contingent approach is not subject to the same shortcomings as the expected utility approach. Recent work by Chambers and Quiggin (2000) has shown that many results from expected utility can be generalized by way of the state contingent approach. Unlike the expected utility approach, this generalization makes no assumptions about probabilities, allowing for subjective weighting of possible states of the world. In addition to these positive advantages, the state contingent approach establishes a clearer association between the theory of production with certainty (i.e., neoclassical approaches) and uncertainty. However, gaps still remain.

One of these gaps is the neoclassical interpretation of the comparative price effects. Using a Slutsky style approach, Hurley (2015) characterized the comparative price effects by decomposing them into substitution and scale effects. Furthermore, by generalizing Nau's (2003, 2003) uncertainty aversion coefficients and creating new characterizations for uncertain technology and markets, Hurley (2015) was able to show how a proportional increase in all prices affects optimal input and output choice by revisiting Sandmo (1971).

We apply Hurley's (2015) general "Slutskyesque" approach to crop choice to understand the comparative static effects of three policy levers. Using the state-contingent analogue to the Arrow-Pratt measure of relative risk aversion and notions of relative uncertainty, we characterize the comparative static effects of these three policy levers (i.e., establishment cost-share, per acre payments, and price matching) on perennial acreage.

3.2 Analysis

We start out by describing the production function and the state-contingent model. From this we can derive the optimality conditions and the comparative static effect for a general policy lever. We then turn to the derivation of the sufficient conditions for the three policy levers to increase perennial bioenergy crop acerage.

The profit function is defined using state ($_s$) dependent per acre profits ($pq - c$) for a farmer's current production system (^{c}) and a perennial bioenergy crop (^{p}).

Per acre net revenue is price (p_s) multiplied by quantity (q_s) minus per acre costs (c_s). Total profits are perennial profits from production on perennial acreage (L^p) plus current profits on available land ($\bar{L}$), minus the opportunity cost of perennial acreage. The profit function includes three policy levers: price subsidy (γ), per acre subsidy (τ), and establishment subsidy (κ). We define the profit function as

$$\pi_s = L^p \left(p_s^p \gamma q_s^p - c_s^p + \tau\right) + \left(\bar{L} - L^p\right)\left(p_s^c q_s^c - c_s^c\right) - K + \kappa. \tag{3.1}$$

The farmer's optimization problem is to choose the perennial acreage that maximizes his/her state contingent utility,

$$\max_{\bar{L} \leq L^p \leq 0} W(\boldsymbol{\pi}) \tag{3.2}$$

where $\boldsymbol{\pi}$ represents a vector of state-contingent profit and $W(\boldsymbol{\pi})$ is the utility of state-contingent profit. $W(\boldsymbol{\pi})$ is assumed to be increasing in π_s, continuous and twice differentiable. Assuming an interior solution ($\bar{L} > L^p > 0$) the first order condition is

$$W' = \sum_{s=1}^{S} \frac{\partial W(\boldsymbol{\pi})}{\partial \pi_s} \frac{\partial \pi_s}{\partial L^p} = 0 \tag{3.3}$$

where

$$\frac{\partial \pi_s}{\partial L^p} = p_s^p q_s^p \gamma - c_s^p + \tau - \left(p_s^c q_s^c - c_s^c\right). \tag{3.4}$$

Using the first order condition we can show that at the interior solution the marginal benefits of perennial acreage must equal the marginal cost

$$\sum_{s=1}^{S} \frac{\partial W(\boldsymbol{\pi})}{\partial \pi_s} \left(p_s^p q_s^p \gamma - c_s^p + \tau\right) = \sum_{s=1}^{S} \frac{\partial W(\boldsymbol{\pi})}{\partial \pi_s} \left(p_s^c q_s^c - c_s^c\right). \tag{3.5}$$

Turning to the comparative static effects for the policy levers, we take the total derivative of W' with respect to a general policy lever (α) which is

$$\frac{dW'}{d\alpha} = \frac{\partial W'}{\partial \alpha} + \frac{\partial W'}{\partial L^p} \frac{dL^{p*}}{d\alpha} \quad \text{for} \quad \alpha = \tau, \gamma, \kappa. \tag{3.6}$$

Solving for $dL^*/d\alpha$, the general comparative statistic can be written as

$$\frac{dL^{p*}}{d\alpha} = -\frac{\frac{\partial W'}{\partial \alpha}}{\frac{\partial W'}{\partial L^{p*}}} \text{ for } \alpha = \tau, \gamma, \kappa \tag{3.7}$$

where

$$\frac{\partial W'}{\partial \alpha} = \sum_{s=1}^{S} \left(\frac{\partial W(\boldsymbol{\pi})}{\partial \pi_s} \frac{\partial^2 \pi_s}{\partial L \partial \alpha} + \sum_{t=1}^{S} \frac{\partial^2 W(\boldsymbol{\pi})}{\partial \pi_s \partial \pi_t} \frac{\partial \pi_s}{\partial L} \frac{\partial \pi_t}{\partial \alpha} \right), \tag{3.8}$$

and

$$\frac{\partial W'}{\partial L^{p*}} = \sum_{s=1}^{S} \sum_{t=1}^{S} \frac{\partial^2 W(\boldsymbol{\pi})}{\partial \pi_s \partial \pi_t} \frac{\partial \pi_s}{\partial L} \frac{\partial \pi_s}{\partial L} < 0 \tag{3.9}$$

by second order sufficiency conditions. Therefore, the sign of the comparative static of the policy is equal to the sign of $\frac{\partial W'}{\partial \alpha}$.

For convenience of notation, explanation, and graphical illustration and without loss of generality we order the states from the lowest per acre perennial return to the highest per acre perennial net return:

$$s > s' \text{ for all } R_s^p \geq R_{s'}^p \tag{3.10}$$

where $R_s^p = p_s^p q_s^p - c_s^p$.

Some assumptions are necessary to proceed. We first need to assume that states that are net revenue increasing for one crop are also net revenue increasing for the other,

$$\Delta R_{ss'}^p \geq 0 \iff \Delta R_{ss'}^c \geq 0 \text{ for all } s \tag{3.11}$$

where

$$\Delta R_{ss'} = p_s q_s \gamma - c_s - (p_{s'} q_{s'} \gamma - c_{s'}). \tag{3.12}$$

This assumes that states are also ordered for conventional crops by the per acre net return (see figure 3.1a). If we think about states of the world in terms of weather this assumption seems reasonable. States with good growing conditions will be revenue increasing for both crops. This assumption may not hold if there is weather conditions in which one crop does better and the other worse (e.g., willows perform well even in wet years and poorly drained soils). This assumption results in the profits also being ordered by states.

We also need to make an additional assumption regarding the relative uncertainty,

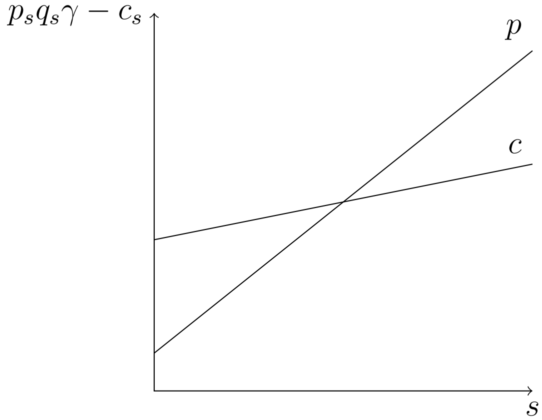
$$|\Delta R^p_{ss'}| \leq |\Delta R^c_{ss'}| \text{ for all } s \text{ and } s' \text{ or} \tag{3.13a}$$

$$|\Delta R^p_{ss'}| \geq |\Delta R^c_{ss'}| \text{ for all } s \text{ and } s', \tag{3.13b}$$

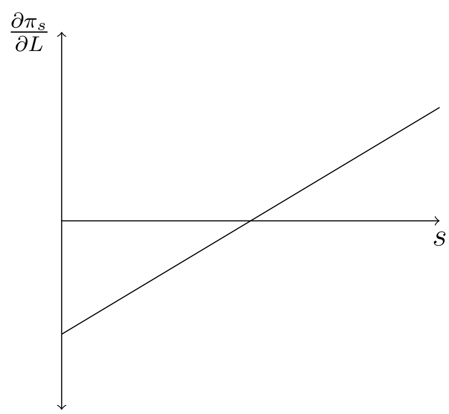
which is a single crossing condition (see figure 3.1). The per acre profits may not cross precisely at a particular state. Thus, define s_- and s^+ as the states immediately before and after this crossing point. Equation 3.13 defines the relative uncertainty between the per acre net returns for the two crops and assumes that the uncertainty between any two states is always greater for one crop. Inequality 3.13a implies that uncertainty is greater for current crops. Inequality 3.13b implies that uncertainty is greater for perennial crops. The latter seems more likely given that farmers are familiar with their current crops, these crops are largely insured and farmers have a broad range of management strategies to reduce uncertainty.

To facilitate the development of sufficiency conditions, we now define a state-contingent analogue to the Arrow-Pratt measure of risk aversion (see figure 3.2) and generalize the notion of relative risk by inclusion of a gradient (g). The state-contingent analogue is

Figure 3.1: Single Crossing Condition (This figure shows an example when uncertainty is higher for perennial crops as in inequality 3.13b)



(a) per acre profit by crop



(b) marginal profit

$$\varphi_s(\boldsymbol{\pi}, \boldsymbol{g}) = -\frac{\sum_{t=1}^{S} g_s \frac{\partial^2 W(\boldsymbol{\pi})}{\partial \pi_s \partial \pi_t}}{\frac{\partial W(\boldsymbol{\pi})}{\partial \pi_s}} \tag{3.14}$$

where

- If $\varphi_s(\boldsymbol{\pi}, \boldsymbol{g}) = \varphi_{s'}(\boldsymbol{\pi}, \boldsymbol{g}) = \varphi(\boldsymbol{\pi}, \boldsymbol{g})$ for all π_s and $\pi_{s'}$, then we have an analogue to constant relative risk aversion (CRRA).
- If $\varphi_s(\boldsymbol{\pi}, \boldsymbol{g}) > \varphi_{s'}(\boldsymbol{\pi}, \boldsymbol{g})$ for all $\pi_s > \pi_{s'}$, then we have an analogue to increasing relative risk aversion (IRRA).
- If $\varphi_s(\boldsymbol{\pi}, \boldsymbol{g}) < \varphi_{s'}(\boldsymbol{\pi}, \boldsymbol{g})$ for all $\pi_s > \pi_{s'}$, then we have an analogue to decreasing relative risk aversion (DRRA).

In the the special case where the gradient is equal to one for all states ($g_s = 1$ for all s) then we have the state-contingent analogues to the Arrow-Pratt measure of absolute risk aversion:

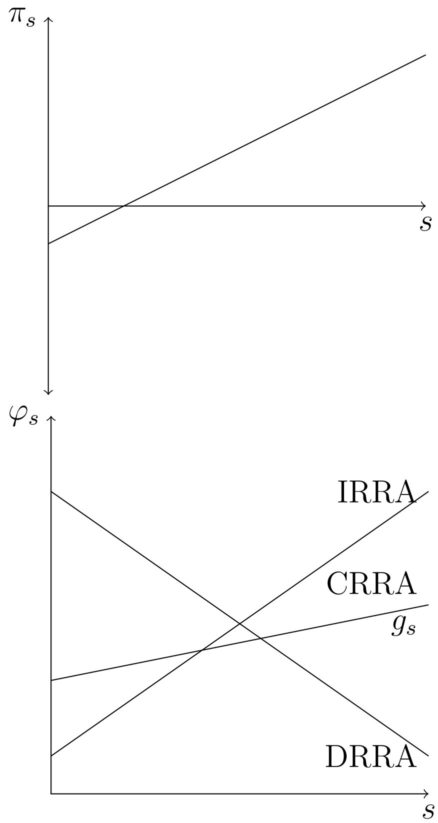
- Constant Absolute Risk Aversion (CARA)
- Increasing Absolute Risk Aversion (IARA)
- Decreasing Absolute Risk Aversion (DARA)

3.2.1 Establishment Subsidy

We first start by evaluating the establishment subsidy. Using equation 3.8 and noting that $\frac{\partial^2 \pi_s}{\partial L \partial \kappa} = 0$ and $\frac{\partial \pi_t}{\partial \kappa} = 1$, the sign of the effect of the establishment subsidy on perennial acreage (κ) is

$$\sum_{s=1}^{S} \frac{\partial \pi_s}{\partial L} \sum_{t=1}^{S} \frac{\partial^2 W(\boldsymbol{\pi})}{\partial \pi_s \partial \pi_t}. \tag{3.15}$$

Figure 3.2: Relative Uncertainty Aversion



CARA

Proposition 3.2.1 *With CARA preferences, a perennial crop establishment subsidy has no effect on the optimal perennial crop acreage.*

In the case of CARA, expression 3.15 can be written as

$$-\varphi\left(\boldsymbol{\pi},\boldsymbol{g}\right)\sum_{s=1}^{S}\frac{\partial W\left(\boldsymbol{\pi}\right)}{\partial \pi_s}\frac{\partial \pi_s}{\partial L}=0 \tag{3.16}$$

by the first order condition. Therefore, $\frac{dL^*}{d\kappa}=0$ with CARA preferences. With constant absolute risk aversion there is no indirect effect of increased profits on perennial acreage. This result does not require the assumptions of equations 3.11 or 3.13.

