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Economic and Environmental Assessment of Advanced Biofuels : Adoption Under Uncertainty, Farmer Willingness, and Land Use Implications

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ECONOMIC AND ENVIRONMENTAL ASSESSMENT OF ADVANCED BIOFUELS: ADOPTION UNDER UNCERTAINTY, FARMER WILLINGNESS, AND LAND USE IMPLICATIONS

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ABSTRACT

ECONOMIC AND ENVIRONMENTAL ASSESSMENT OF ADVANCED BIOFUELS: ADOPTION UNDER UNCERTAINTY, FARMER WILLINGNESS, AND LAND USE IMPLICATIONS

by Pralhad Burli

The production of biofuels offers the prospect of enhancing a country's energy security by limiting petroleum imports and supporting domestic economic activity by bolstering agricultural and allied sectors. Additionally, advanced biofuels can reduce the reliance on food-grain based first generation ethanol, replace a part of our fossil fuel consumption, and potentially reduce environmental impacts through greenhouse gas emission reductions. However, the cellulosic biofuel industry has not developed as anticipated due to slow advancements in the technology for converting feedstock to fuel, improvements in vehicular efficiency, which has muted fuel demand, and lack of an assured year-round supply of feedstock that has hindered commercial viability of cellulosic biofuel production.

Against this backdrop, this dissertation explores the development of switchgrass based bioenergy from economic, environmental, and policy perspectives. We evaluate switchgrass adoption under uncertainty by developing a discrete-time binomial framework to model output prices. This approach allows us to incorporate the time-to-establishment attributes of switchgrass cultivation into the modeling framework. We analyze the economic viability of investments in switchgrass cultivation under various

price transitions, evaluate the relationship between risk and profitability, and estimate the value of flexible decision-making.

Understanding the perceptions of the farming community about producing crops used in biofuel production, and whether they will adopt switchgrass cultivation, is a crucial part of the bioenergy feedstock supply puzzle. To our knowledge, our study undertook the first survey of farmers in Missouri to delineate their perceptions and preferences around bioenergy production since the new administration assumed office. Therefore, our survey results are timely and provide valuable insights regarding the potential for switchgrass-based bioenergy. We unravel the influence of a host of factors on farmer willingness to cultivate switchgrass.

Finally, we study the role of farmer perceptions around the suitability of switchgrass for their operations and assess their initial land allocation decisions. We find that land allocated for switchgrass cultivation is more likely to come from lands under hay or under other uses. Our research contributes to the body of knowledge about energy crop cultivation and has important implications for designing policies that consider financial incentives, risk management, and future land use perspectives.

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To my family

Table of Contents

List of Tables

List of Figures

List of Abbreviations

BCAP: Biomass Crop Assistance Program

CRP: Conservation Reserve Program

EISA: Energy Independence and Security Act

GHG: Greenhouse Gas

NPV: Net Present Value

NRDC: Natural Resources Defense Council

RFS: Renewable Fuel Standard

USDA: United States Department of Agriculture

USEIA: United States Energy Information Administration

USEPA: United States Environmental Protection Agency

USDOE: United States Department of Energy

1 Introduction

1.1 Background

Conventional fossil fuels such as coal, oil, and natural gas have played an important role in the industrialization and technological advancement of societies across the globe (Srirangan et al., 2012). However, the continued consumption of these fuels is unsustainable, owing to the non-renewable nature of the resources and the environmental consequences associated with fossil fuel use. Biofuels have emerged as a favored alternative in several countries because they can enhance a country's energy security by displacing imported fuels with domestically produced alternatives, provide support to domestic agricultural markets, and offer the prospect of reducing environmental impacts through greenhouse gas (GHG) emission reductions (Childs et al., 2008).

The United States (U.S.) government has emphasized the need to develop alternate energy sources by instituting mandates and production targets under the 2007 Energy Independence and Security Act and renewable fuel standards (RFS). Biofuels seem to be an attractive alternative as the physical and chemical properties of liquid biofuels require relatively few modifications to modern engine technology and fueling infrastructure (Rajagopal et al., 2007). As a result, the biofuels industry in the U.S. has benefitted from several policy initiatives, including mandates, tax credits and subsidies from the government, largely as parts of the 2002 Farm Bill, 2005 Energy Policy, 2007 Energy Independence and Security Act (EISA), and the 2008 Farm Bill (Miranowski, 2007; De Gorter & Just, 2009).

First generation biofuels, such as grain-based ethanol, could lead to an increase in food prices and competition for prime land between food crops and biofuel crops (Doornbosch & Steenblik, 2008). Producing biofuels using food crops like corn is a contentious issue and raises concerns about its long-term sustainability because higher demand for biofuels could lead to a diversion of food crops to biofuel production. This highlights the need for developing biofuels from non-food sources, and sets the stage for researching the viability of alternate sources for bioenergy production. Against this backdrop, second-generation biofuels are anticipated to be one of the key contributors to the energy supply mix in the future (Carriquiry et al., 2011).

Second-generation biofuels, also referred to as advanced biofuels, can be produced from a wide variety of materials including wood and forest residues, energy crops, grasses, and farm-residues. Previous research has evaluated potential feedstocks such as short-rotation woody sources such as poplar and loblolly pine (Sannigrahi et al., 2010; Susaeta et al., 2012), agricultural residues including straw and corn stover (Lal, 2005), and grasses such as miscanthus, switchgrass (Somerville et al., 2010).

Tyner (2008) catalogues a brief timeline of legislative actions pertaining to ethanol subsidies in the United States since the late 1970's. In 1978, under the aegis of the Energy Policy Act , a subsidy of $ 0.40 per gallon helped launch the industry. Furthermore, between 1978 and 2008 the per gallon subsidy for ethanol ranged between $0.40 and $0.60. In the Energy Policy Act of 1992, a tax deduction for vehicles that operated on E85 (a blend of 85% ethanol and 15% gasoline) was introduced. In the Jobs Creation Act of 2004, the mechanism of the ethanol subsidy was modified from a tax exemption to a blender tax credit under the Volumetric Ethanol Exercise Tax Credit (VEETC) (Tyner, 2008 ; Sorda et al., 2010). A consumption mandate for biofuels was introduced for the first time in the Energy Policy Act of 2005 with the inclusion of the Renewable Fuels Standard (RFS1) (Sorda et al., 2010). Under the RFS2, the production target for biofuels set at to 36 billion gallons by 2022, up from 15.5 billion gallons in 2012. The 2007 EISA capped the contribution of corn-based ethanol to 15 billion gallons with cellulosic ethanol and other advanced biofuels constituting the remaining 21 billion gallons. However, these volumetric targets have been revised on several occasions since, owing to a host of factors ranging from lower demand because of improved vehicular efficiency, to slower than expected progress in the development of conversion technologies for cellulosic biofuel production (Lynes et al., 2016). On July 21, 2017, the US Environmental Protection Agency (EPA) proposed to set the targets for 2018 under the RFS at 19.24 billion gallons, of which cellulosic biofuels constituted a mere 238 million gallons.

While it is important to assess the indirect impacts stemming from the competition for agricultural land, Rubin (2008) contends that cellulosic biofuels are a potential source for large-scale liquid biofuels that can meet our transportation needs without significantly affecting land needed for food crop production. Meanwhile, despite the thrust on developing advanced cellulosic biofuels, corn remains a major source for biofuel production in the U.S., and will likely remain the main contributor to the overall biofuel mix (Tyner, 2008). However, it is necessary to diversify the feedstock portfolio from a long-term sustainability viewpoint and to minimize the externalities associated with large-scale feedstock cultivation (Eisentraut, 2010; Lowrance, 2010).

Following a series of screening trials and assessments, switchgrass (*Panicum virgatum*), a native perennial warm-season grass with a potential for high biomass yield, was identified by the United States Department of Energy as a dedicated energy crop (Wright, 2007). These trials and assessments examined several crop species, soil types, and geographic locations because agricultural productivity and crop growth are highly dependent on such factors. Although most evaluations of switchgrass focus primarily on its use in the production of cellulosic biofuels, it has been widely recommended use in for soil and wildlife conservation, summer grazing in pasture systems for beef cattle, and co-firing with coal to produce electricity (Rasnake et al., 2013).

Under favorable conditions, switchgrass can reach heights of up to 10 feet and its deep-root system produces substantial below-ground biomass to prevent soil erosion. Switchgrass adapts well in nutrient deficient systems, and does not require an extensive use of fertilizers or pesticides to thrive. Studies also suggest that switchgrass cultivation results in a significant level of carbon sequestration and improves soil productivity and nutrient cycling (McLaughlin and Kszos, 2005; Tilman et al., 2006; Schmer et al., 2014). Furthermore, Schmer et al. (2008) estimated that GHG emissions from cellulosic ethanol made from switchgrass were, on average, 94% lower than emissions from gasoline (Schmer et al., 2008). However, the effectiveness of using biofuels to achieve carbon savings depends on how they are produced (Fargione et al., 2008; Searchinger et al., 2008). Finally, a life-cycle analysis-based study by McLaughlin and Kszos (2005) indicates that switchgrass-based biofuel has the potential to compete favorably from an economic perspective (McLaughlin and Kszos, 2005).

1.2 Research Objectives

The cellulosic biofuels industry has not been adequately researched or understood. So far, many studies have focused on the estimation of costs associated with the production of biofuel feedstocks including an analysis of facility size, location, transportation etc. (Kocoloski et al., 2010; Langholtz et al., 2011). Others have focused on the domestic energy policy and its potential impact on the biomass market (Whistance, 2012) or evaluated community and farmer views on socioeconomic benefits of bioenergy crops at a local level (Rossi, 2011). These studies have provided valuable insights into the overall development of the biomass market.

An important aspect of adopting switchgrass cultivation relates to its profitability. Land devoted to switchgrass cultivation could come out of land already being used for row crops, although it could entail larger opportunity costs. Marginal land, usually described as land that are the first to be abandoned if prices are not favorable can also be used to cultivate switchgrass. Varvel et al. (2008) conducted a study on marginal land to examine the yield potential of switchgrass and corn respectively and found that the potential total ethanol yield for switchgrass was greater than the potential for corn grain and stover combined even at the same level of fertilization. Furthermore, pasture lands, land currently under hay or forage crop cultivation are well suited for growing switchgrass;

which seems plausible because the equipment required to harvest and bale hay can be used interchangeably for switchgrass, thereby entailing lower upfront capital costs. Moreover, the establishment period for switchgrass ranges between 2-3 years, after which the crop reaches full production levels until replanting after 10-15 years to maintain productivity levels (Caddel et al., 2009). Thus, in order to compare the economic viability of a long-duration crop such as switchgrass, the time horizon needs to be selected carefully.

Additionally, a competitive, year-round supply of biomass feedstock is considered as one of the major constraints in the commercial deployment of cellulosic biofuel production (Sims et al., 2009). Supply-side aspects, such as feedstock cultivation intended for biofuel production and the decision making process of a landowner concerning the cultivation of a dedicated bioenergy feedstock are critical (Jensen et al., 2007). Qualls et al. (2011) analyzed the factors affecting willingness to produce switchgrass in the southeastern Unites States, while Jensen et al. (2007) conducted their study on Tennessee farmers.

It is also necessary to analyze the decision making process from a socioeconomic and demographic perspective, as those could be factors that determine the willingness of a landowner to supply biomass. Earlier studies have explored factors such as age, education, non-farm income, nature of land ownership, input use, access to equipment, views on national energy security and environmental impacts as potential drivers for switchgrass adoption (Hipple & Duffy, 2002 ; Jensen et al., 2007; Qualls et al., 2012).

Furthermore, the potential impact of a shift in agricultural patterns and its impact on land conversion rates ought to be evaluated. Biomass-based energy is land intensive and there are direct costs associated with land use change in biomass production (Timmons, 2013). Cultivating perennial biomass feedstocks on degraded or abandoned agricultural land could result in GHG reductions (Campbell et al., 2008) and switchgrass adds to the organic content of the soil, as carbon sequestration under switchgrass is much higher than row crops (Mclaughlin & Walsh, 1998).

The overarching goal of this dissertation is to analyze the drivers for and barriers to switchgrass adoption in the state of Missouri evaluate whether or not farmers are willing to participate in bioenergy markets. This research addresses three closely linked objectives and will focus on answering the following questions:

- Is switchgrass adoption influenced by prevailing uncertainty in the biofuel industry? Can we identify a set of conditions or thresholds for which switchgrass cultivation will be economically viable?
- What are the drivers for adopting switchgrass? How do risk tolerance, farm level characteristics, socioeconomic and demographic attributes, knowledge of the biofuels industry, government programs and outreach affect adoption rates?
- If farmers are interested in cultivating energy crops, what proportion of their land are they willing to devote to switchgrass? What type of land will be converted to switchgrass cultivation?

Specifically, the research objectives are to:

1. Assess optimal decision criteria for switchgrass adoption under uncertainty.
2. Assess factors that influence farmer willingness to produce switchgrass for biofuel production.
3. Assess land allocations and conversion from existing use to switchgrass

The analysis of investment decisions in switchgrass cultivation is, like other long-term investments, a complex task. Investments are subject to several types of uncertainties including those commonly associated with biological systems, including crop growth and agricultural productivity. Farmer decisions are also likely to be influenced by the uncertainty arising from the fluctuation of interest rates, which impact the cost of capital for borrowed funds, as well as the policy environment for renewable energy. However, one of the most important sources of uncertainty emanates from fluctuations in product prices.

In Chapter 2, we highlight that uncertainty in future prices and large establishment costs are some of the most important factors that inhibit cultivation of switchgrass. We posit that standard discounted cash flow techniques are not the most appropriate tool for analyzing investments in switchgrass because such models are not well-suited to incorporate uncertainty and flexible decision making into the modeling framework. We develop a discrete-time binomial model for output prices, allowing us to incorporate price uncertainty, stand age, and variable crop yields into the analytical framework. We analyze the feasibility of investments in switchgrass cultivation under varying price transition paths, evaluate the relationship between risk and profitability, and estimate the value of flexible decision-making options wherein the farmer can alter cultivation choices.

In Chapter 3, we evaluate the role of farmer risk preferences and information about switchgrass on switchgrass adoption decisions using a logistic regression framework. Against the backdrop of uncertainty of switchgrass cultivation, we hypothesize that farmers who have a higher tolerance for risk would be more likely to be willing to cultivate switchgrass. On the other hand, we evaluate the influence of prior awareness/ information about switchgrass on farmer adoption decisions and consider farmer preferences about engagement with university extension services. We study the role of peer-influence in terms of preference for observing the actions of other farmers and its impact on cultivation decisions. Earlier studies have highlighted that farmers are often unaware of the potential for switchgrass as a bioenergy feedstock (Jensen et al., 2007) and we explore this issue through our research. We also delineate the role of land holding, existing land use, enrollment in government support programs such as the Conservation Reserve Program (CRP), and factors such as water stress including flooding or drought-like conditions on the farm on switchgrass adoption decisions. Finally, we also include some demographic variables in our analysis.

In Chapter 4, we study the impact of farmer perceptions and land use type on willingness and land allocation decisions using a 2-step Heckman selection model. We explore the role of a set of variables that capture farmer perceptions with regard to switchgrass cultivation. These variables include their perceptions about whether switchgrass can create a habitat for wildlife on their farm, help reduce soil erosion on their land, and whether switchgrass-based bioenergy industry can help create jobs in their community. We also include variables such as size of land holding, and access to equipment for harvesting switchgrass that could influence the profits arising out of switchgrass cultivation as well as demographic variables such as gender, ethnicity, and on-farm residence in our analysis.

1.3 Study Area, Survey Design and Administration

1.3.1 Study Area

The potential for switchgrass as a bioenergy crop has been studied in some of the states in the Midwestern and Southern U.S. However, farmer willingness to cultivate switchgrass has not been studied adequately in Missouri. According to 2012 USDA Census of Agriculture, the market value of agricultural products sold in the state of Missouri exceeded $ 9 billion, 42% of which came from the sale of grains, oilseeds, beans and peas. The state has over 15 million acres of cropland and over 1.2 million acres of land enrolled under the Conservation Reserve Program (CRP). A significant portion of the state's cropland is devoted to the production of corn and soybean, which accounted for almost 17% and 21.5% of the state's agricultural output by value in 2012 (USDA, 2012). While estimates suggest that Missouri produces approximately 2.5% of the nation's corn ethanol (NRDC, 2015), it is plausible that some of this grain is being diverted to ethanol production as opposed to being used for food - a criticism of the corn-ethanol industry as a whole. Studies evaluating the potential for switchgrass in Missouri indicate significant economic and environmental potential for switchgrass on agricultural lands, marginal lands, and floodplains (Bardhan & Jose, 2012; Gu & Wylie, 2017). Figure 1 also shows that the estimated yields for switchgrass are relatively high throughout the state of Missouri.

Estimates from the U.S. Energy Information Administration (EIA) indicate that biomass based energy contributed approximately 4 % of Missouri's total energy consumption in 2015 (USEIA, 2015). Currently, the state ranks 13th in terms of ethanol production capacity in the United States with a capacity of 271 million gallons per year (Nebraska Energy Office, 2017). However, Missouri is considered to be well placed to become a national leader in the development of advanced biofuels and the U.S. Department of Energy along with the US Department of Agriculture have supported research and development efforts at several universities in the state. A Natural Resources Defense Council (NRDC) report claims that the "potential biomass feedstock in Missouri, including just 25 percent of the total residue for existing crops, amounts to seven million tons each year—without including any new production of energy crops" (Cohen, 2010). This, against the backdrop of cultivation of dedicated energy crops, suggests that Missouri has significant potential to promote and develop a strong cellulosic biofuels industry that can exploit the advantages of producing ethanol from corn crop residue and feedstocks such as switchgrass.