IARA

Proposition 3.2.2 *With IARA preferences and* $|\Delta R_s^p| \leq (\geq)\,|\Delta R_s^c|$*, perennial crop establishment subsidy will increase (decrease) optimal perennial crop acreage.*

Here we evaluate the case of IARA. First we define the certain profit that is greater than the profit at s_- but less than the profit at s^+,

$$\pi_{s_-} \leq \pi_o \leq \pi_{s^+}, \tag{3.17}$$

where

$$\pi_o = L\left((p_o^p q_o^p - c_o^p)\gamma + \tau\right) + \left(\bar{L}-L\right)\left(p_o^c q_o^c - c_o^c\right) - K + \kappa. \tag{3.18}$$

Assuming inequality 3.13a and an interior solution there will be a certain per acre perennial profit such that

$$\frac{\partial \pi_s}{\partial L} \leq 0 \iff p_s^p q_s^p \gamma - c_s^p \geq p_o^p q_o^p \gamma - c_o^p. \tag{3.19}$$

The marginal profit is negative when the conventional per acre returns are greater than the perennial per acre returns and positive otherwise. Furthermore, assuming statement 3.11,

$$\pi_s \geq \pi_0 \iff p_s^p q_s^p \gamma - c_s^p \geq p_o^p q_o^p \gamma - c_o^p \,. \tag{3.20}$$

IARA implies there exists φ_o such that $\varphi_s \geq (\leq) \varphi_o \iff \pi_s \geq (\leq) \pi_o$. Using this and statement 3.19 we have

$$p_s^p q_s^p - c_s^p \geq p_o^p q_o^p - c_o^p \implies \varphi_s \frac{\partial \pi_s}{\partial L} \leq \varphi_o \frac{\partial \pi_s}{\partial L} \text{ and} \tag{3.21a}$$

$$p_s^p q_s^p - c_s^p \leq p_o^p q_o^p - c_o^p \implies \varphi_s \frac{\partial \pi_s}{\partial L} \leq \varphi_o \frac{\partial \pi_s}{\partial L}, \tag{3.21b}$$

so

$$\varphi_s \frac{\partial \pi_s}{\partial L} \leq \varphi_o \frac{\partial \pi_s}{\partial L} \text{ for all } s. \tag{3.22}$$

Inequality 3.22 can be rewritten as

$$\frac{\partial \pi_s}{\partial L} \sum_{t=1}^{S} \frac{\partial^2 W(\boldsymbol{\pi})}{\partial \pi_s \partial \pi_t} \geq \varphi_o \frac{\partial W(\boldsymbol{\pi})}{\partial \pi_s} \frac{\partial \pi_s}{\partial L} \text{ for all } s. \tag{3.23}$$

Summing across all states this becomes

$$\sum_{s=1}^{S} \left(\frac{\partial \pi_s}{\partial L} \sum_{t=1}^{S} \frac{\partial^2 W(\boldsymbol{\pi})}{\partial \pi_s \partial \pi_t} \right) \geq \sum_{s=1}^{S} \varphi_o \frac{\partial W(\boldsymbol{\pi})}{\partial \pi_s} \frac{\partial \pi_s}{\partial L} \tag{3.24}$$

but

$$\varphi_o \sum_{s=1}^{S} \frac{\partial W(\boldsymbol{\pi})}{\partial \pi_s} \frac{\partial \pi_s}{\partial L} = 0 \tag{3.25}$$

by the first order conditions, such that

$$\sum_{s=1}^{S} \left(\frac{\partial \pi_s}{\partial L} \sum_{t=1}^{S} \frac{\partial^2 W(\boldsymbol{\pi})}{\partial \pi_s \partial \pi_t} \right) \geq 0. \tag{3.26}$$

When the current crop returns are more uncertain than the returns from perennials and the landowner has IARA preferences, the landowner will produce more perennials when given an establishment subsidy. This result will have the opposite sign if we assumed inequality 3.13b instead of inequality 3.13a. With an increasing aversion to uncertainty a establishment subsidy will increase acres of the crop with less uncertainty in returns.

DARA

Proposition 3.2.3 *With DARA preferences and* $|\Delta R_s^p| \leq (\geq) |\Delta R_s^c|$, *a perennial crop establishment subsidy will decrease (increase) optimal perennial crop acreage.*

Using the same logic as with IARA, inequality 3.22 for DARA will be

$$\varphi_s \frac{\partial \pi_s}{\partial L} \geq \varphi_o \frac{\partial \pi_s}{\partial L} \text{ for all } s. \tag{3.27}$$

Therefore, the sign of $\frac{dL^*}{d\kappa}$ will be negative. When the perennial crop returns are more uncertain than current crop returns and the landowner has DARA, the landowner will produce less perennials when given an establishment subsidy. This result will have the opposite sign if we assumed equation 3.13b instead of equation 3.13a. With a decreasing aversion to uncertainty the establishment subsidy will decrease acres of the crop with less uncertainty in returns.

3.2.2 Per Acre Subsidy

We now evaluate the per acre subsidy. This policy lever affects farmer's preferences and revenue uncertainty. Using equation 3.8 and noting that $\frac{\partial^2 \pi_s}{\partial L \partial \tau} = 1$ and $\frac{\partial \pi_t}{\partial \tau} = L^*$ for the per acre subsidy, the sign of the effect of τ on the perennial acreage is

$$\sum_{s=1}^{S} \left(\frac{\partial W(\boldsymbol{\pi})}{\partial \pi_s} + \frac{\partial \pi_s}{\partial L} \sum_{t=1}^{S} \frac{\partial^2 W(\boldsymbol{\pi})}{\partial \pi_s \partial \pi_t} L^* \right). \tag{3.28}$$

CARA

Proposition 3.2.4 *With CARA preferences a perennial crop per acre subsidy will increase optimal perennial crop acreage.*

In the case of CARA, expression 3.28 can be written as

$$\sum_{s=1}^{S} \frac{\partial W(\boldsymbol{\pi})}{\partial \pi_s} - L^* \varphi(\pi) \sum_{s=1}^{S} \frac{\partial W(\boldsymbol{\pi})}{\partial \pi_s} \frac{\partial \pi_s}{\partial L}. \tag{3.29}$$

Using the first order condition and the properties of the utility function this becomes

$$\sum_{s=1}^{S} \frac{\partial W(\boldsymbol{\pi})}{\partial \pi_s} \geq 0. \tag{3.30}$$

A per acre subsidy has no indirect effect when the farmer's aversion to uncertainty is constant. This result does not require the assumptions of statement 3.11 or inequality 3.13.

IARA and DARA

Proposition 3.2.5 *With DARA (IARA) preferences and* $|\Delta R_s^p| \geq (\leq) |\Delta R_s^c|$, *the per acre perennial crop subsidy will unambiguously increase optimal perennial crop acreage.*

IARA

We start from inequality 3.23. Multiplying by the optimal acreage (L^*) we have

$$L^* \frac{\partial \pi_s}{\partial L} \sum_{t=1}^{S} \frac{\partial^2 W(\boldsymbol{\pi})}{\partial \pi_s \partial \pi_t} \geq L^* \varphi_o \frac{\partial W(\boldsymbol{\pi})}{\partial \pi_s} \frac{\partial \pi_s}{\partial L} \text{ for all } s \tag{3.31}$$

Summing across all states this is

$$\sum_{s=1}^{S} \left(L^* \frac{\partial \pi_s}{\partial L} \sum_{t=1}^{S} \frac{\partial^2 W(\boldsymbol{\pi})}{\partial \pi_s \partial \pi_t} \right) \geq L^* \varphi_o \sum_{s=1}^{S} \frac{\partial W(\boldsymbol{\pi})}{\partial \pi_s} \frac{\partial \pi_s}{\partial L} \text{ for all } s \tag{3.32}$$

but

$$\sum_{s=1}^{S} \frac{\partial W(\boldsymbol{\pi})}{\partial \pi_s} \frac{\partial \pi_s}{\partial L} = 0 \tag{3.33}$$

by the first order conditions. Therefore

$$\sum_{s=1}^{S} \left(L^* \frac{\partial \pi_s}{\partial L} \sum_{t=1}^{S} \frac{\partial^2 W(\boldsymbol{\pi})}{\partial \pi_s \partial \pi_t} \right) \geq 0. \tag{3.34}$$

We also know that

$$\sum_{s=1}^{S} \frac{\partial W(\boldsymbol{\pi})}{\partial \pi_s} \geq 0, \tag{3.35}$$

such that

$$\sum_{s=1}^{S} \left(\frac{\partial W(\boldsymbol{\pi})}{\partial \pi_s} + L^* \frac{\partial \pi_s}{\partial L} \sum_{t=1}^{S} \frac{\partial^2 W(\boldsymbol{\pi})}{\partial \pi_s \partial \pi_t} \right) \geq 0. \tag{3.36}$$

When the uncertainty is higher for the landowner's current crops than the perennial crop, a per acre perennial subsidy will increase perennial acreage. If instead we assume inequality 3.13b, then inequality 3.34 has the opposite sign and the effect of the per acre subsidy on perennial acreage is ambiguous.

DARA

Combining the logic used in the DARA perennial establishment subsidy section with that used in the IARA per acre perennial subsidy section, we have the opposite result from IARA. When the uncertainty is lower for the landowner's current crops than the perennial crop, a per acre perennial subsidy will increase perennial acreage. When the uncertainty is higher for the landowner's current crops than the perennial crop, a per acre perennial subsidy has an unknown effect on perennial acreage.

For a per acre subsidy, the substitution effect is always positive. An increase in returns for perennials will incentivize the farmer to substitute perennial acres for conventional acres. The indirect effect is positive when the change in preferences due to the increases in profit is aligned with the relative uncertainty of the crops. The indirect effect is negative when the change in preferences is not aligned with the relative uncertainty of the crops. In this case, the comparative static effect is ambiguous.

3.2.3 Price Subsidy

We now evaluate the comparative static effect of the price subsidy. Using equation 3.8 and noting that $\frac{\partial^2 \pi_s}{\partial L \partial \tau} = p_s^p q_s^p$ and $\frac{\partial \pi_t}{\partial \tau} = L^* p_s^p q_s^p$ for the per acre subsidy the sign of the effect of γ on the perennial acreage is.

$$\sum_{s=1}^{S} \left(\frac{\partial W(\boldsymbol{\pi})}{\partial \pi_s} p_s^p q_s^p + L^* \sum_{t=1}^{S} \frac{\partial \pi_s}{\partial L} \frac{\partial^2 W(\boldsymbol{\pi})}{\partial \pi_s \partial \pi_t} p_s^p q_s^p \right) \tag{3.37}$$

CRRA

Proposition 3.2.6 *With CRRA preferences $\varphi(\boldsymbol{\pi}, \boldsymbol{g})$ where g˙s=p˙sq˙s, a perennial crop price subsidy will increase optimal perennial crop acreage.*

In the case of CRRA where the gradient is the per acre perennial revenue $(p_s q_s)$, this becomes

$$\sum_{s=1}^{S} \frac{\partial W(\boldsymbol{\pi})}{\partial \pi_s} p_s^p q_s^p - L^* \varphi(\pi, p_s q_s) \sum_{s=1}^{S} \frac{\partial \pi_s}{\partial L} \frac{\partial W(\boldsymbol{\pi})}{\partial \pi_s}. \tag{3.38}$$

By the first order conditions and the properties of the utility function this simplifies to

$$\sum_{s=1}^{S} \frac{\partial W(\boldsymbol{\pi})}{\partial \pi_s} p_s^p q_s^p \geq 0 \tag{3.39}$$

Therefore, a price subsidy increases perennial acreage when the uncertainty aversion is constant relative to the perennial crop revenue.