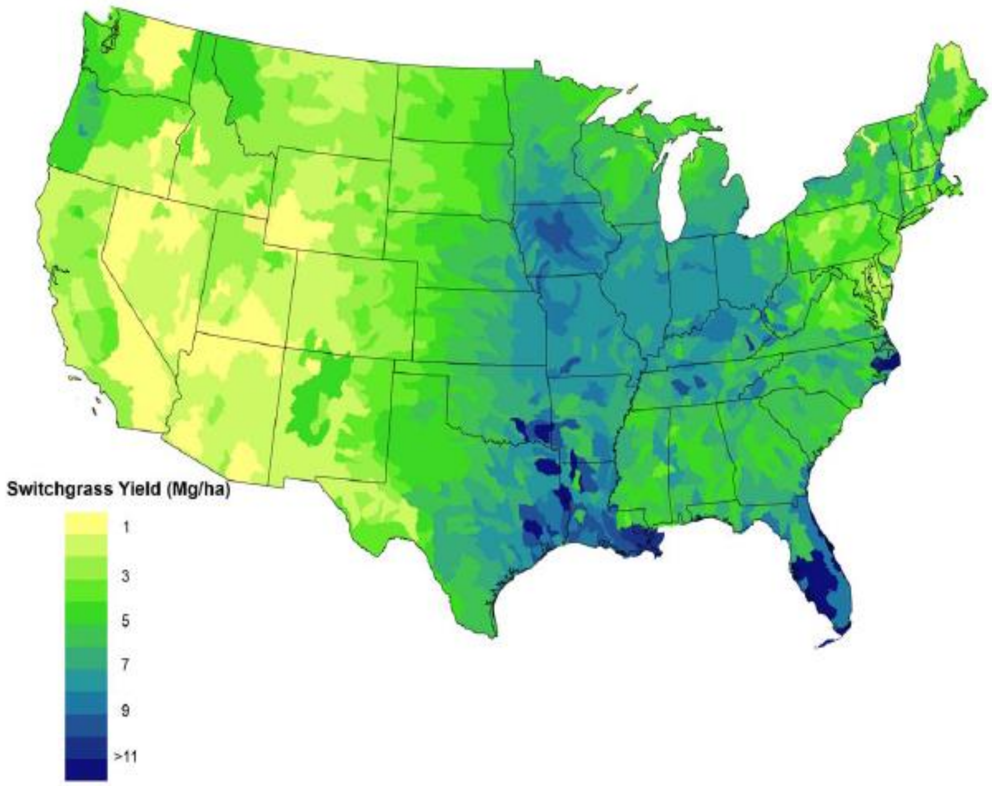

Figure 1.1: Simulated potential 30-yr average switchgrass yields for lowland and upland ecotype with one harvest per year (Source: Thomson et al., 2009)

1.3.2 Survey Design and Administration

To our knowledge, this is the first survey undertaken to assess the farmer preferences and participation in bioenergy markets in Missouri after the new administration has assumed office in January 2017. Primary data was collected using a mail survey whereby respondents were contacted via postal mail. We used the standard survey protocol outlined in Dillman (2011) to reach out to 1000 randomly selected respondents out of the potential respondent pool of farmers and landowners. The Tailored Design Method follows a well-defined procedure including follow-up reminders and postage-paid return envelopes to increase response rates. One week after the initial mail, we sent a reminder postcard to the respondents. Further, at an interval of about three weeks we sent duplicate survey form to the non-respondents. The survey document included a brief cover letter highlighting the importance of this study and its potential implications for policy makers. It was conveyed to the participants that their participation in the study was voluntary and that there were no immediate benefits to them. The survey was approved by the Montclair State University (MSU) Institutional Review Board (IRB) under #001784. The survey response rates and data analysis are discussed in subsequent chapters.

We collected information on variables that would help us identify key factors that influence crop-adoption such as availability of adequate information, knowledge and interest in switchgrass production, uncertainty in prices and demand, transportation networks, opinions and concerns about profitability etc. Data related to current cropping choices including type of crop, percentage of land being cultivated, reasons for not cultivating entire land parcel etc. were also be sought. In addition, we will collect data related to the socioeconomic and demographic characteristics of the respondents. The modeling and data analysis was performed using two statistical software programs R and JMP.

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2 Switchgrass adoption under uncertainty: A discrete-time modeling approach[1]

2.1 Introduction

The United States (U.S.) government has emphasized the need to develop alternate energy sources amid high dependence on petroleum imports, the volatility of global crude oil prices, and greenhouse gas (GHG) emissions resulting from fossil fuel use (USEPA, 2011). Biofuels have emerged as a favored alternative because they can enhance a country's energy security by displacing imported petroleum with a domestically produced alternative, provide support to domestic agricultural markets, and possibly reduce environmental impacts through GHG emissions reduction (Childs et al., 2008). In addition, the physical and chemical properties of liquid biofuels require relatively limited modifications to engine technology and fueling infrastructure (Rajagopal et al., 2007). The biofuels industry in the U.S. has also benefitted from several policy initiatives, including mandates, tax credits and subsidies from federal and state governments.

However, first generation biofuels, such as corn-based ethanol, could lead to food shortages and competition for prime land between food crops and biofuel crops (Doornbosch and Steenblik, 2008). In addition, whether biofuels can result in carbon savings depends on how they are produced (Fargione et al., 2008; Searchinger et al., 2008). A prevailing belief is that producing biofuels using food crops like corn is unsustainable because higher demand for biofuels could lead to a diversion of food crops to biofuel production. This also highlights the need for developing biofuels from non-

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food sources. Against this backdrop, the 2007 Energy Independence and Security Act (EISA) increased the renewable fuel standards (RFS) to 36 billion gallons by 2022 up from 15.5 billion gallons in 2012. However, the 2007 EISA capped the contribution of corn-based ethanol to 15 billion gallons with cellulosic ethanol and other advanced biofuels constituting the remaining 21 billion gallons.

The U.S. government, through several policies such as the 2002 Farm Bill, the 2005 Energy Policy, the 2007 EISA, and the 2008 Farm Bill, has repeatedly encouraged the production of cellulosic biofuels produced using feedstocks such as woody biomass, grasses, and the non-edible parts of plants. Cellulosic biofuels can act as a potential source for large-scale liquid biofuel production that can meet our transportation needs without significantly affecting land needed for food crop production (Rubin, 2008). Despite the thrust on developing advanced cellulosic biofuels, corn remains a major source for biofuel production in the U.S., however, it is necessary to diversify the feedstock portfolio from a long-term sustainability viewpoint (Eisentraut, 2010).

The initial volumetric production targets set under the RFS have been lowered on many occasions owing to lower fuel consumption for vehicles resulting in lower demand, and slower than expected development of cellulosic biofuel production, among other factors (Lynes et al., 2016). One of the factors inhibiting the biofuel production using cellulosic feedstocks is that of biomass availability. Along with technological advancement in the feedstock-to-fuel conversion process, a competitive, year-round supply of biomass feedstock is a major constraint in the commercial deployment of advanced biofuel production (Sims et al., 2010). Supply-side aspects, such as feedstock cultivation intended for biofuel production and the decision-making process of a landowner with regard to the adoption of switchgrass owing to its favored position as a high-potential energy feedstock, are critical (Jensen et al., 2007). Therefore, an important aspect of switchgrass adoption relates to its profitability. It is worth noting that land devoted to switchgrass cultivation could come out of land already used for row crops, forage crops, or land that is considered marginal and unsuitable for row crop production. However, in order to compare the economic viability of a long-duration crop such as switchgrass, the time horizon needs to be selected carefully. The establishment period for switchgrass ranges between 2-3 years after which the crop reaches full production levels. However, once established it is recommended that switchgrass crop be replanted after 10-15 years to maintain productivity levels (Caddel et al., (2009).

Uncertain future crop yields and prices, coupled with relatively large upfront establishment costs, are characteristics of perennial crop production (Price and Wetzstein, 1999). Furthermore, allocating land for switchgrass cultivation requires a long-term commitment from the farmer and is often characterized with substantial entry and exit costs. Coupled with low yields in the early stages, there are limited revenues from agricultural activity, at least in the initial years. On the other hand, converting the land back to its traditional use might necessitate some exit costs associated with completely killing switchgrass root-stocks and limiting competition for subsequent crops. Thus, a financial analysis of investments in switchgrass cultivation is, like other long-term investments, fraught with various types of uncertainties. Along with the biological uncertainty associated with growing crops, factors such as climate change, an evolving policy environment, and volatile input costs, add to the complexity of analyzing economic attractiveness of switchgrass cultivation. The price of feedstocks used to produce biofuels tends to be linked to the global price of crude oil, which itself exhibits varying levels of price volatility over time (Tyner, 2008). Furthermore, Song et al. 2011 suggest that the volatility of energy crop prices is likely to fluctuate in response to the relative competitiveness of biofuels as a substitute for gasoline.

While standard discounted cash flow techniques such as the net present value (NPV) have been commonly used to evaluate investment decisions, they are relatively rigid and do not incorporate uncertainty and dynamic decision making (Duku-Kaakyire and Nanang, 2004; Song et al., 2011). In their general framework examining entry and exit decisions of a firm, Dixit and Pindyck (1994) assumed that output prices are uncertain and follow a geometric Brownian motion. In this paper, we extend the theoretical framework developed by Dixit (1989), and focus on a discrete time version of the model while accounting for the option to reverse the decision and convert the land back to its original use.

This chapter contributes to the existing literature in multiple ways. We utilize a discrete-time model, which allows us to incorporate the biological aspects of switchgrass cultivation whereby we accommodate for switchgrass age and corresponding yields over the life of the project. Furthermore, we vary our cost assumptions to account for higher upfront establishment costs and lower operational costs in subsequent time-periods.

While Song et al. (2011) highlight the importance of switchgrass age and establishment costs, their continuous-time model does is limited as they do not account for these factors. Additionally, in our model framework we integrate multiple real-world dimensions of switchgrass cultivation. Our analysis is an improvement over results obtained from purely deterministic analyses, such as James et al. (2010), as we incorporate uncertainty into the price transition for switchgrass. We evaluate the potential price transitions and associated cash flows and compute corresponding probabilities for positive and negative returns on investment in a dynamic setting. We use a recent time series for ethanol prices to estimate the parameters of the model, making our work both relevant and timely against the backdrop of recent declines in global gasoline prices.

Finally, we introduce flexible decision making at the farm level wherein the farmer has the option to increase switchgrass acreage or exit the investment during the project life after observing the corresponding output price following the principle of adaptive management. By allowing for reversibility of land-use, our model highlights some of the conditions under which a farmer could alter his/her cultivation choices and underscores the importance of active on-farm management decisions. From a policy perspective, these insights could assist in designing a program that can provide incentives and accommodate for the uncertainty associated with entering the market for advanced bioenergy.

2.2 Model Framework

2.2.1 Binomial Model and Analysis of Net Present Value

Under the framework of a binomial model, the per ton price of switchgrass is assumed to evolve as a multiplicative binomial distribution in discrete time. Figure 2.1 depicts a binomial tree that extends across two time-periods. The model adopted in this paper is based on a similar binomial tree that extends across ten time-periods, spanning the productive age for a switchgrass stand. At time t = 0, the per ton price of switchgrass is assumed to be P. In time period t = 1, the price either moves up by a multiplicative factor u with probability q to reach P_u or moves down by a factor d with probability (1 - q) to P_d. The binomial tree is referred to as a recombining tree because an up-move followed by a down-move, yields the same value as a down-move followed by an up-move. Thus, at time t = 2, the price is given by one of three potential values: P_{uu}, P_{dd}, or $P_{ud} = P_{du}$.

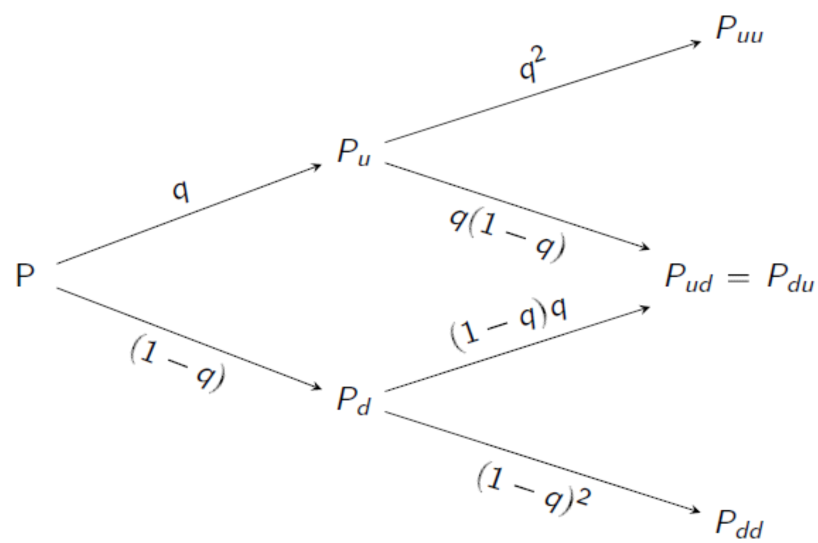

Figure 2.1: A two-period recombining binomial tree depicting potential price paths and associated probabilities

In this framework, we assume that the volatility in prices σ is known and remains constant. The risk-neutral probabilities, i.e. the probabilities of future outcomes adjusted for risk, q and (1 - q) are also known. Based on these assumptions and the general framework developed under the Cox-Ross-Rubenstein Binomial Option Pricing Model (Chriss, 1996), the respective values for q, u, and d can be given by

$$q = \frac{e^{r\Delta t} - d}{u - d} \qquad (1)$$

$$u = e^{\sigma\sqrt{\Delta t}} \qquad (2)$$

$$d = \frac{1}{u} \qquad (3)$$

where Δt is the step size and r is the risk-free rate of interest. As t →0, the multiplicative binomial process described above converges to the geometric Brownian motion (GBM) (Duku Kaakyire and Nanang, 2004) and the evolution of P can be described by

$$dP = \mu P dt + \sigma P dW \qquad (4)$$

where μ is the drift, σ is the volatility and dW is the increment of a standard Wiener process. The continuous approximation of the GBM is used to estimate the parameters in Eqs. (1)-(3). Subsequently, the parameters can be utilized to model the evolution of price in the discrete version of the model.

The net present value (NPV) of a project is the sum of discounted cash flows associated with a project. Mathematically it can be described as:

$$NPV = CF_0 + \sum_{t=1}^{T} \frac{CF_t}{(1+r)^t} \qquad (5)$$

where CF_0 is the initial investment at time t = 0 and CF_t represents the net cash flow at time t. The inflows/revenues at each time-step are the value of agricultural output computed using the estimated per ton market price of switchgrass P_t times the quantity of output or yield per acre Y_t. Similarly, the outflows/expenditures represent the costs C_t associated with harvesting the produce and other on-farm/off-farm activities. Therefore, the CF_t term in Eq. (5) can be expressed as $CF_t = P_tY_t - Ct$. Finally, r is the interest rate used to discount future cash flows to their present value. A positive NPV, i.e. NPV > 0, indicates that the present value of inflows exceeds the value of outflows over the life of the project thereby yielding a positive return on investment.

2.2.2 Analysis of Profitability

For a 10-period binomial tree, there are $2^{10} = 1024$ possible price transition paths that can yield different NPVs. We use a combination of probability and matrix algebra to delineate all the potential price paths and associated NPVs using tools in R (Winston, 2012; Warnes et al., 2014) We consider a matrix $U_{1024x10}$ that represents the magnitude of all the possible permutations of an up-move u and a down-move d over the life of the project. Multiplying U by a scalar P allows us to capture the transition of switchgrass prices over the 10-year period. Similarly, we consider a matrix of yearly yields Y_{10x10}, which incorporates varying yields during the project life, i.e. lower yields in the early years until the switchgrass stand is established and optimal/full potential yields during the latter years of the project. We consider a non-stochastic matrix of costs $C_{1024x10}$. Although the costs vary based on the year of operation, we assume that the costs are known prior to initiation of the project. The above matrices are used to compute year-on-year net revenues over the project life. Finally, discounting yearly net revenues to year 0, aggregating net revenues over the project life, and subtracting initial establishment costs CF_0 incurred in time-period t = 0, gives us the NPV under each price transition scenario.

The analysis allows one to study the distribution of NPVs and to summarize statistics to evaluate project profitability under varying price transition scenarios.

2.3 Data and Parameter Estimates

In order to estimate the returns to a farmer, we construct a hypothetical time series of switchgrass prices. Using the Nebraska Energy Office database (http://www.neo.ne.gov/statshtml/66.html), we obtained a month-on-month time series of per gallon ethanol prices from December 2006 to December 2015. We chose this database due to the availability of recent data on ethanol prices. In addition, our cost and yield estimates for switchgrass pertain to the U.S. Midwest region, and ethanol prices in Nebraska can be considered representative for this region. The time period for the data series spans a period of 9 years and includes the twelve months prior to the passage of the 2007 EISA, which came into effect in December 2007. To arrive at the farmgate price of switchgrass, we adapt the methodology described in Song et al. (2011). We begin with historical per gallon ethanol prices and assume three levels of conversion efficiency (gallons per ton of ethanol) to estimate dollar prices per ton of switchgrass. We subtract conversion costs and transportation costs to estimate the ethanol producers' willingness to pay for the feedstock. The ethanol producers' willingness to pay for the feedstock along with government subsidies determine the farmgate price.