IRRA and DRRA

Proposition 3.2.7 *With DRRA (IRRA) preferences ($\varphi_s(\boldsymbol{\pi}, \boldsymbol{g})$) where g˙s=p˙sq˙s and $|\Delta R_s^p| \geq (\leq) |\Delta R_s^c|$, the perennial price crop subsidy will increase optimal perennial crop acreage.*

IRRA

Before we proceed we will need an assumption in addition to statement 3.11,

$$\Delta R_s^p \geq 0 \iff \Delta p_s^p q_s^p \geq 0 \text{ for all } s\,. \tag{3.40}$$

This assumption says that the direction of change in net revenue must be the same as the direction of change in revenue. A more restrictive assumption along these lines is that the per acre perennial costs (c_s^p) are not state dependent ($c_s^p = c^p$). Using inequality 3.23, we have

$$p_s^p q_s^p \frac{\partial \pi_s}{\partial L} \sum_{t=1}^{S} \frac{\partial^2 W(\boldsymbol{\pi})}{\partial \pi_s \partial \pi_t} \geq p_0^p q_o^p \varphi_o \frac{\partial W(\boldsymbol{\pi})}{\partial \pi_s} \frac{\partial \pi_s}{\partial L} \text{ for all } s. \tag{3.41}$$

Multiplying by the optimal acreage (L^*), we have

$$L^* p_s^p q_s^p \frac{\partial \pi_s}{\partial L} \sum_{t=1}^{S} \frac{\partial^2 W(\boldsymbol{\pi})}{\partial \pi_s \partial \pi_t} \geq L^* p_0^p q_o^p \varphi_o \frac{\partial W(\boldsymbol{\pi})}{\partial \pi_s} \frac{\partial \pi_s}{\partial L} \text{ for all } s. \tag{3.42}$$

Summing across all states, yields

$$\sum_{s=1}^{S} \left(L^* p_s^p q_s^p \frac{\partial \pi_s}{\partial L} \sum_{t=1}^{S} \frac{\partial^2 W(\boldsymbol{\pi})}{\partial \pi_s \partial \pi_t} \right) \geq L^* p_0^p q_o^p \varphi_o \sum_{s=1}^{S} \frac{\partial W(\boldsymbol{\pi})}{\partial \pi_s} \frac{\partial \pi_s}{\partial L} \text{ for all } s \tag{3.43}$$

but

$$\sum_{s=1}^{S} \frac{\partial W(\boldsymbol{\pi})}{\partial \pi_s} \frac{\partial \pi_s}{\partial L} = 0 \tag{3.44}$$

by the first order conditions. Therefore

$$\sum_{s=1}^{S} \left(L^* p_s^p q_s^p \frac{\partial \pi_s}{\partial L} \sum_{t=1}^{S} \frac{\partial^2 W(\boldsymbol{\pi})}{\partial \pi_s \partial \pi_t} \right) \geq 0. \tag{3.45}$$

We also know that

$$\sum_{s=1}^{S} \frac{\partial W(\boldsymbol{\pi})}{\partial \pi_s} p_s^p q_s^p \geq 0, \tag{3.46}$$

therefore

$$\sum_{s=1}^{S} \left(\frac{\partial W(\boldsymbol{\pi})}{\partial \pi_s} p_s^p q_s^p + L^* \sum_{t=1}^{S} \frac{\partial \pi_s}{\partial L} \frac{\partial^2 W(\boldsymbol{\pi})}{\partial \pi_s \partial \pi_t} p_s^p q_s^p \right) \geq 0. \tag{3.47}$$

When the uncertainty is higher for the landowner's current crops than the perennial crop, a perennial price subsidy will increase perennial acreage. If instead we assume inequality 3.13b, then inequality 3.45 has the opposite sign and the effect of the per acre subsidy on perennial acreage is unknown.

DRRA

Combining the logic used in the DARA perennial establishment subsidy section with that used in the IRRA perennial price subsidy section, we have the opposite result from IRRA. When the uncertainty is lower for the landowners current crops than the perennial crop, a perennial price subsidy will decrease perennial acreage. When the uncertainty is higher for the landowner's current crops than the perennial crop, a perennial price subsidy the effect is unknown.

For a price subsidy the substitution effect is always positive. An increase in returns for perennials will incentivize the farmer to substitute perennial acres for conventional acres. The indirect effect is positive when the change in preferences due to the increases in profit is aligned with the relative uncertainty of the crops. The indirect effect is negative when the change is preferences is not aligned with the relative uncertainty of the crops. In this case, the comparative static effect is ambiguous.

3.3 Conclusion

We have characterized the comparative static effects of three policy levers for increasing perennial crop acreage by decomposing this effect into a direct substitution and indirect income effect using a state-contingent approach to crop choice. For the establishment subsidy, the substitution effect is zero because there is no opportunity to increase profits by changing the optimal perennial acreage. The direction of the indirect effect depends on the relative uncertainty of the crops and the uncertainty preferences. If the establishment subsidy decreases aversion to uncertainty and the perennial crops is the more uncertain crop or it increases aversion to uncertainty and the perennial crop is the less uncertain crop, then this effect is positive, otherwise it is negative.

For the per acre and price subsidy, the comparative static effect is either positive or ambiguous. The substitution effect is always positive. That is to say that higher perennial crop profits will incentivize farmers to produce more perennials acres. Similar to the establishment subsidy, the indirect effect can be positive or negative. This results in an ambiguous comparative static effect when the indirect effect is negative. Farmers would like to substitute from conventional to perennial crops for the additional profits but the uncertainty at this acreage allocation is less preferred. In some cases, the indirect effect will just dampen the substitution effect, reducing the effect of the policy to promote perennial bioenergy crops. In others, a farmers preferences may be such that the increase in uncertainty aversion due to the increased profit from the subsidy will result in a reduction in perennial acreage. In this case, the farmer prefers less uncertainty to the increase in profits.

These results have interesting implications for policy meant to encourage perennial bioenergy production. At the intensive margin, it is possible that the intended substitution from other crops to perennial will be muted by the uncertainty and a farmers aversion to it. For some farmers, the subsidy may even decrease production at the intensive margin because they prefer more certain profits to higher returns. Therefore, policy makers who wish to support perennial crop production must understand the implications of their policies in an uncertain world. Policy levers that reduce uncertainty in perennial crop returns may be necessary, in conjunction with other incentives, to encourage adoption.

Chapter 4

An Empirical Analysis of the Risks of Perennial Bioenergy Crop Production

4.1 Introduction

As a result of concerns over energy security and the environmental impacts of fossil fuels, recent United States energy policy has included provisions to promote renewable energy. In the transportation sector, which relies almost exclusively on liquid fuels, renewable energy is based primarily on corn ethanol and soy biodiesel. Therefore, policies encouraging renewable energy have driven demand for agricultural commodities. This has resulted in a land-use shift from perennial conservation acres, pasture, and hay to annual field crops such as corn and soybean (U. S. Department of Agriculture National Agricultural Statistics Service, 2014; U. S. Department of Agriculture, 2013b; U. S. Department of Agriculture Farm Service Agency, 2014). This change in land use has several environmental consequences including increases in greenhouse gas emissions and reductions in water quality (Fargione et al., 2008; Rajagopal et al., 2007).

The Energy Policy Act does include provisions for advanced biofuels from cellulosic biomass (i.e., structural material of plants). However, commercial scale production, which utilizes annual crop residues for its primary feedstock, has been lagging far below the required production mandates. Cellulosic biofuels from crop residues further increase the environmental impacts of US liquid fuels energy policy by reducing surface residue (Lal, 2005).

Perennial bioenergy crops such as perennial grasses and woody crops are an alternative source of feedstock for biofuel with lower environmental impacts than their annual counterparts (Lemus and Lal, 2005; McLaughlin and Walsh, 1998). Perennial bioenergy crops can mitigate the environmental impacts of changing land use that has resulted from the Energy Policy Act and increase the sustainability of U.S. energy policy.

The 2008 Farm Bill included provisions to support biomass production on agricultural land. The Biomass Crop Assistance Program (BCAP) provides payments for perennial production establishment, payments based on acreage, and price matching payments. Eligible crop producers can receive reimbursements for up to 75 percent of their establishment costs, up to five years of annual payments and price matching up to $45 per dry ton.

Previous work (see chapter 2) has shown that, when perennial grasses are financially competitive with a farmer's current crops, a majority of farmers will produce perennial grasses. However, they are only willing to plant perennials on a small portion of their land. One potential explanation for this is the risk posed by growing a new crop and selling it into a new emerging market (Just and Zilberman, 1988). The relative magnitude of the risk can affect both the willingness to produce and the number of acres. Crops that are financially competitive, but pose greater risks than their current crops, will be tested in a small area as part of a diversified production portfolio. This strategy will reduce aggregate risk (Bocquého and Jacquet, 2010; Larson, English, and He, 2007).

New cropping regimes require a significant investment in both human capital and capital goods. When the agronomics differ as widely as they do between conventional and perennial bioenergy crops, large investments in the development of human capital resources must be undertaken to successfully and optimally manage the new system.

Understanding the magnitude of the risks and the fixed adoption costs can help to better predict perennial supply and the impact of government policies. As we noted in chapter 3, farmers' preferences can limit the effect of subsidies and in some cases, the effect is unknown.

This study estimates the relative risk ratio and fixed adoption costs for perennial grasses and woody crops by parameterizing a structural model of crop choice under risk. Previous work has estimated perennial acreage using simulations of a crop choice under risk framework (Bocquého and Jacquet, 2010; Larson, English, and He, 2007). We use a similar structural model of crop choice under risk, but estimate the parameters econometrically using data from a crop choice approach of agricultural landowners from the Upper Mississippi River Basin.

We choose to develop and estimate a structural model, which has several advantages. First, it provides a theoretical explanation for the the choice of explanatory variables, including their interactions. Second, it provides for a behavioral interpretation of the coefficients of these variables and their marginal effects as it relates to crop choice under risk. Third, parameters of the crop choice model, including the relative risk ratio and the fixed adoption costs can be estimated, which is not possible with the reduced form approach. Fourth, using the structural relationship between the discrete and continuous variables, we can estimate the variance of the error of the risk-adjusted profit. Fifth, using the simultaneous Heckman correction and the nonlinear constraints, we can reduce the bias of the results due to sample selection while increasing the efficiency of the estimator over multi-step procedures.

4.2 Conceptual Model

We start by constructing an expected utility analogue to the more general model in chapter 3 using the profit function as defined in this chapter. While the state-contingent model has many conceptual advantages over the expected utility approach it lacks the mathematical traceability of expected utility. In addition the expected utility model still allows us to explore risk, a specific construct of uncertainty. The expected utility model gives us an explicit solution for the risk adjusted profit and the optimal acreage. Finally, we use these optimal conditions to establish the comparative static effects of the policy levers, relative returns, and available acreage ($\bar{L}$). Assuming the per acre returns are random and distributed normally $\tilde{\pi} \sim N(\pi, \sigma)$, and that the landowners have constant absolute risk aversion (CARA) ($U(\tilde{\pi}) = 1 - e^{-\phi\tilde{\pi}}$ where $\phi = -U''(\bar{w})/U'(\bar{w})$), we can transform the utility function into the certainty equivalent model $E(U) = \pi - \frac{\phi}{2}\sigma^2$ using Freund (1956), where σ^2 is the variance of the profit. One change that we make from the profit function in chapter 4 is to add non-monetary per acre net benefits.[1] Our certainty equivalent objective function is then,

$$\max_{\substack{L_p \geq 0 \\ A=0,1}} \; V = \pi_c\bar{L} - \frac{\phi}{2}\bar{L}^2\sigma_c^2 + A\Bigg[(\pi_p - \pi_c)L_p + (b+\tau)L_p - K + \kappa \\ - \frac{\phi}{2}\left(L_p^2\gamma^2\sigma_p^2 + (L_p^2 - 2\bar{L}L_p)\sigma_c^2 + 2L_p\left(\bar{L} - L_p\right)\rho\gamma\sigma_p\sigma_c\right)\Bigg], \quad \text{s.t.} \quad L_p \leq \bar{L}. \tag{4.1}$$

We do not assume an interior solution and so A is the decision to produce perennials or not. Following Just and Zilberman (1988), the solution to the maximization problem is,

$$L_p^* = \begin{cases} \bar{L} & \text{if} \quad A = 1 \quad \text{and} \quad V'(\bar{L}) \geq 0 \\ \tilde{L}_p & \text{if} \quad A = 1 \quad \text{and} \quad V'(\tilde{L}_p) = 0 \\ 0 & \text{if} \quad A = 0 \end{cases} \tag{4.2}$$

where $\tilde{L}_p = [\pi^p - \pi^c + b + \tau]\,\phi^{-1}(\sigma_p^2\gamma^2 + \sigma_c^2 - 2\rho\sigma_p\gamma\sigma_c)^{-1} + \bar{L}(\sigma_c^2 - \rho\sigma_p\gamma\sigma_c)(\sigma_p^2\gamma^2 + \sigma_c^2 - 2\rho\sigma_p\gamma\sigma_c)^{-1}$ is the optimal perennial acreage with an interior solution and L_p^* is the optimal perennial acreage. Farmers will grow perennial bioenergy crops

[1] The non-monetary per acre net benefits are the non-pecuniary benefits per acre minus the non-pecuniary benefits plus a misspecification parameter.

$(A = 1)$ when the risk adjusted profit is positive,

$$\begin{aligned}&(\pi_p\gamma - \pi_c)L_p + (b+\tau)L_p - K + \kappa \\ &- \frac{\phi}{2}\left(L_p^2\gamma^2\sigma_p^2 + (L_p^2 - 2\bar{L}L_p)\sigma_c^2 + 2L_p\left(\bar{L} - L_p\right)\rho\gamma\sigma_p\sigma_c\right) > 0.\end{aligned} \tag{4.3}$$

By assuming an interior solution equation 4.3 can be written as $\tilde{L}_p^2\frac{\phi}{2}\,\mathrm{Var}(\pi_p - \pi_c) > K - \kappa$, where $\mathrm{Var}(\pi_p - \pi_c) = \gamma^2\sigma_p^2 + \sigma_c^2 - 2\rho\gamma\sigma_p\sigma_c$. The left hand side is always non-negative. Assuming the fixed costs of perennials minus the establishment subsidy is positive $K - \kappa > 0$ then the farmer will not grow perennials $(A = 0)$ when $\tilde{L}_p < \sqrt{2\frac{K-\kappa}{\phi\,\mathrm{Var}(\pi_p - \pi_c)}}$. Given the optimal interior solution the farmer must produce enough perennial acreage so that the risk adjusted profits are greater than the fixed costs of perennials.

4.2.1 Comparative Statics

In this section we determine the comparative static effects of the policy levers, relative returns and the available acreage.

Establishment Subsidy: Given that we have assumed CARA, an establishment subsidy does not effect the optimal perennial acreage (see chapter 3). This is not a surprising result since we know that, with CARA, the risk aversion remains constant as the level of profit changes.

Annual Subsidy, Non-pecuniary Benefits, Relative per acre returns: We know from chapter 3 that a per acre subsidy has a positive impact on acreage when the landowner has CARA preferences. There is no scale effect with CARA preferences but there is a substitution from conventional to perennial bioenergy crops with a per acre subsidy. Using the certainty equivalent approach, we can determine not only the direction of the effect but also the magnitude. Assuming an interior solution the per acre subsidy effect on perennial acreage is

$$\frac{\partial \tilde{L}_p}{\partial \tau} = \frac{1}{\phi(\gamma^2 \sigma_p^2 + \sigma_c^2 - 2\rho\gamma\sigma_p\sigma_c)}. \tag{4.4}$$

This value is always positive given that the individual is risk averse ($\phi > 0$) and $\gamma^2\sigma_p^2 + \sigma_c^2 - 2\rho\gamma\sigma_p\sigma_c = \text{Var}(\pi^p - \pi^c) > 0$. The comparative static effect is equal to the effect of the non-monetary benefits and the relative per acre returns on perennial acres, $\frac{\partial \tilde{L}_p}{\partial \tau} = \frac{\partial \tilde{L}_p}{\partial b} = \frac{\partial \tilde{L}_p}{\partial(\pi_p - \pi_c)}$.

Land: The relationship between total acreage and perennial acreage is,

$$\frac{\partial \tilde{L}_p}{\partial \bar{L}} = \frac{\sigma_c^2 - \rho\sigma_c\gamma\sigma_p}{\gamma^2\sigma_p^2 + \sigma_c^2 - 2\rho\gamma\sigma_p\sigma_c}. \tag{4.5}$$

This value is positive when $\sigma_c > \rho\gamma\sigma_p$ and negative otherwise. Using $\rho = \frac{\sigma_{cp}}{\sigma_c\gamma\sigma_p}$, the comparative static effect of available land on perennial acreage is positive when the variance of conventional returns is greater than the covariance of the conventional and perennial returns ($\sigma_c^2 > \sigma_{cp}$).

4.2.2 Relative Risks

Using equation 4.5 we can determine the relationship between the conventional and perennial return risks:

$$\left(\frac{\partial \tilde{L}_p}{\partial \bar{L}}\right)^{-1} - 1 = \frac{\gamma^2\sigma_p^2 - \rho\gamma\sigma_p\sigma_c}{\sigma_c^2 - \rho\sigma_c\gamma\sigma_p}. \tag{4.6}$$

This is the perennial per acre return variance minus the conventional and perennial per acre return covariance. If the correlation (ρ) is equal to zero, then this is the ratio of the per acre return variances. If the correlation is equal to one, then this is the negative of the ratio of the standard deviations. If the correlation is equal to minus one, then this is the ratio of the standard deviations.

If this ratio is greater than one, the perennial per acre profit risks are greater than the current per acre profit risks ($\gamma^2\sigma_p^2 > \sigma_c^2$). If this ratio is less than one then the current per acre profits risk are greater ($\gamma^2\sigma_p^2 < \sigma_c^2$). If it is equal to one then the per acre profit risks are equal ($\gamma^2\sigma_p^2 = \sigma_c^2$). Note that this result doesn't require any assumptions about the correlation between current and perennial per acre returns.

Using this relationship and equation 4.6 we can show that when the comparative static effect of land on perennial acres is less than one-half, the perennial per acre profits risk is greater than the current per acre profit risk ($\gamma^2\sigma_p^2 > \sigma_c^2 \Leftrightarrow \frac{\partial \tilde{L}_p}{\partial \bar{L}} > \frac{1}{2}$). The intuition behind this results from recognizing that the land comparative static effect is equal to the fraction of land planted to perennials when evaluated at zero relative profit ($\frac{\partial \tilde{L}_p}{\partial \bar{L}} = \frac{\tilde{L}_p(\pi_p - \pi_c + b + \tau = 0)}{\partial \bar{L}}$). The landowner is deciding how to allocate his/her land between two risky crops. If risk and returns are the same for both crops then producing equal areas minimizes the aggregate risk. If the returns are the same for two crops and the risks are greater for one crop the landowner will allocate less land to the risker crop.

4.3 Empirical Methods

Our conceptual model above outlined the certainty equivalent utility function (4.1) for crop choice under risk. When solved for the optimal perennial acreage, the certainty equivalent utility function gives us a set of analytical solutions and comparative static effects. The observable variables were collected using a survey, which included stated choice questions with randomized relative returns to conventional and perennial crops as treatments. In chapter 2 this data was analyzed without assumptions regarding the structure of the utility function. Here we use the same data but specify the structural relationship as outlined in the conceptual model.

The farmer's decision is two-fold: whether or not to produce perennial crops and how much acreage to allocate for perennial production. Based on the conceptual model the decision to produce or not depends on how many acres would be planted if in fact, perennials are planted. This is because the acreage decision effects the expected profit and the risk. However, the acreage decision is only observed for the farmers who choose to produce. First, we outline the econometrics needed to estimate the two decisions independently. Once we have a clear understanding of these two decisions, we can outline techniques to deal with the inter-dependency and the unobserved data.

4.3.1 Willingness to Supply

The willingness to supply (WTS) questions in the survey were designed as closed-ended pure dichotomous choice questions. This minimizes bias by avoiding leading the respondent. Dichotomous choice questions necessitate the use of a discrete choice statistical analysis (e.g., probit, logit). Using a random utility model framework, one can derive the probability the respondent will answer yes to the question given assumptions about the underlying utility function and the distribution of the error term (Wooldridge, 2002). Let U be the utility for the respondent:

$$U(\tilde{\pi}_p - \tilde{\pi}_c, L_p, \bar{L}, K, b) \tag{4.7}$$

where the variables are defined as they are in equation (4.1). The WTS questions ask respondents if they would grow perennial crops given a randomized net return relative to their current crop choices. The respondent will answer "yes" to the question if

$$U(A = 1) > U(A = 0), \tag{4.8}$$

where the left hand side of the inequality (4.8) is the utility from producing perennials and the right hand side is the utility from producing no perennials. Using the certainty equivalent utility, equation 4.1 and equation (4.8), we have the conditions under which adoption occurs,

$$\begin{aligned} V &= V^1 - V^0 \\ &= (\pi_p - \pi_c + \tau)L_p + bL_p - K \\ &\quad - \frac{\phi}{2}\left(L_p^2\gamma^2\sigma_p^2 + (L_p^2 - 2\bar{L}L_p)\sigma_c^2 + 2L_p\left(\bar{L} - L_p\right)\rho\gamma\sigma_p\sigma_c\right) > 0, \end{aligned} \tag{4.9}$$

which is the certainty equivalent of the utility of adoption $(V^1(A = 1))$ minus the certainty equivalent of utility of not adopting $(V^0(A = 0))$. The utility is unobservable but the dichotomous choice, relative returns per acre, and the available land is observable. The adoption decision, as outlined in equation (4.1), is dependent on the optimal interior perennial acreage. The perennial acreage is only observable for respondents answering "yes" to the WTS question. Based on our conceptual model, the respondents answering "no" to the WTS question must have had a perennial acreage in mind when they made the decision to produce or not. This is because the perennial acreage effects the risk adjusted profit. An estimate of the perennial acreage can be determined from the observable assuming the optimal perennial acreage solution. Therefore we substitute the optimal perennial acreage given adoption into equation (4.9). The probability model is then,

$$\Pr\left[\frac{(\pi_p-\pi_c+b+\tau)^2}{2\phi(\gamma^2\sigma_p^2+\sigma_c^2-2\rho\gamma\sigma_p\sigma_c)}+\frac{(\pi_p-\pi_c+b+\tau)(\sigma_c^2-\rho\sigma_c\gamma\sigma_p)}{(\gamma^2\sigma_p^2+\sigma_c^2-2\rho\gamma\sigma_p\sigma_c)}\bar{L}\right.$$
$$\left.+\frac{\phi(\sigma_c^2-\rho\sigma_c\gamma\sigma_p)^2}{2(\sigma_p^2+\sigma_c^2-2\rho\gamma\sigma_p\sigma_c)}\bar{L}^2-K>\epsilon_A\right] \tag{4.10}$$

where $\epsilon_A = \epsilon_1 - \epsilon_0$ is the error in the estimates of the risk adjusted profit which is something that we don't observe. In order to simplify this equation we define $\beta_1 = \phi^{-1}(\gamma^2\sigma_p^2+\sigma_c^2-2\rho\gamma\sigma_p\sigma_c)^{-1}$ and $\beta_2 = (\sigma_c^2-\rho\sigma_c\gamma\sigma_p)(\gamma^2\sigma_p^2+\sigma_c^2-2\rho\gamma\sigma_p\sigma_c)^{-1}$. Substituting this into the previous equation we have

$$\Pr\left[\frac{\beta_1}{2}(\pi_p-\pi_c+b)^2+\beta_2(\pi_p-\pi_c+b)\bar{L}+\frac{\beta_2^2}{2\beta_1}\bar{L}^2-K>\epsilon_A\right]. \tag{4.11}$$

Using this probability model and reducing the unobservables to a single coefficient on the observables and noting that the probability model is normalized to the standard normal for a probit estimation, we can determine the estimation equation,

$$\Phi\left(\alpha_1(\pi_p-\pi_c)+\alpha_2\bar{L}+\alpha_3\bar{L}(\pi_p-\pi_c)+\alpha_4(\pi_p-\pi_c)^2+\alpha_5\bar{L}^2+\alpha_6\right) \tag{4.12}$$

where $\alpha_1 = b\beta_1/\sigma$, $\alpha_2 = b\beta_2/\sigma$, $\alpha_3 = \beta_2/\sigma$, $\alpha_4 = \beta_1/(2\sigma)$, $\alpha_5 = \beta_2^2/(2\beta_1\sigma)$, and $\alpha_6 = -K\sigma^{-1}+b^2\beta_1/(2\sigma)$. This is the reduced form equation were the independent variables are the relative net return, available land, squares and interactions. The normalization parameter prevents an estimation of the β parameters.