Our assumptions pertaining to conversion costs are informed by previously published literature and a site visit to a cellulosic biofuel pilot plant operated by the University of Florida, Gainesville at their facility in Perry, Florida. Haque and Epplin (2012) collate cellulosic ethanol production costs reported by other studies ranging from $0.79 per gallon to $3.37 per gallon (Haque and Epplin, 2012). Differences in conversion costs arise from a variety of factors ranging from type of feedstock, pre-treatment, type of enzyme, yield as well as other economic assumptions. As a result, conversion costs exhibit large variations across different studies. Based on a recent study conducted by the University of Florida, we assume the conversion cost is $1.64 per gallon (Gubicza et al., 2016). Although the primary feedstock used in their study was sugarcane bagasse, discussions with the research team at the Perry plant suggested that the input requirements and the conversion process for ethanol produced using switchgrass would be similar [personal communication with Dr. L. Ingram at the University of Florida, Gainesville on 11/12/2015]. Additionally, the conversion cost assumed in this article lies within the range obtained from the meta-analysis conducted in Haque and Epplin (2012). Furthermore, transportation costs are assumed at $8 per ton (Babcock et al., 2007).

The United States Department of Agriculture (USDA) provides financial assistance to farmers and landowners for growing, maintaining and harvesting biomass used for energy and bioproducts under the Biomass Crop Assistance Program (BCAP). The support usually comes in the form of establishment payments for growing new biomass crops, annual maintenance payments and matching payments towards collection, harvesting, transportation and storage costs (USDA, 2016b). In August 2015, the USDA revised the cost-share match to a maximum of $20 per dry ton of feedstock (USDA, 2016c). In our computations, we assume the government subsidy is $20 to compute our farm gate price. However, the USDA provided matching payments to the tune of $45 per ton under an earlier version of the BCAP program, which we assume as the level of subsidy in our modified scenario (USDA, 2013). We estimate parameters under both scenarios and compare our analysis under varying subsidy regimes. This helps to highlight the importance of government subsidies to make switchgrass cultivation economically competitive.

We compute farmgate prices under three conversion scenarios with conversion rates of 66, 71, and 91 gallons of ethanol per ton of switchgrass. These three conversion rates are categorized as the Low, Medium, and High scenarios in the remainder of the paper. Unless specified otherwise, all the results are presented for the Medium scenario. In order to estimate the parameters of the model, prices and costs are deflated using a monthly series of the Personal Consumption Expenditures Price Index obtained from the St. Louis Federal Reserve (available at https://fred.stlouisfed.org/series/CPIAUCSL#0). The base year is 2009 [CPI; 2009 = 100] which indicates that all prices and costs have been scaled to represent equivalent dollar values in 2009. To estimate the drift μ and the volatility σ parameters for the price process, we use a discrete version of the GBM. If P_t follows a GBM,

$$\ln P_t - \ln P_{t-1} = \left(\alpha - \frac{1}{2}\right)\sigma^2 + \sigma\varepsilon \tag{6}$$

where ε ~ N(0, 1) (Song et al., 2011). The maximum likelihood estimates of α and σ are $\hat{\alpha} = m + \frac{1}{2}s^2$ and $\hat{\sigma} = s$ where m and s are the sample mean and standard deviation of the $\ln P_t$ - $\ln P_{t-1}$ series (Dixit and Pindyck, 1994; Song et al., 2011). Our analysis confirms that the transformed time-series for the data is stationary, allowing us to arrive at reliable estimates for our parameters. For the NPV analysis, we made informed assumptions pertaining to the per acre yield, potential yield in the early years prior to stand establishment, stand life, establishment costs, operational costs and interest rates.

Switchgrass grows well in a wide variety of soil types and climatic conditions. However, its annual yields may vary depending upon several factors including cultivar type, fertilizer application rates, rainfall and moisture, and temperature (Wullschleger et al., 2010). Typically, a switchgrass stand remains productive for around 10 years. In some cases, estimated yields are 50 percent of the potential in year 1, and reach full potential thereafter until replanted assuming a ten-year cycle (Hoque et al., 2016). In other cases, it is assumed that the crop takes up to 3 years to be fully established after which yields attain full potential. Following Garland (2008), we assume that yields during the first two years are at 30 percent and 70 percent of the full potential respectively and beginning in year 3 maximum yields are attained for the remainder of the project (Garland, 2008).

In addition, per acre yields also depict substantial variation. In a study conducted across several sites in the United States, Wullschleger et al. (2010) found that the mean biomass yield for the upland and lowland ecotypes were 8.7 ± 4.2 Mg ha^{-1} (approximately 3.9 ± 1.8 tons/acre) and 12.9 ± 5.9 (approximately 5.7 ± 2.6 tons/acre)Mg ha^{-1} respectively. Meanwhile, Garland (2008) estimated yields as high as 10 tons per acre on test plots, but between 6 and 8 tons on commercial scale plots. Hoque et al. (2016) assumed yields at 6 dry tons per acre for Liberty switchgrass in Iowa. For our research, we adopt a similar approach and assume switchgrass yield at 6 tons per acre.

The analysis of long-term investments, such as those typically performed in a cost benefit analysis, is sensitive to the choice of the discount rate (Feldstein, 1964). The USDA Farm Service Agency (FSA) provides Farm Operating Loans ranging between $50,000 and $300,000 to cover for items such as farm equipment, livestock and feed, fuel, farm chemicals, insurance, etc. As of May 1, 2016 the interest rates on Direct Farm Operating Loans was 2.375% USDA (2016a). Additionally, during 2014 and 2015, the market yield on the 10-year constant maturity U.S. Treasury security stood at 2.54% and 2.14% respectively (US Federal Reserve, 2016). Meanwhile, Associated Farm Mortgage Inc. (AFM) offered interest rates ranging between 4.20% and 4.60% on a 10-year loan with monthly and semi-annual payment options, respectively (AFM, 2016). For Liberty Switchgrass, Hoque et al. (2016) assumed an interest rate of 8% on establishment costs and an interest rate of 5% on loans for operating expenses. In our analysis, we assumed a similar discount rate of 4.6% over the 10-year period.

We followed the cost estimates from Hoque et al. (2016) as the baseline to guide our assumptions and deflated them to 2009 dollars. While the estimated establishment costs include planting of soybean and oats during the field preparation stage of crop production, we do not include any revenues from the sale of any produce from pre-establishment activities. Only revenues from the sale of switchgrass are considered in the analysis. The assumptions for the NPV analysis are outlined in Table 2.1.

Table 2.1: Summary of assumptions for the NPV analysis

Variable	Assumption	Source
Duration	10 years	Garland (2008)
Acreage	1 acre	
Establishment costs (t = 0)	\$407.72	Hoque et al. (2016); deflated to 2009 prices
Operational Costs (years 1 and 2)	\$256.36 and \$265.43	Hoque et al. (2016); deflated to 2009 prices
Operational Costs (years 3 - 10)	\$243.12 per year	Hoque et al. (2016); deflated to 2009 prices
Yield per acre	6 tons	Hoque et al. (2016); Garland (2008)
Yield (years 1 and 2)	30% and 70%	Garland (2008)
Yield (years 3 - 10)	100%	Garland (2008)
Interest rate (r)	4.6%	AFM (2016)

2.4 Results and Discussion

2.4.1 Fixed Prices and General Framework

We formulate a general framework of the investment in switchgrass cultivation to assess the conditions under which the investment yields a non-negative return. If the per ton price of switchgrass P_t were assumed to be constant over the life of the project, we can compute the break-even price P such that the NPV of the project is zero. Recalling that $NPV = -CF_0 + + \sum_{t=1}^{T} \frac{CF_t}{(1+r)^t}$, setting NPV = 0 and using $CF_t = P_tY_t - C_t$, we obtain

$$0 = -CF_0 + \sum_{t=1}^{T}\left[\frac{P_t Y_t}{(1+r)^t} - \frac{C_t}{(1+r)^t}\right]$$

Furthermore, since P_t is constant in the static scenario, one has

$$0 = -CF_0 + P\sum_{t=1}^{T}\frac{Y_t}{(1+r)^t} - \sum_{t=1}^{T}\frac{C_t}{(1+r)^t}$$

Solving explicitly for the break-even price (P), gives

$$P = \frac{CF_0 + \sum_{t=1}^{T}\frac{C_t}{(1+r)^t}}{\sum_{t=1}^{T}\frac{Y_t}{(1+r)^t}}$$

Based on the assumptions stated above, $P \approx 56.84$.

Figure 2.2 shows the estimated monthly per ton price of switchgrass for the Medium conversion scenario. This time-series was utilized to derive the parameters of the model. Our estimates for the average price P_{avg} , drift α and volatility σ in the three scenarios for the entire data-set under the $25 subsidy regime are given in Table 2.2.