4.3.2 Perennial Acreage

If the respondents answer yes to the willingness to supply question, they are asked a follow up question on the acreage they would use for perennial crop production given the relative expected net incomes per acre. The linear estimation model of the perennial acreage using the certainty equivalent model is,

$$L_p = \beta_1(\pi_p - \pi_c) + \beta_2\bar{L} + \beta_3 + \epsilon_L \tag{4.13}$$

where $\beta_3 = b/\beta_1$. This equation which can be estimated by ordinary least squares (OLS) regression for the observations in which the acreage is positive, assuming that $\epsilon_L \sim N\left(0, \sigma_{\epsilon_L}\right)$. Equation 4.13 directly estimates the β parameters and the estimate of b can be obtain by β_3/β_1. This linear equation is only a consistent estimator of the coefficients if

$$\begin{aligned}\mathbb{E}\left[\beta_1(\pi_p - \pi_c) + \beta_2\bar{L} + \beta_3 + \epsilon_L \middle| A = 1\right] \\ = \mathbb{E}\left[\beta_1(\pi_p - \pi_c) + \beta_2\bar{L} + \beta_3 + \epsilon_L\right].\end{aligned} \tag{4.14}$$

The acreage decision is observed if $A = 1$, thus the subsample will include only observations for which $L_p \geq \sqrt{2K\beta_1}$. Those farmers that perceive a high risk of perennials would allocate a lower fraction of land making it less likely that they would adopt. Substituting for L_p, this becomes $\epsilon_L \geq \sqrt{2K\beta_1} - \mathbb{E}[L_p]$, which shows that μ is bound from below. Given that ϵ_L is normally distributed, $\mathbb{E}[\epsilon_L|A = 1] > \mathbb{E}[\epsilon_L] = 0$ therefore

$$\mathbb{E}\left[\beta_1(\pi_p - \pi_c) + \beta_2\bar{L} + \beta_3 + \epsilon_L \,|A = 1\right] = \beta_1(\pi_p - \pi_c) + \beta_2\bar{L} + \beta_3 + \mathbb{E}[\epsilon_L|A = 1]. \tag{4.15}$$

where $\mathbb{E}[\epsilon_L|A = 1]$ is the source of the sample selection bias.

Self Selected Sample

The coefficients of the acreage decision can be consistently estimated by the selected sample, of respondents that indicated perennial crop adoption, if the expectations of the selected sample equal that of the random sample. If this is not the case, as we have shown, the estimates are biased. The Heckman correction model is commonly used to account for this bias (Heckman, 1979). The perennial acreage is only observed if $L_p \geq \sqrt{2K\beta_1}$. The simultaneous Heckman correction is a system of equations

$$1\{V > 0\} = V(\boldsymbol{\alpha}) + \epsilon_A \tag{4.16a}$$

$$L_p = \beta_1(\pi_p - \pi_c) + \beta_2\bar{L} + \beta_3 + \epsilon_L. \tag{4.16b}$$

where $= V(\boldsymbol{\alpha})$ is the reduced form of equation 4.12. We assume a bivariate normal $\epsilon = (\epsilon_A, \epsilon_L) \sim N(0, \Sigma)$ with the following variance co-variance matrix

$$\Sigma = \begin{bmatrix} 1 & \sigma_{A,L} \\ \sigma_{A,L} & \sigma_L \end{bmatrix} \tag{4.17}$$

where $\sigma_{A,L}$ is the covariance of ϵ_A and ϵ_L. Using $\rho_{A,L} = \frac{\sigma_{A,L}}{\sigma_A\sigma_L}$ the log likelihood function[2] is,

$$\begin{aligned} &\ln\Phi\left[V(\alpha)\right]^{[L_p\in\emptyset]} + \left[\ln\Phi\left(\frac{V(\alpha) + \rho_{A,L}\frac{L_p-\beta_1(\pi_p-\pi_c)-\beta_2\bar{L}-\beta_1 b}{\sigma_L}}{\sqrt{1-\rho^2_{A,L}}}\right)\right. \\ &\left. + \ln\phi\left(\frac{L_p - \beta_1(\pi_p - \pi_c) - \beta_2\bar{L} - \beta_1 b}{\sigma_L}\right) - \sigma_L\right]^{L_p\notin\emptyset} \end{aligned} \tag{4.18}$$

where Φ (ϕ) is the standard normal cumulative distribution (probability density) function (Wooldridge, 2002).

4.3.3 Joint Estimation Model

Using the Heckman approach we can get consistent and unbiased estimates of β_1, β_2, and b. Using these estimates and our linear equation we could predict Ł$_p$

[2]In practice we estimate $\tanh^{-1}\rho_{A,L}$ to restrict $\rho_{A,L}$ to be between minus one and one and $\ln\sigma_L$ to restrict σ_L to positive values

and then estimate the discrete choice equations (i.e. two-step approach) giving us predictions of risk adjusted profit variance σ and the fixed costs (K). Jointly estimating this structural model in a single step will increase the efficiency of the estimator. The system of equations that we are estimating is

$$\begin{aligned}\Pr[A=1] = \Phi\Bigg(&\frac{\beta_2 b(\pi_p - \pi_c) + \beta_2 b\bar{L} + \beta_2 \bar{L}(\pi_p - \pi_c)}{\sigma_A} \\ &+ \frac{\beta_1/2(\pi_p - \pi_c)^2 + \beta_2^2/(2\beta_1)\bar{L}^2 + b^2\beta_1/2 + K}{\sigma_A}\Bigg)\end{aligned} \tag{4.19a}$$

$$L_p = \beta_1(\pi_p - \pi_c) + \beta_2\bar{L} + \beta_1 b. \tag{4.19b}$$

The log likelihood function is

$$\begin{aligned}&\ln\Phi\left[-V(\beta)\right]^{[A=0]} + \ln\Phi\left[V(\beta)\right]^{[A=1,L_p\in\emptyset]} \\ &+ \left[\ln\Phi\left(\frac{V(\beta) + \rho_{A,L}\frac{L_p - \beta_1(\pi_p-\pi_c) - \beta_2\bar{L} - \beta_1 b}{\sigma_L}}{\sqrt{1-\rho_{A,L}^2}}\right)\right. \\ &\left. + \ln\phi\left(\frac{L_p - \beta_1(\pi_p - \pi_c) - \beta_2\bar{L} - \beta_1 b}{\sigma_L}\right) - \sigma_L\right]^{[A=1],L_p\notin\emptyset}\end{aligned} \tag{4.20}$$

where $\ln\Phi\left[V(\beta)\right]^{[A=1,L_p\in\emptyset]}$ is an additional modification to the log-likelihood function to include observations for which the respondent indicated that they would produce perennials but did not indicate the number of acres for perennial production.

4.4 Data

Table 4.1 summarizes the data used for the analysis. On average, landowners owned or rented 318 acres. About one-quarter (24 percent) rented land. The crop choice approach randomly assigned per acre net returns for grasses and woody

Table 4.1: Summary Statistics

Variable	**Description**	**Mean**	**St. Dev.**	N
Land	Land owned plus land rented	318	393	435
Grass Returns	Perennial grass returns per acre relative to current returns per acre	76.9	112	435
woody crop Returns	Woody crop returns per acre relative to current returns per acre	129	113	435
Grass Yes	Willing to grow perennial grasses at relative net returns (0,1)	0.59		433
woody crop Yes	Willing to grow woody crops at relative net returns (0,1)	0.44		432
Grass Acres	Number of acres the landowner is willing to grow perennial grasses on.	80.2	99.2	228
woody crop Acres	Number of acres the landowner is willing to grow woody crops on.	49.1	53.1	170

crops relative to their current per acre net returns. The treatments ranged from -\$100 to \$250 for grass and -\$50 to \$300 for woody crops at \$50 increments. The average grass and woody crop relative returns for surveys received was not significantly different from what we would expect based on a balanced sample (\$75 and \$125).

4.5 Results

4.5.1 Reduced Form Models

Table 4.2 compares the reduced form models based on equation 4.18. Model one restricts the error correlation (ρ) to zero (i.e., no simultaneous Heckman correction) and model two includes the error correlation. We estimate these two models for both grasses and woody crops.

For both grasses and woody crops, the relative per acre returns and its square

are significant predictors of perennial bioenergy crop adoption. Adoption is increasing in per acre relative perennial returns. The rate of increase is declining with higher relative net incomes. For both grasses and woody crops, adoption is no longer increasing above \$400 per acre. The effect of relative net incomes is not significantly different from zero for relative net incomes above approximately \$270.

The marginal effect of the relative net income amount, for the acres equation, is 0.19 and 0.12 for grasses and woody crops respectively. Since this is constant, the change in acreage is 19 and 12 acres for each \$100 change in relative net income for grasses and woody crops respectively. A farmer with an additional 100 acres of available land will produce 7.8 (0.96) more acres of grasses (woody crops). Using this estimate and the constant coefficient, we can estimate the fraction of land at zero relative net income for the mean available acres. The fraction of available land for producing grasses (woody crops) is 18% (9%).

The second model uses the simultaneous Heckman procedure to correct the bias of the estimation of the acreage equation. The correlation of the errors is not significantly different from zero for either grasses or woody crops.

4.5.2 Structural Model

Tables 4.3 and 4.4 illustrate the parameter estimates from the structural model (see equation 4.20). Model 3 assumes the ρ and b are equal to zero and Model 4 assumes that ρ is equal to zero. Model 5 is the unrestricted model. We estimate the beta parameters, the non-pecuniary benefits, fixed capital costs, and the variance of the risk adjusted profit. Using $1/\beta_2 - 1 = (\sigma_p^2 - \sigma_{cp})(\sigma_c^2 - \sigma_{cp})^{-1}$, we estimate the ratio of the variance in the perennial returns minus the covariance over the variance of current returns minus the covariance. Assuming the correlation

Table 4.2: Reduced Form Coefficients With and Without Heckman Sample selection Correction

	Grasses		**woody crops**	
	(1)	(2)	(1)	(2)
Yes				
Land†	0.078*	0.082*	−0.067	−0.070
	(0.040)	(0.042)	(0.049)	(0.052)
Returns†	0.80***	0.80***	0.68***	0.68**
	(0.13)	(0.13)	(0.15)	(0.15)
Land*Returns†	0.0078	0.0090	0.023	0.023
	(0.018)	(0.018)	(0.021)	(0.021)
$\text{Land}^{2\dagger}$	−0.0029	−0.0031	0.0034	0.0036
	(0.0018)	(0.0019)	(0.0032)	(0.0034)
$\text{Returns}^{2\dagger}$	−0.20***	−0.20***	−0.167**	−0.167**
	(0.060)	(0.060)	(0.054)	(0.054)
Constant	−0.20	−0.21*	−0.53***	−0.52***
	(0.12)	(0.13)	(0.15)	(0.15)
Acres				
Returns	0.19*	0.18*	0.116**	0.118**
	(0.080)	(0.082)	(0.040)	(0.040)
Land	0.078*	0.077*	0.0096	0.0098
	(0.030)	(0.030)	(0.0069)	(0.0069)
Constant	31.0*	33.5*	27.0***	25.7***
	(13.3)	(14.1)	(4.9)	(5.6)
σ	63 ***	63 ***	36.2***	36.2***
	(13)	(13.0)	(4.5)	(4.5)
ρ		−0.045		0.030
		(0.041)		(0.033)
log likelihood	−2559.708	−2559.630	−1818.300	−1818.258
N	430	430	430	430

Robust standard errors and are in parentheses; * $p < 0.10$, ** $p < 0.01$, *** $p < 0.001$

† The land and return variables were rescaled for the discrete choice equation to more easily report the results. To obtain the unscaled coefficients and standard errors for land and returns divide by 100. To obtain the unscaled coefficients and standard errors for the interaction and the squared terms divide by 10,000. The returns and land where not rescaled for the acres equation.

is zero, this ratio is the ratio of the variances, σ_p^2/σ_c^2. For grasses, the ratio is 36 and significantly different from one (equal variance) at the 90% significance level. For woody crops, the value is 99 but not significantly different from one. These results are partly driven by the relatively low risk of corn and soybean production due to crop insurance, future markets, and risk management strategies. In contrast perennial bioenergy crops lack well established markets, rely on government programs, and do not have the same risk reduction options as corn and soybean. Therefore, landowners' subjective risk of perennial bioenergy production would be much higher than risks for their current crops.

In addition to the parameters that can be estimated from the reduced form models, we can estimate three additional parameters with the structural model. Our estimation of the parameters for the structural models are in table 4.3 and 4.4. The structural model allows for an estimation of the fixed capital cost of adoption, which is \$11,000 for grasses and \$14,000 for woody crops. We also estimate the standard deviation of the error of the risk adjusted profit, which is \$18,000 for grasses and \$16,000 for woody crops. For both grasses and woody crops these non-pecuniary benefits are significantly different from zero for the structural model.

4.6 Conclusion

This research uses a structural model and stated crop choice approach to examine perennial bioenergy production. Since markets do not currently exist, we randomly assign relative returns to agricultural landowners. Using their stated preferences and a structural model we estimate three determinants of crop choice (risk, non-pecuniary benefits, and capital investment costs).

Table 4.3: Structural Parameter Estimates for Perennial Grasses with and without Heckman Sample Selection Correction

	Model		
Heckman Correction	No	No	Yes
Parameter	(3)	(4)	(5)
$\frac{1}{\phi(\sigma_p^2+\sigma_c^2-2\rho\sigma_p\sigma_c)}$	0.39***	0.22**	0.19**
	(0.053)	(0.077)	(0.073)
$\frac{\sigma_c^2-\rho\sigma_c\sigma_p}{\sigma_p^2+\sigma_c^2-2\rho\sigma_p\sigma_c}$	0.076***	0.034*	0.027*
	(0.018)	(0.019)	(0.016)
b		199.5*	268.9*
		(109.1)	(132.6)
K	−1459.0	−9033.1*	−11776.4**
	(2177.8)	(3688.8)	(4444.7)
σ_L	65 ***	67 ***	67 ***
	(12)	(13)	(13)
σ_A	22297*	17160***	18000***
	(11421)	(4440)	(4650)
ρ			−0.120*
			(0.051)
log likelihood	−2604.523	−2584.929	−2584.411
N	430	430	430

Significance levels : * 0.10 ** 0.01 *** 0.001

Table 4.4: Structural Parameter Estimates for Woody Crops with and without Heckman Sample Selection Correction

	Model		
Heckman Correction	No	No	Yes
Parameter	(3)	(4)	(5)
$\frac{1}{\phi(\sigma_p^2+\sigma_c^2-2\rho\sigma_p\sigma_c)}$	0.22***	0.10**	0.10**
	(0.027)	(0.032)	(0.032)
$\frac{\sigma_c^2-\rho\sigma_c\sigma_p}{\sigma_p^2+\sigma_c^2-2\rho\sigma_p\sigma_c}$	0.020***	0.010*	0.0099*
	(0.0060)	(0.0039)	(0.0039)
b		278.8*	290.2*
		(122.7)	(125.6)
K	−6447.1***	−13257.0***	−13676.9***
	(1219.0)	(2946.6)	(3013.4)
σ_L	36.2***	36.2***	36.2***
	(4.5)	(4.5)	(4.5)
σ_A		16122***	16288***
		(3177)	(3150)
ρ			−0.019
			(0.013)
log likelihood	−1818.258	−1825.603	−1825.583
N	430	430	430

Significance levels : * 0.10 ** 0.01 *** 0.001

The findings show that agricultural landowners would be willing to diversify production with perennial bioenergy crops if financially competitive but only on a portion of their land. Estimation of the structural model shows that agricultural landowners perceive a significantly higher risk to perennial bioenergy production than their current crops. However, even with high capital investment costs, agricultural landowners would be willing to produce perennial bioenergy crops as a result of non-pecuniary benefits.

These results have implications for perennial bioenergy supply. Many perennial bioenergy supply models use a simplifying assumption that farmers are risk neutral (i.e., they grow only the crop with the higher returns) or that returns are risk free. Results from our research suggest that if perennial bioenergy crops are financially competitive, farmers will grow both crops. Farmers will only grow perennial bioenergy crops on a small portion of their land due to the subjective risks of perennial bioenergy production. Therefore, the perennial bioenergy supply models which assume risk neutrality or risk free returns over-estimate perennial bioenergy supply. In addition, many bioenergy production plant models assume high rates of conversion within the supply shed. Our results suggest that conversion rates will be low and therefore the supply shed will need to be larger. A larger search radius will increase the transportation costs.

The results also have implications for the impact of policies to promote perennial bioenergy crops. The subjective risks for perennial bioenergy crops are an order of magnitude greater than the landowners current risks. Therefore, policies that only address the expected returns without reducing the risk will have minimal impact at the intensive margins. Bioenergy policies must address the risks associated with perennial bioenergy in addition to the returns to have a significant impact on production. Policies that reduce risk may only need to be temporary until private insurance, contracts, futures markets and risk management strategies are developed.

Finally, this research presents a methodology for modeling choice under risk when the agent has a discrete and continuous choice to make. By applying a structural model we are able obtain a richer understanding of the determinants of those choices. This methodology can be applied to many fields.

Chapter 5

Discussion

Perennial bioenergy crops provide an opportunity to produce renewable liquid fuels in a more sustainable way than current feedstock production methods (i.e., corn ethanol, soy biodiesel, or cellulosic ethanol from crop residue). However, farmers and landowners are largely unfamiliar with perennial bioenergy crop production. In addition, emerging markets that depend on subsidies can be highly volatile. The risks involved in producing a novel crop and the uncertainty in how to manage that risk will affect the willingness of farmers and landowners to produce perennial bioenergy crops at the intensive and extensive margins. The goal of this dissertation is to better understand the potential supply of perennial bioenergy crops and the role that risk, uncertainty, and policy levers play in crop choice decisions of farmers and landowners.

Using a stated crop choice approach (see chapter 2), we examined the willingness of agricultural landowners to produce perennial bioenergy crops at the intensive and extensive margins given expectations about relative net returns per acre. We found that a majority of landowners would be willing to produce perennial bioenergy crops if financially competitive. However, they are only willing to produce these crops on a small portion of their land. The portion of landowners and acreage is increasing in relative net returns. Given the same net returns for grasses (e.g., switchgrass) and short rotation woody crops (SRWC), landowners prefer grasses and are willing to produce more acreage. In addition, non-farming landowners, although less willing than farmers, would produce perennial bioenergy crops on more acres.

One possible explanation for the high level of interest in perennial bioenergy crops, but the low production levels, is due to the risk and uncertainty in growing a crop that is largely unknown to the farmer. Using the state-contingent approach, we characterize the comparative static effects of different policies levers on perennial bioenergy acres (see chapter 3). These policy levers are similar to the payment options in the Biomass Crop Assistance Program. There are two taxonomies of effects: substitution and indirect. The substitution effect is non-negative for all three policies. Landowners and farmers prefer higher returns. The indirect effect due to changes in uncertainty and preferences can be positive or negative. The indirect effect and the comparative static effect is positive when the landowner or farmer prefers this change in uncertainty and preferences. Otherwise the indirect effect is negative and the comparative static effect is ambiguous. In some cases the substitution from conventional to perennial bioenergy crops will be muted by the indirect effect and, for some farmers, the policy could decrease perennial acreage.

Given the ambiguity of the impact of policies to promote perennial bioenergy on production at the intensive margins and the importance of the relative magnitude of the risks we use a structural model to estimate the relative risks and fixed costs of adoption (see chapter 4). We find that the landowners' perception of the net return risks were an order of magnitude greater for grasses when compared to their current crops. For SRWC, the perception of risk was two orders of magnitude greater. We also found significantly lower fixed adoption costs for grasses than for trees.

In this research, we have shown that risk and uncertainty can be an important driver in decisions regarding perennial bioenergy crop production. Bioenergy polices need to consider the role that risk and uncertainty can have in determining the successful promotion of perennial bioenergy crops. Given the perception of higher risks of perennial bioenergy production, policies can increase their effectiveness by reducing risk or promoting perennial bioenergy crop insurance.

More research is necessary to understand the heterogeneity of risks and fixed costs in perennial crop production. Farmers perceptions, attitudes, and barriers can have non-pecuniary impacts on willingness to produce and acreages. Finally, incorporation of risk aversion into partial and general equilibrium models, even in a very simplistic way, can increase the reliability of these models to predict bioenergy feedstock supply.

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Appendix A

Nonresponse

A.1 Comparative Analysis

Using the United States Department of Agriculture (USDA) census data, we can compare the responses to questions in our survey to the general population in the nine county area. The challenge in comparing the census data with our respondents is that the census data is of farms and our population is farmland owners. There is significant overlap between farmers and farmland owners. We estimate that just over half (56%) of the farmland owners are farmers.

One direct comparison that we can make is between land use as indicated by our farmland owner respondents and the planted acres within the nine county area. The census is taken once every five years and was not taken the year that we conducted the survey. The question in our survey asked for the average acreages per year to account for rotating. Table A.1 summarizes the proportion of cropland acres the respondents own that is being used for a particular crop and the portion of the planted acres from the 2007 and 2012 USDA census. Our survey appears to over-sample farmland owners that have a higher proportion of soybean acres and under-sample farmland owners that have a higher proportion of hay acres. This result is the opposite of what we would have expected given that hay is a perennial crop and has a similar production system to grass bioenergy crops.

A.2 Response Round

The survey methodology included multiple contacts with the farmland owners. This included two mailings of the questionnaire along with postcard followups. The second round of questionnaires was mailed only to the farmland owners that

Table A.1: Share of Cropland

	Census		Survey 2009	
	2007	2012	Est.	SE
Corn	53.9	54.6	52.7	3.7
Soybeans	35.5	36.2	42.2	2.7
Alfalfa	1.8	1.5	2.0	0.2
Vegetables			0.9	0.3
Small Grains	1.5	1.0	0.8	0.1
Hay	7.3	6.6	0.7	0.1
SugarBeets	0.1	0.1	0.3	0.1

Table A.2: Difference in Response Between Rounds (Round 2 - Round 1)

	Yes/No				**Acres**			
	Grasses		**Trees**		**Trees**		**Grasses**	
Amt	**Δ**	**SE**	**Δ**	**SE**	**Δ**	**SE**	**Δ**	**SE**
-\$100	-0.09	0.11					-14	13
-\$50	-0.06	0.12	-0.04	0.06	-5		-30	23
\$0	0.13	0.07	0.02	0.18	-1	15	-30	29
\$50	-0.03	0.14	0.00	0.15	1	15	21	23
\$100	-0.06	0.12	0.12	0.14	33	17	3	18
\$150	0.00	0.15	0.00	0.14	7	15	29	27
\$200	0.12	0.11	0.01	0.14	56	27	-3	29
\$250	-0.11	0.11	0.00	0.14	-22	27	76	71
\$300			0.17	0.14	37	28		
	-0.02	0.05	0.01	0.05	14	9	16	13

Significance levels : * : 10% ** : 1% *** : 0.1%

had not responded and was slightly modified[1] to allow collection of data on the survey round. The second round respondents are non-respondents to the first round and can give us an indication of how the non-respondents differ from the respondents (Lindner, Murphy, and Briers, 2001). These second round respondents may still be interested in perennial bioenergy crops but did not respond because of common non-response reasons. Following up with nonrespondents, Paulrud and Laitila (2010) found that 83% of the nonrespondents indicated a lack of time to answer the questionnaire or a lack of interest in answering surveys. In our survey 37% of the responses were to the second round of surveys. Table A.2 summarizes the difference in the means from the second round to the first round. There is no significant difference between the percentage of respondents that would grow grasses or trees or the acres of grasses or trees between the two rounds.[2]

A.3 Interest

As part of the survey we asked respondents to rate their current level of interest in perennial bioenergy crops given that they were financially competitive using a Likert scale[3] This question was asked the page before the questions with the treatment amounts. Respondents that had no interest in perennial bioenergy crops are likely similar to farmland owners that did not respond to the questionnaire because of a lack of interest in perennial bioenergy crops. Our pre-survey prediction was that the respondents with no interest would not be willing to grow perennial bioenergy crops. However, some of the respondents (22%) that had no interest were willing

[1]The first round of questionnaires had a color front page and the second round had the same front page but in black and white

[2]Respondents that were non-respondents to the first round did not differ significantly from the first round respondents.

[3]The Likert Scale had four response options: No, Little, Some, High.