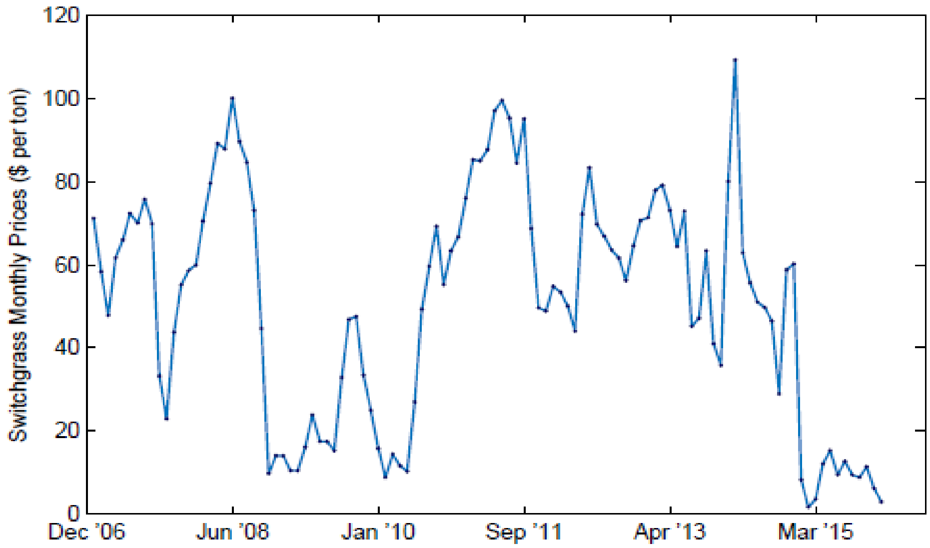

Figure 2.2: Switchgrass prices for the Medium scenario estimated using historical ethanol prices and a $20 subsidy

Table 2.2: Average prices and parameters under Low, Medium, and High conversion scenarios with a $20 subsidy per ton of switchgrass

Low	Medium	High
P_{avg} = 47.97	P_{avg} = 50.73	P_{avg} = 61.75
α_l = 0.06	α_m = 0.07	α_h = 0.11
σ_l = 0.41	σ_m = 0.44	σ_h = 0.55

Since the parameters were estimated using monthly data, it is important to use the appropriate time-step in order to compute the magnitude of the up-move u and the down-move d. The adjusted magnitudes, shown in Table 2.3, are computed using Eqns. (2)-(3) with a $\Delta t = 1/12$.

Under the framework of the binomial model it is possible to find the lower and upper bound for the price such that an entry decision can be made by observing the price at time t = 0. The lower bound on price P indicates the lowest price at which a farmer could enter the market and cultivate switchgrass. This assumes a best-case scenario wherein prices increase at every time-step in the future. On the other hand, the upper bound on P indicates the highest price at which a farmer could enter the market and cultivate switchgrass and assumes a worst-case scenario wherein prices fall at every time-step in the future.

Table 2.3: Magnitude of up-move and down-move under Low, Medium, and High scenarios

Low	Medium	High
$u_l = 1.12$ $d_l = 0.89$	$u_m = 1.13$ $d_m = 0.88$	$u_h = 1.17$ $d_h = 0.85$

Based on the cost, yield, and interest rate assumptions for the NPV analysis stated earlier, the computed values for the up move and the down move described above, and parameters estimated in the Medium scenario, we can evaluate the lower and upper bound on the price so that a decision rule can be derived for a farmer/landowner who chooses to cultivate switchgrass on his/her plot of land by only observing the price at time t = 0. Similar to the approach above, we derive the boundary prices for the two scenarios where

$$P_{lower\ bound} = \frac{CF_0 + \sum_{t=1}^{T} \frac{C_t}{(1+r)^t}}{\sum_{t=1}^{T} \frac{u^t Y_t}{(1+r)^t}}$$

and

$$P_{upper\ bound} = \frac{CF_0 + \sum_{t=1}^{T} \frac{C_t}{(1+r)^t}}{\sum_{t=1}^{T} \frac{d^t Y_t}{(1+r)^t}}$$

Table 2.4: Price bounds and corresponding investment rules

Range	Investment Rule
$P_0 < 26.21$	Never Invest
$P_0 > 110.27$	Always Invest

2.4.2 NPV Computations

We set the initial per ton price for switchgrass at $50.73, which is the average per ton price estimated using historical ethanol prices as well as conversion and transportation costs for switchgrass. Beginning with this initial price, we construct a binomial tree that extends in time for ten periods. The magnitude of the up-move and down-move are u = 1.13 and d = 0.88 respectively. The entire tree is quite large and contains 66 nodes. In Figure 2.3, we depict a part of the binomial tree, which shows the initial transition of prices in time-periods 0, 1, and 2 as well as the terminal prices in time-period 10. To compute the NPV of an investment in switchgrass cultivation we consider one price realization at each time period. The revenues from the cultivation activity are computed using these prices whereas the costs, yield, and interest rate assumptions are identical to those stated previously.

We evaluate a subset of these potential price paths and compare the NPVs under these scenarios. Beginning with an initial price of $50.73, the scenarios include an up-move in prices during subsequent periods, a down-move in subsequent periods, prices move up in the initial 5 periods and then down, prices move down in the initial 5 periods and then up, move up and down in alternate periods and finally a combination of up and down moves in select scenarios. These computations help us highlight the sensitivity of the NPV to favorable and unfavorable price transitions. Tables 2.5 and 2.6 provide a summary of the price scenarios and the NPVs.

					$172.21
					$134.11
			$73.20		$104.44
		$64.78			$81.33
	$57.32		$57.00		$63.33
$50.73		$50.44		....	$49.32
	$44.64		$44.39		$38.41
		$39.28			$29.91
			$34.57		$23.30
					$18.14
					$14.13

Figure 2.3: Excerpt from a ten-period binomial tree depicting the transition of price P beginning at t = 0 through t = 3 and the terminal prices at t = 10

Table 2.5: Price Transition scenarios and corresponding NPVs

Price Transition	Net Present Value
P_t ↑ (price moves up in every subsequent period)	NPV_{HIGH} = \$2078.6
P_t ↗ ↘ (price moves up first 5 periods, and then down 5 periods)	NPV_{HL} = \$612.0
P_t ↗ ↘ (price moves up-down in alternate periods)	NPV_{UD} = \$ − 144.7
$P_t = P_0$ (Price constant at \$50.73)	NPV = \$ − 245.6
P_t ↘ ↗ (price moves down-up in alternate periods)	NPV_{DU} = \$ − 397.0
P_t ↘ ↗ (price moves down first 5 periods, and then up 5 periods)	NPV_{LH} = \$ − 851.9
P_t ↓ (price moves down in every subsequent period)	NPV_{LOW} = \$ − 1272.0

Table 2.6: Additional price transition scenarios and corresponding NPVs

Price Transition	Net Present Value
P_t ↗ ↘ (price moves up first 3 periods, and then down 7 periods)	NPV_{U3D7} = \$ − 196.5
P_t ↗ ↘ (price moves up first 4 periods, and then down 6 periods)	NPV_{U4D6} = \$209.0
P_t ↘ ↗ (price moves down first 3 periods, and then up 7 periods)	NPV_{D3U7} = \$ − 197.5
P_t ↘ ↗ (price moves down first 2 periods, and then up 8 periods)	NPV_{D2U8} = \$350.8

Out of the 7 scenarios described in Table 2.5, the NPV was positive only in two scenarios; (i) when prices increased in all periods, and (ii) when prices rose in the initial 5 periods and fell thereafter. In the constant price scenario, since the initial price at $50.73 was below the break-even price derived in subsection 2.4.1 the NPV is negative. These results are not particularly surprising because under the NPV framework revenues and costs arising in the early years after project inception are valued more whereas revenues/costs in the later years are heavily discounted and thus valued lower. However, a relatively wide spread in NPV among the diff t scenarios highlights the influence of the price transition on project NPVs with the spread between the NPVs in best and worst-case scenarios, i.e. the scenario in which prices rise in all periods vis-a`-vis the scenario in which prices fall in all subsequent periods, exceeding $3350.

In Table 2.6, we present additional price transition scenarios that help us identify critical-points in the NPV time-line wherein a switch occurs from negative to positive NPVs. Under the assumptions of the model, NPV_{U4D6} indicates that if prices move up for the first four time-periods, then even if prices decline in the remaining six time-periods, the project NPV is positive. However, an up-move in prices only for the first three time-periods, followed by a decline in prices in subsequent periods, is not sufficient to cover for the project costs. On the other hand, a negative value for NPV_{D3U7} indicates that if price declines during the first three time-periods, an up-move in prices in the subsequent periods is insufficient to result in a positive project NPV. This also provides the farmer/landowner vital information about the potential profitability of the project much ahead of the project termination date. Under the existing binomial framework, if the per ton price of switchgrass falls to $34.57 by the third time-period, the prospects for the project are unfavorable. Meanwhile, if the per ton price rises to $82.71 by the fourth time-period the project outcome will always be favorable for the farmer given the assumptions of this model.

2.4.3 Profitability and Risk

Evaluating the entire set of potential price paths, associated revenues, and costs allows us to closely study the distribution of NPVs. Figure 2.4 provides a histogram of project NPVs indicating a positive skew to the distribution. Summary statistics indicate that at time period t = 0, the expected NPV of the project is $- 245.6. On the upside, the maximum potential NPV is as high as $2078.6 whereas the most a farmer can lose in the project is $1272.0. While the spread of NPVs is quite wide, it is important to highlight that the probability of achieving a positive NPV is approximately 0.33 while the odds of making a loss are approximately 0.67. In other words, the project will yield a positive return approximately only 33% of the time.