Table A.3: Difference in Response Between Interest and No Interest

	Grasses				**Trees**			
	Yes/No		**Acres**		**Yes/No**		**Acres**	
Amt	**Δ**	**SE**	**Δ**	**SE**	**Δ**	**SE**	**Δ**	**SE**
-$100	0.18	0.16						
-$50	0.23	0.14			0.06	0.06		
$0	0.51*	0.20	60		0.42*	0.14	20	
$50	0.56**	0.21	-32		0.51***	0.20		
$100	0.56**	0.20	-15		0.57***	0.21		
$150	0.44*	0.18	43		0.42**	0.14	-3	26
$200	0.31	0.21	16		0.21	0.18	67	48
$250	0.29*	0.15	48	114	0.35*	0.14	-68*	30
$300					0.46**	0.15	17	46
	0.41***	0.07	18		0.38***	0.05	-11	16

Significance levels : * : 10% ** : 1% *** : 0.1%

to grow perennial bioenergy crops when given the relative net income treatments. Table A.3 summarizes the difference in means for the respondents with at least some interest and no interest. This difference is statistically significant at the 0.001 level for the percentage of respondents willing to grow grasses and trees. The significance and magnitude is consistently positive with an inconsistent magnitude across the relative net income amounts. The difference is the largest and most significant at the relative net income amounts that are positive but closer to zero for both grasses and trees. When the relative net income amounts are negative, the difference is not significant because of the low percentage of interested farmland owners willing to grow perennial bioenergy crops. When the relative net income amounts increase above $100, the difference declines because respondents not interested in perennial bioenergy crops are more willing to grow them with higher relative returns. This suggest that with high enough net returns interest doesn't matter. Estimates of the percentage of farmland owners willing to grow perennial bioenergy crops from our sample will be higher than a random sample of our population. The level of bias can be estimated by applying the willingness to grow percentage for those with no interest to an estimate of non-respondents with no interest and our estimate of willingness to grow percentage for respondents to the rest of the sample. We use the estimate of no interest in perennial bioenergy crops for the non-respondents from the Paulrud and Laitila (2010) study (13%). This gives us an estimated bias of 2.7%. The difference between interest and no interest is not significant for the acres of grasses and trees.

By using the difference in means for the response round and interest as proxies for the reasons that people choose not to respond to bioenergy surveys, we are able to show that the non-response bias is limited to the willingness to grow estimates. That is, we see no difference in grass or tree acres between response rounds and interest. Other studies that have conducted a follow up to determine the reason for nonresponse find that most of the nonrespondents don't have time or don't like to answer questionnaires. Non-respondents that have no interest in perennial bioenergy crops will bias our estimate of willingness to grow upwards. The bias will depend on the the interest levels in the population and the relative net income amounts. Higher interest and relative net income amounts further from zero will lead to lower bias.

Appendix B

Coefficients of the Unrestricted Model

B.1 Coefficients of Unrestricted Model

The following table provides the coefficients of the model. The results section presented the marginal effects.

Table B.1: Conditional Mixed-Process Multivariate Regression

	Grasses		Trees	
Variable	**Yes**	**Acres**	**Yes**	**Acres**
Treatments				
Grass net income	0.60***	8.8	-0.27*	2.7
	(0.11)	(11)	(0.11)	(5.1)
Tree net income	0.0070	3.8	0.47***	9.7*
	(0.080)	(5.4)	(0.096)	(4.3)
Interaction	0.050	-1.1	0.083	0.47
	(0.083)	(4.7)	(0.069)	(2.4)
Design				
Round 2	0.053	-0.68	0.028	-14.6*
	(0.17)	(9.42)	(0.16)	(6.89)
County	Yes	Yes	Yes	Yes
Tenure				
Area Owned	0.000050	0.27***	0.00081	0.10*
	(0.00070)	(0.066)	(0.00056)	(0.040)
Area Rented	-0.00044	0.28***	0.0026***	0.082*
	(0.00081)	(0.065)	(0.00077)	(0.035)
Area Farmed	0.00045	-0.22***	-0.0017**	-0.086**
	(0.00070)	(0.056)	(0.00062)	(0.031)
Landuse				
SRWC area	0.087	5.60	0.23**	11.7***
	(0.11)	(4.47)	(0.086)	(2.51)
Hay area	-0.0089	-1.20*	-0.019	0.18
	(0.013)	(0.62)	(0.013)	(0.71)
Alfalfa area	-0.0049	-0.098	-0.0026	-0.043
	(0.0059)	(0.36)	(0.0049)	(0.25)
Pasture area	0.00060	0.096	-0.0049	0.46**

Continued on next page

Table B.1 – *Continued from previous page*

	Grasses		Trees	
Variable	**Yes**	**Acres**	**Yes**	**Acres**
	(0.0056)	(0.23)	(0.0039)	(0.15)
Orchards area	-0.0098	7.57*	0.089	0.28
	(0.088)	(4.08)	(0.088)	(2.89)
Wetland area	0.00030	1.97**	0.015**	-0.13
	(0.0068)	(0.66)	(0.0054)	(0.21)
CRP area	0.027	-1.10***	0.00075	-0.10
	(0.021)	(0.26)	(0.0049)	(0.19)
Woods area	0.0018	-1.30**	-0.0036	-0.046
	(0.0051)	(0.48)	(0.0049)	(0.30)
Recreation area	-0.0020	-0.62*	0.019*	-0.085
	(0.0056)	(0.29)	(0.0080)	(0.20)
Native Prairie area	0.0030	0.42	0.0049	0.11
	(0.0066)	(0.39)	(0.0056)	(0.36)
Wildlife area	0.0010	-0.57*	-0.0064	-0.090
	(0.0039)	(0.24)	(0.0058)	(0.24)
Conservation				
CRP	0.11	-15.1	-0.20	0.18
	(0.21)	(17.2)	(0.21)	(9.34)
CSP	-0.078	-9.54	0.61*	-22.9*
	(0.24)	(15.9)	(0.26)	(10.2)
Soil Conservation	0.10	11.5	-0.29*	-8.71
	(0.19)	(9.55)	(0.17)	(8.34)
Demographics				
Gender				
Female	0.000	0.000	0.000	0.000
	(.)	(.)	(.)	(.)
Male	0.516*	-16.230	0.712**	-22.532*
	(0.246)	(12.830)	(0.233)	(12.560)
Age	-0.0019	-0.057	-0.012*	-0.36
	(0.0067)	(0.42)	(0.0056)	(0.29)
Work off Farm				
No	0.00	0.00	0.00	0.00
	(.)	(.)	(.)	(.)
Yes	-0.21	5.82	0.089	-12.4*
	(0.20)	(12.3)	(0.18)	(7.41)

Continued on next page

Table B.1 – *Continued from previous page*

	Grasses		Trees	
Variable	**Yes**	**Acres**	**Yes**	**Acres**
Education				
Some high school	0.00	0.00	0.00	0.00
	(.)	(.)	(.)	(.)
High School	-0.059	-10.9	0.053	28.7*
	(0.35)	(20.0)	(0.40)	(14.5)
Some College	-0.22	8.77	0.30	27.1
	(0.39)	(18.8)	(0.43)	(19.6)
2 year degree	0.25	-9.73	-0.016	26.2*
	(0.36)	(24.1)	(0.42)	(14.6)
Bachelor's	-0.11	-2.36	0.19	12.4
	(0.39)	(24.0)	(0.43)	(15.3)
Graduate	0.20	-18.0	-0.045	10.4
	(0.41)	(24.1)	(0.45)	(16.1)
No answer	0.47	20.8	-0.45	39.0
	(0.91)	(71.1)	(0.82)	(27.3)
Household Income				
less than $25,000	0.00	0.00	0.00	0.00
	(.)	(.)	(.)	(.)
$25,000-50,000	0.42	-12.5	-0.13	7.09
	(0.37)	(18.8)	(0.38)	(12.8)
$50,000-75,000	0.62	-24.2	-0.21	20.1
	(0.38)	(24.3)	(0.39)	(15.4)
$75,000-100,000	1.00**	-20.2	0.24	4.27
	(0.39)	(29.2)	(0.41)	(14.5)
$100,000-150,000	0.99*	-8.73	-0.0019	26.5
	(0.40)	(32.2)	(0.42)	(18.6)
more than $150,000	0.77*	23.5	0.32	26.2*
	(0.46)	(24.0)	(0.43)	(15.2)
No answer	0.54	-8.74	-0.25	-23.6
	(0.49)	(31.8)	(0.47)	(19.2)
Farm Income				
Net Loss	0.00	0.00	0.00	0.00
	(.)	(.)	(.)	(.)
$0-5,000	0.074	36.6	0.021	40.9*
	(0.47)	(27.8)	(0.40)	(18.0)

Continued on next page

Table B.1 – *Continued from previous page*

	Grasses		Trees	
Variable	**Yes**	**Acres**	**Yes**	**Acres**
$5,000-10,000	0.41	41.4	-0.076	62.2***
	(0.53)	(27.7)	(0.38)	(18.1)
$10,000-25,000	-0.035	61.4*	0.050	49.9**
	(0.45)	(30.6)	(0.36)	(16.1)
$25,000-50,000	-0.20	67.7*	0.51	75.6***
	(0.44)	(32.1)	(0.37)	(19.3)
more than $50,000	0.021	57.1	0.40	50.4**
	(0.47)	(38.5)	(0.41)	(16.3)
No answer	-0.26	49.4	0.10	54.6*
	(0.52)	(42.9)	(0.47)	(26.6)
Interest Grass				
No	0.00		0.00	
	(.)		(.)	
Little	0.20		-0.77*	
	(0.37)		(0.37)	
Some	1.17**		0.23	
	(0.37)		(0.32)	
High	1.84**		0.52	
	(0.63)		(0.40)	
No answer	0.32		-0.21	
	(0.39)		(0.37)	
Interest Tree				
No	0.00		0.00	
	(.)		(.)	
Little	0.58*		1.09***	
	(0.27)		(0.27)	
Some	0.47*		1.29***	
	(0.23)		(0.26)	
High	0.43		2.27***	
	(0.73)		(0.34)	
No answer	1.02*		0.99*	
	(0.42)		(0.43)	
Constant	-2.24*	41.7	-1.11	2.90
	(0.91)	(91.7)	(0.76)	(30.2)
N				419

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Table B.1 – *Continued from previous page*

	Grasses		Trees	
Variable	**Yes**	**Acres**	**Yes**	**Acres**
Log pseudolikelihood				-2381.31
Likelihood Ratio Test (Constant Model) $\chi^2(222)$				784.16

Appendix C

Survey

UNIVERSITY OF MINNESOTA

Twin Cities Campus

Center for Integrated Natural Resources and Agricultural Management

College of Food, Agricultural and Natural Resource Sciences

107 Green Hall
1530 Cleveland Avenue North
St. Paul, MN 55108-6112

Office: 612-624-4299 or 612-624-7418
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http://www.cinram.umn.edu/

Minnesota Agricultural Landowner Survey of Energy Crops

Dear Landowner,

The United States has set goals to significantly increase the amount of electricity, thermal energy, and biofuels made from renewable sources. One important source is perennial plants grown on farmland. The Center for Integrated Natural Resources and Agriculture at the University of Minnesota is collecting information from farm landowners regarding their attitudes and opinions towards perennial energy crops.

You do not need to have any expertise in farming, farm the land yourself or even have heard of perennial energy crops to successfully complete this survey.

The survey is intended for the **owner** of farmland in Minnesota. Your individual responses will be completely confidential and anonymous. No individual responses will be reported. The survey will take between 15-20 minutes to complete.

Please return the questionnaire in the enclosed, self-addressed, postage-paid envelope within 10 days of receipt. Once we have received your completed questionnaire, your name and any identifying information will be deleted from our database.

Survey # 130

If you have any questions or concerns, please contact me at (612) 624-4299 or email me at curre002@umn.edu. Thank you in advance for participating in this important project.

Sincerely,

Dean Current, Ph.D.
Project Leader

Landowner and Land Use Profile

1. What is the total acreage of farmland your household owns, leases, and/or farms regardless of location or use?

	Total Acres
Land I Own	________
Land I Lease/sharecrop **TO** others	**-** ________
Land I rent/sharecrop **FROM** others	**+** ________
Total Land I Farm	**=** ________

2. How long have you or your immediate family owned your farmland?

_______________ Years

3. What current uses are made of the farmland that you OWN, regardless of whether or not you farm it? *Please indicate the total acreage. If you rotate crops please indicate average acreage per year.*

Acres

_______ Corn

_______ Soybeans

_______ Wheat, oats, and other small grains

_______ Sugar beets

_______ Alfalfa

_______ Hay—not including alfalfa

_______ Pasture livestock

_______Vegetables

Acres

_______ Confined livestock

_______ Short rotation woody crops

_______ Orchards

_______ Native prairie

_______ Wetland

_______ Wildlife habitat

_______ Recreation—such as hunting, bird watching

_______ Other___________________________________

4. What is the average rental rate for land that you own? *If you don't rent out your land please estimate based on rental rates in your area.*

Cropland $_____________ Acre/Year ___ Don't Know

Pastureland $_____________ Acre/Year ___ Don't Know

2

5. **Have you ever implemented any of the following programs or practices on your land?** *Please circle the number corresponding to your answer.*

	Yes	No	Don't Know
Conservation easement such as Conservation Reserve Program (CRP)	1	2	9
Government conservation program that conserves natural resources while farming such as the Conservation Security Program (CSP)	1	2	9
Soil conservation practice such as no-till/low-till, direct seeding, nutrient management	1	2	9

6. **Everyone has different plans for how their land will be used in the future. How likely are each of the following situations to occur <u>within the next ten years</u>?** *Please circle the number that fits each situation the best.*

	Highly Unlikely	Somewhat Unlikely	Somewhat Likely	Highly Likely	Don't Know
Land will be operated by family member(s)	1	2	3	4	9
Land will be inherited by family member(s)	1	2	3	4	9
Land will be sold for agricultural use	1	2	3	4	9
Land will be sold for a non-agricultural use	1	2	3	4	9
Land will be rented	1	2	3	4	9
Land will be used for recreation	1	2	3	4	9
Land will be taken out of production and used for conservation	1	2	3	4	9
I will diversify the current use(s) of my land	1	2	3	4	9
I will reduce the current use(s) of my land	1	2	3	4	9
I will maintain the current use(s) of my land	1	2	3	4	9
I will cease to use my land	1	2	3	4	9
I will grow a different crop	1	2	3	4	9

7. **Which of the following best describes your awareness about the using <u>perennial crops</u> grown from farmland for energy production before receiving this survey?**

	No Awareness	Little Awareness	Some Awareness	High Awareness
Perennial Grasses	1	2	3	4
Trees	1	2	3	4

Fast Facts about Perennial Grasses, Legumes and Forbs

- High yielding, drought tolerant, and requires lower fertilizer and herbicide quantities compared to row crops
- Once planted, needs to be re-planted only once every 10 years in early spring
- No-till practices can be used
- Harvested annually in late fall or early spring after nutrients have returned to the roots
- Less time to manage throughout plant's life cycle
- Harvested using conventional haying equipment

Fast Facts about Trees

- Requires lower fertilizer and herbicide quantities compared to row crops
- Harvested between 3 and 12 years after planting
- Once established, can be harvested for 20-30 years without any root disturbance or replanting
- Less time to manage throughout plant's life cycle
- Harvested using standard forestry equipment

What are the Benefits of Perennial Energy Crops?

- Adds organic matter to soils
- Reduces erosion
- Improves water quality
- Provides wildlife habitat
- Sequesters carbon from atmosphere

Attitudes and Perceptions

8. Please indicate the extent to which you agree or disagree with the following statements. *Circle the number that corresponds with your opinion.*

	Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree	Don't Know
I am concerned with the quality of my farm soil	1	2	3	4	9
I am concerned with the effect my land has on water quality	1	2	3	4	9
I believe it is important to provide habitat for wildlife on my land	1	2	3	4	9
Growing perennial energy crops could improve water quality in my area	1	2	3	4	9
Growing perennial energy crops could provide wildlife habitat on my land	1	2	3	4	9
Diversifying my production will reduce financial risk on my farm	1	2	3	4	9
If I were to grow perennial energy crops I would be perceived as a land steward by my peers	1	2	3	4	9
The United States should increase domestic sources of renewable energy	1	2	3	4	9
Farmland should be used to increase the United States' energy independence	1	2	3	4	9
I have a responsibility to conserve the land for use by future generations	1	2	3	4	9

9. Assuming growing perennial crops for energy production was financially competitive with your current use, how would you rate your current level of interest?

	No Interest	Little Interest	Some Interest	High Interest
Perennial Grasses	1	2	3	4
Trees	1	2	3	4

10. Below is a list of potential barriers a landowner might encounter when considering growing perennial crops, both grasses and trees. To what degree would each of the following factors limit your willingness to grow perennial crops for energy? *Circle the number that corresponds with your opinion.*

Potential Barrier	Highly Limiting	Moderately Limiting	Slightly Limiting	Not Limiting	Don't Know
A lapse in income until first harvest	1	2	3	4	9
Risk of unsuccessful establishment	1	2	3	4	9
Lack of access to proper equipment	1	2	3	4	9
Risk involved with growing a new crop	1	2	3	4	9
Cost to establish	1	2	3	4	9
Lack of financial assistance	1	2	3	4	9
Lack of information about growing crop	1	2	3	4	9
Lack of renter or contract service provider	1	2	3	4	9
Necessity to learn new skills	1	2	3	4	9
Opinion of my family and friends	1	2	3	4	9
Spending time to learn about a different system	1	2	3	4	9
Having to sign a contract with the government	1	2	3	4	9
Having to sign a contract with an energy producer	1	2	3	4	9
Having to complete paperwork involved with program	1	2	3	4	9
Loss of base acreage eligible for government subsidies	1	2	3	4	9
Loss of bank loan eligibility for converted acres	1	2	3	4	9
Working with government technical assistance	1	2	3	4	9
Current renter not interested	1	2	3	4	9

11. Below is a list of potential barriers a landowner might encounter when considering growing trees specifically. To what degree would each of the following factors limit your willingness to grow trees for energy? *Circle the number that corresponds with your opinion*

Potential Barrier	Highly Limiting	Moderately Limiting	Slightly Limiting	Not Limiting	Don't Know
Long delay till first harvest (3-12 years)	1	2	3	4	9
Access to equipment for harvesting	1	2	3	4	9
Having tree roots and stumps in tillable land	1	2	3	4	9
Long term commitment for the land (20-30 years)	1	2	3	4	9

12. If growing perennial energy crops was financially competitive with your current practice and there was an energy buyer, which financial arrangements you would prefer, assuming annual net farm income is the SAME under all arrangements? *Rank **all** of the following choices 1-5 with 1 being your top choice and 5 being your bottom choice. Rank perennial grasses and trees separately.*

	Perennial Grasses	Trees
A. Planting, maintenance, and harvest would be my own responsibility and I would be paid for biomass crop upon delivery.	________	________
B. A portion of the cost of planting would be covered; I would receive an **annual payment** for the **first 5 years**; maintenance and harvest would be my own responsibility; I would be paid for biomass crop upon delivery.	________	________
C. 10 year easement for which I would receive an **annual payment**; planting, maintenance, and harvest would be my responsibility; I would also be paid for biomass crop upon delivery.	________	________
D. 10 year easement for which I would receive an **annual payment**; planting, maintenance, and harvest would be the responsibility of a **contract service provider** that I hire; I would be paid for biomass crop upon delivery.	________	________
E. 10 year or longer rental agreement with contract service provider; establishment, maintenance, and harvest would the responsibility of **contract service provider**; I would be paid an **annual rental payment**.	________	________

13. If your annual net farm income from growing perennial grasses was $100 per acre LOWER than your current annual net farm income per acre would you grow perennial grasses on at least some of your land? *Net farm income is total farm revenue minus all farm costs and expenses.*

☐ Yes ⟶ How many acres would you grow at this net farm income? ______________acres
☐ No

14. If your annual net farm income from growing trees was the SAME per acre as your current annual net farm income per acre would you grow trees on at least some of your land? *Net farm income is total farm revenue minus all farm costs and expenses.*

☐ Yes ⟶ How many acres would you grow at this net farm income? ______________acres
☐ No

15. If the particular perennial crop you were considering growing was known to be a noxious or invasive weed (causes or is likely to cause environmental harm) how would you answer question 13 and 14?

Question 13-Grasses

☐ Yes _________acres
☐ No

Question 14-Trees

☐ Yes _________acres
☐ No

16. If you were to grow <u>perennial energy crops</u> which type of farmland would you target for establishment? *Please check all that apply.*

☐ Sandy soils
☐ Poorly drained soils
☐ Land near a lake, river or stream
☐ All my land
☐ Poor quality soil
☐ Sloped land
☐ Most productive land

Land Tenure

17. Which of the following best describes your farming operation? *Please check one*

☐ I own and operate my own land (***Please skip to question # 24***)
☐ I have a one year lease and receive cash rent
☐ I have a multiple year lease and receive cash rent
☐ I have a share cropping arrangement
☐ Other_______________________________________

If selected please answer questions 18 through 23

18. How long have you had your current renter/sharecropper?

__________ years

19. Is your current renter/sharecropper an immediate or extended family member?

☐ Yes ☐ No

20. Are conservation practices mentioned in your lease or lease supplement?

☐ Yes ☐ No (***Please skip to question # 21***)

Please check all below that apply.

☐ No-till
☐ Specific crop rotation
☐ Perennial crop
☐ Conservation drainage
☐ Conservation Reserve Program
☐ Environmental Quality Incentives Program
☐ Other: _____________________________
☐ Precision planting
☐ Planting or maintenance of buffers
☐ Cover crop_______________
☐ Pasture management______________
☐ Conservation Stewardship Program
☐ Re-Invest in Minnesota

21. Have you discussed conservation practices with your current renter?

☐ Yes Who initiated the discussion?

☐ No What is keeping you from initiating this conversation?

22. Would you like to incorporate conservation practices into your lease with your renter?

☐ Not Interested ☐ Little Interest ☐ Some Interest ☐ High Interest ☐ N/A

23. People have different approaches when making decisions about their land. How well do you agree with the following statements? *Please circle number that corresponds with your opinion.*

	Highly Disagree	Somewhat Disagree	Somewhat Agree	Highly Agree	Don't Know
The renter makes most of the decisions about the type of crops grown	1	2	3	4	9
The renter makes most of the decisions about tillage practices	1	2	3	4	9
I make the decisions about conservation on my land	1	2	3	4	9
My renter farms the land the way I want it to be farmed	1	2	3	4	9
I encourage my renter to utilize soil conserving practices	1	2	3	4	9
I can freely discuss the use of different practices with my renter	1	2	3	4	9
The type of relationship I have with the renter strongly influences decisions made about the farm	1	2	3	4	9
The length of my relationship with the current renter strongly influences decisions made about the farm	1	2	3	4	9
My renter's opinion significantly influences decision made about the farm	1	2	3	4	9

Landowner Information

24. Are you a

☐ Male ☐ Female

25. Your age

________years old

27. Does anyone in your household work off-the-farm?

☐ Yes ☐ No

26. Which of the following best describes your farming status? *Please check one.*

☐ I am a full-time farmer
☐ I am a part-time farmer
☐ I am a retired farmer
☐ I am a retired non-farmer
☐ I am a non-farmer
☐ Other________________

28. Is your permanent home located on your farmland?

☐ Yes, my home is located on my land
☐ No, I live within 30 miles from my land
☐ No, I live between 31 and 150 miles from my land
☐ No, I live between 151 and 300 miles from my land
☐ No, I live more than 300 miles from my land

30. What is highest level of formal education you have completed?

☐ Some High School or Less
☐ Technical/Community College Degree
☐ High School/GED
☐ Bachelor's Degree
☐ Some College
☐ Graduate/Professional Degree

31. What was your total annual household income from all sources, before taxes, in 2009?

☐ less than $25,000
☐ $75,001-$100,000
☐ $25,001-$50,000
☐ $100,001-$150,000
☐ $50,001-$75,000
☐ more than $150,000

32. What was your net cash farm income from farm operations in 2009, including rental income?

☐ Less than $0 (Net Loss)
☐ $10,001-$25,000
☐ $0-$5,000
☐ $25,001-$50,000
☐ $5,001-$10,000
☐ more than $50,000

33. What was your debt ratio (total debts divided by total assets) in 2009?

☐ 0-15%
☐ 45-60%
☐ 15-30%
☐ 60-80%
☐ 30-45%
☐ 80-100%

34. **We will be conducting in-person and phone interviews with landowners to further understand their thoughts about perennial energy crops. Would you be interested in participating?**

☐ Yes ☐ No

If **yes**, what is your:

phone number:_______________________________

email:______________________________________

Is there anything else you would like to share with us?

Thank you for taking the time to complete this questionnaire!

Please return this form using the prepaid, self-addressed envelope.

If you have any questions regarding the study, please feel free to contact us.

Dr. Dean Current, Center for Integrated Natural Resources and Agriculture, University of Minnesota
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