In addition, an analysis of the odds of making profits or incurring losses with the passage of time reveals some interesting results. We compute summary statistics for project NPVs at t = 1, t = 2, t = 3 and t = 4 for cases where the prices have transitioned upwards or downwards in all preceding time periods. Although we analyzed the probability of profits and losses in the intermediate scenarios, the results are not quite as revealing.

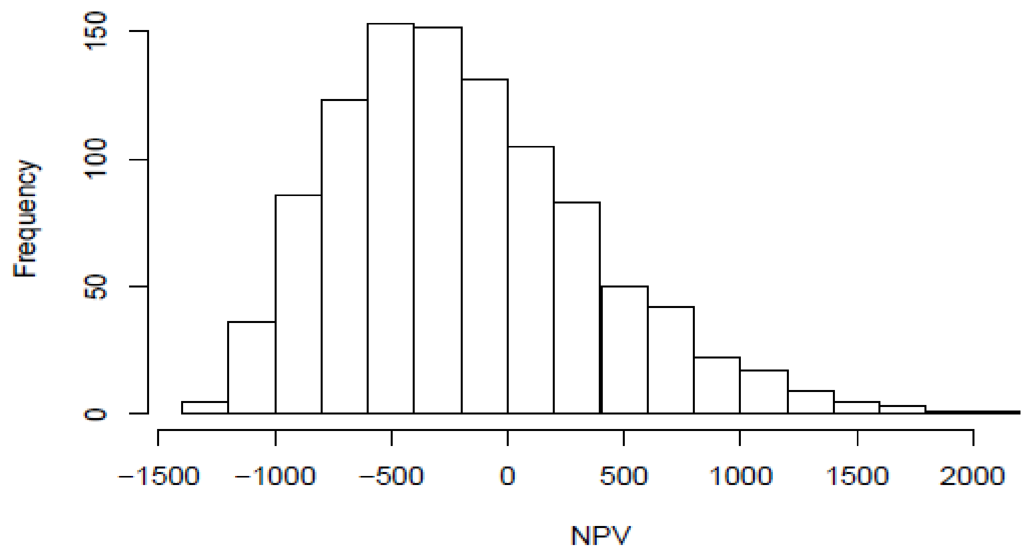

Figure 2.4: Histogram of Net Present Values for the Medium Scenario

Table 2.7: Case 1 - Comparison of project profitability and NPVs wherein prices rise in all preceding periods

	t = 0	t = 1	t = 2	t = 3	t = 4
Profit Odds	0.33	0.51	0.74	0.95	1.0
Loss Odds	0.67	0.49	0.26	0.05	0.0
	t = 0	t = 1	t = 2	t = 3	t = 4
Minimum NPV	$-1272.0	$-964.4	$-597.2	$-196.5	$209.0
Expected NPV	$-245.6	$28.5	$325.8	$629.2	$921.9
Maximum NPV	$2078.6	$2078.6	$2078.6	$2078.6	$2078.6

From an a priori probability of a positive return on investment at 0.33 at time t = 0, if the per ton price of switchgrass moves up during period t = 1, the odds of making a profit on the investment increase to 51%. Moreover, if the price moves up in periods 1 and 2, the odds of a positive NPV increase to 74%. If prices continue to transition upwards in periods 3 and 4 the probability of attaining a positive NPV on the project are 95% and 100% respectively as also noted in Table 2.7.

On the other hand, Table 2.8 shows that the probability of incurring losses increases if the per ton price of switchgrass declines with time. From an a priori probability of loss at 0.67, if the price falls at time t = 1, the probability of incurring a loss increases to 85%. Similarly, if the price declines during periods 1 and 2, the likelihood of incurring a loss rises to 97%. Furthermore, a decline in prices for the 3 consecutive periods at t = 1, t = 2 and t = 3 results in a probability of loss at 100%, i.e. the NPV will always be negative irrespective of favorable future price movements.

Table 2.8: Case 2 - Comparison of project profitability and NPVs wherein prices fall in all preceding periods

	t = 0	t = 1	t = 2	t = 3
Profit Odds	0.33	0.15	0.03	0.0
Loss Odds	0.67	0.85	0.97	1.0
	t = 0	t = 1	t = 2	t = 3
Minimum NPV	$-1272.0	$-1272.0	$-1272.0	$-1272.0
Expected NPV	$-245.6	$-498.8	$-712.5	$-882.1
Maximum NPV	$2078.6	$1097.5	$350.8	$-197.5

2.4.4 Computation of Option Values

The results from Table 2.6 and section 2.4.3 provide interesting insights, and present an opportunity to evaluate the influence of dynamic management pertaining to on-farm cultivation decisions. Given individual specific risk tolerance, a farmer has the option to expand the acreage of land under cultivation if the odds of making a profit on the investment or the magnitude of the NPV are beyond his/her preferred threshold or exit the investment if the price transitions appear to be unfavorable. We consider two management options: (1) the option to expand, and (2) the option to abandon.

2.4.4.1 Option to Expand Cultivation

Under this management option, we assume that the farmer has the ability to scale-up his operation by doubling the area under switchgrass cultivation from one acre to two acres. The costs associated with pre-establishment activities and year-on-year cultivation are assumed to remain the same as those stated earlier. In other words, we do not assume any inflation in costs and also do not account for any economies of scale in production activity. In addition, the yields on the additional acre follow the same assumptions, i.e. 30% and 70% of potential in years 1 and 2 and 100% of potential beginning in year 3. However, we assume that the project ends at the end of the 10th year, at the same time as the completion of the fi project. For example, if the farmer decides to expand cultivation in the second year, the revenues from the cultivation begin from the following year. Thus, the end of life of project for the new investment is not exactly in line with the potential duration of the switchgrass stand.

A typical scenario in which a farmer could exercise the option to expand cultivation would be as follows. After observing the prevailing per ton market price for switchgrass at the end of a particular time period, a farmer could decide to expand operations. Establishment costs will be incurred immediately in order to prepare the land for switchgrass cultivation. However, the stream of revenues will only accrue one period later. Thus, if a farmer chooses to increase the area under cultivation by observing prices at the end time-period t = 4, revenues will accrue beginning time period t = 5, and last for another 5 time periods until the end of the ten-year cycle. We compute the NPV of the new investment under varying price scenarios to evaluate whether the option to expand switchgrass production yields an additional value to the farmer.

Following from the results described in Table 2.6, if prices increase during the first four time-periods, the investment always yields a positive return. However, we also observed in Table 2.7, that if the per ton price of switchgrass increases during the first few time-periods, the probability of making a profit increases substantially. As a result, we evaluate a scenario in which prices are increasing and analyze the value associated with entering the market at an early stage vis-a`-vis later in the 10-year project life-cycle.

Assuming that the per ton price of switchgrass rises in all periods prior to exercising the option to expand cultivation, we evaluate the odds of the project being feasible/infeasible based on entry decisions at time periods 1 through 5 and their corresponding NPVs.

Table 2.9: Computation of profitability and corresponding NPVs on expansion option

	t=1	t=2	t=3	t=4	t=5
Expected NPV with expansion	$-23.7	$426.7	$836.5	$1182.7	$1453.1
Expected NPV status quo	$28.5	$325.8	$629.2	$921.9	$1199.0
Option value	$-52.2	$100.9	$207.3	$260.8	254.1

Under the particular assumptions and choice of parameters of this model, one can observe (Table 2.9) that the odds of realizing a profit increase with the passage of time. However, the rate of change in profitability odds appear to plateau after time period t = 4. If an individual farmer were to make a decision primarily based on a particular threshold of the odds of making a profit then he/she can decide to make the additional investment at a later time-period. Meanwhile, from the perspective of maximizing NPV, the optimal decision could be slightly diff t. After observing an up-tick in prices, exercising the option to expand at time period t = 4 compared to t = 5 allows the farmer to capture maximum gains from favorable price movements in the future, albeit exposing him/her to greater downside risks. This computation is influenced by the end date of the project and thus the results do not account for the potential upside or downside of future price movements corresponding to the biological age of the switchgrass stand. Furthermore, since the above analysis considers only the NPV of the additional investment, the mean NPV is analogous to the average value of the option to expand investment corresponding to each time-period.

2.4.4.2 Option to Abandon Cultivation

Similar to the option to expand, we also evaluate the economic value of the option to abandon the current investment in switchgrass. We know that if the per ton price for switch- grass falls to $34.57 by the third time-period, a future up-tick in prices for all subsequent periods will still yield a negative return on investment. Under this scenario, the farmer could be better off by abandoning the investment in switchgrass in order to limit his/her downside losses. We assume a scenario where prices are declining in every preceding period. Further- more, we assume that the cost of switching out of switchgrass cultivation to the alternate land use is $45 per acre (Song et al., 2011). Finally, we assume that the alternate land use is hay cultivation and the average revenue, net of costs, is $100 per acre (Jenner, 2015).

Table 2.10: Option value of exit decision under declining prices and alternate revenue of $100

	t = 1	t = 2	t = 3
Exit NPV	$72.8	$-108.5	$-225.3
Expected NPV status quo	$-498.8	$-712.5	$-882.1
Option value	$571.6	$604.0	$656.8

Based on the computations for the first three time periods, we can observe that the value of the option to exit the investment is the highest at time period t = 3 as shown in Table 2.10. This result is fairly intuitive because the likelihood of profit is zero if prices have declined in the first three time periods and abandoning this investment while choosing an alternative with a positive revenue stream allows the farmer to limit the downside. However, exiting the investment in switchgrass during the earlier time-periods, also results in the farmer losing out on the opportunity to make profit arising from favorable price transitions if they were to occur. At a per acre revenue of $100 for the alternate land use, the farmer continues to experience a negative NPV by exiting the investment in periods 2 or 3 (Table 2.10).

The value of the alternative land use and the exit costs has a significant bearing on the eventual option value. If we assume that the alternate land use yields a per acre net revenue twice as much as previously assumed, i.e. $200, the ensuing results suggest that that the option value demonstrates a monotonic decline. Table 2.11 indicates that, if the magnitude of the revenues from alternate land use is high enough, the timing of the decision to exit the investment in switchgrass becomes very important. However, if we assume that the land is marginal and is not being cultivated, the absence of an alternative land use would only result in a positive option value after year 3, in our model.

Table 2.11: Option value of exit decision under declining prices and alternate revenue of $200

	t = 1	t = 2	t = 3
Exit NPV	$764.6	$491.9	$287.7
Expected NPV status quo	$-498.8	$-712.5	$-882.1
Option value	$1263.4	$1204.4	$1169.8

2.5 Sensitivity Analysis and Alternate Scenarios

We consider alternate scenarios and evaluate their influence on project NPVs. Based on the different conversion efficiencies described in section 2.4.1, we can vary model inputs such as price, magnitude of the up-move, and the down-move to compute a range of project NPVs under the Low and High conversion scenarios. Table 2.12 delineates the parameters that were altered in the model framework.

Table 2.12: Prices and magnitudes of up-move and down-move under different conversion scenarios

Low	High
P_l = \$47.97	P_h = \$61.75
$u_l = 1.12$	$u_h = 1.17$
$d_l = 0.89$	$d_h = 0.85$

Similar to the analysis conducted for the Medium conversion scenario we compute project NPVs for a subset of price paths as well as the expected odds for profit /loss of the investment. Table 2.13 provides a summary of the price scenarios and NPVs.

The results of the NPV analysis under the Low scenarios are similar to those in the Medium scenario. The transition points for the NPV also occur at the same time intervals. The only differences occur in the magnitude and spread of the NPVs, which can be explained from the changes to the parameters of the model. However, results from the High scenario are quite different. As can be seen from Table 2.13 the NPV is positive in most of the cases considered for this analysis.

Table 2.13: Price transition scenarios and corresponding NPVs

Price Transition	NPV_l	NPV_h
P_t ↑ (price moves up in every subsequent period)	\$1603.2	\$4437.4

P_t ↗ ↘ (price moves up first 5 periods, and then down 5 periods)	\$385.5	\$1657.3
P_t ↗ ↘ (price moves up - down in alternate periods)	\$ − 261.6	\$385.3
$P_t = P_0$ (Price constant P_l = \$47.97 and P_h = \$ 61.75)	\$ − 360.3	\$212.7
P_t ↘ ↗ (price moves down-up in alternate periods)	\$ − 482.3	\$ − 7.9
P_t ↘ ↗ (price moves down first 5 periods, and then up 5 periods)	\$ − 887.7	\$ − 671.6
Pt ↓ (price moves down in every subsequent period)	\$ − 1273.5	\$ − 1234.2
P_t ↗ ↘ (price moves up first 3 periods, and then down 7 periods)	\$ − 313.3	\$334.7
P_t ↗ ↘ (price moves up first 4 periods, and then down 6 periods)	\$39.4	\$983.1
P_t ↘ ↗ (price moves down first 3 periods, and then up 7 periods)	\$ − 311.8	\$338.9
P_t ↘ ↗ (price moves down first 2 periods, and then up 8 periods)	\$159.3	\$1254.7

Furthermore, the NPV transitions from negative to positive occur at different time intervals when compared to the Low and Medium scenarios. For example, even if prices rise for the first three time-periods and decline in subsequent periods, the project NPV continues to remain positive. If prices increase for just the first two periods and fall thereafter, the project NPV would be negative. Similarly, the project NPV is negative if prices fell for the first four consecutive time-periods. In effect, the farmer can stay in project much longer compared to the other scenarios, i.e. even if prices decline for the first three time-periods, favorable price transitions in later periods can result in a positive return on investment.

Meanwhile, the analysis of profitability under the two scenarios is quite different from the observations under the Medium scenario. While the odds of profit and loss came to 0.33 and 0.67 respectively in the Medium scenario, Table 2.14 shows the odds for the other two scenarios, which indicates a high sensitivity to initial price and the magnitude of the up- and down-moves.

Table 2.14: Profit/Loss odds in the Low and High Price Scenarios

	P_l	P_h
Profit Odds	0.25	0.40
Loss Odds	0.75	0.60

Finally, as described in Section 2.3 we consider an alternate subsidy regime where the per ton subsidy for switchgrass is $45. The parameters for the model were re-estimated whole the assumptions of the model such as costs, yields and interest rate were kept unchanged. However, the initial price P_0 was different. The magnitudes of the up-moves and the down-moves, which are influenced by the volatility of the underlying time-series, were also different from the previous simulations. The methodology used to compute the NPVs under multiple price transition paths as well as the profit odds was identical to that adopted in the earlier sections of the paper. We considered only the Medium conversion efficiency scenario to highlight our results. The parameters that were changed for this simulation include $P_0 = 74.84$, $u = 1.06$ and $d = 0.94$.

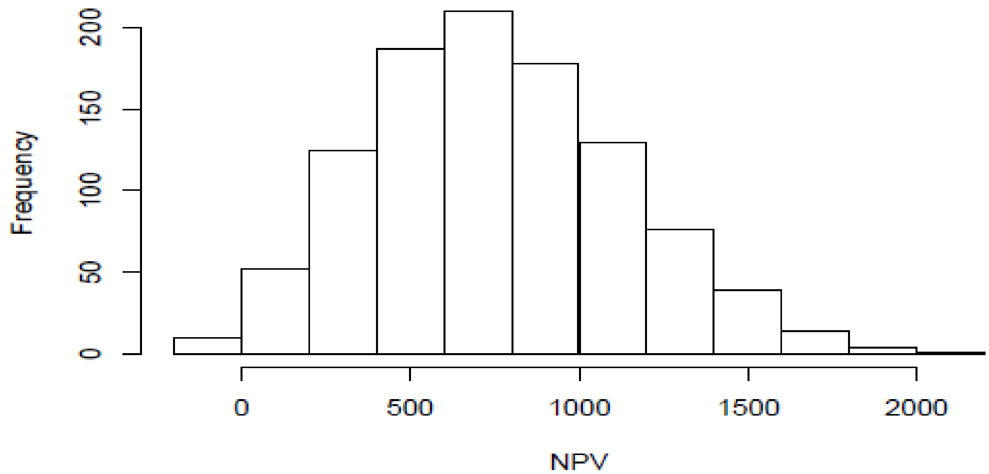

Figure 2.5: Histogram of Net Present Values for the High Subsidy Scenario

It can be seen in Fig. 2.5 that a majority of the NPV values came in positive in this scenario. In fact, under the parameters of this model, the odds of making a loss on the investment were only 1% implying that the farmer can realize a profit in 99 % of the outcomes.

2.6 Conclusions and Policy Implications

This study evaluates the economic value of switchgrass investments with price uncertainty. By adopting a discrete-time model, we are able to incorporate biological attributes of switchgrass cultivation, such as yield variability, in addition to dynamic decision making to analyze the conditions under which a farmer would prefer to expand or abandon the investment in switchgrass. We evaluate the relationship between risk and profitability by computing the odds of profit/loss under varying price transition paths for the feedstock and highlight the sensitivity of the option value, which underscores the importance of active on-farm management and timing of decisions. While our model assumed a relatively conservative yield assumption at 6 tons per acre, higher per acre yields and commercial cultivation of switchgrass could result higher returns on investment. Furthermore, a low interest rate regime, improved access to finance, and technological advancements in conversion processes could increase overall profitability in the bioenergy industry and translate into higher farmgate prices for switchgrass.

The relatively low profitability of switchgrass cultivation against the backdrop of price, demand, and climatic uncertainties, could inhibit farmer participation. Our research is able to shed light on a policy dimension, in particular government subsidies, demonstrating that project profitability is significantly higher in the high-subsidy scenario. Perennial grasses such as switchgrass provide various ecosystem services including substantial carbon sequestration, soil nutrient retention and erosion control. A subsidy that compensates for the market value of the direct and indirect ecosystem services of switchgrass cultivation could be considered. This may, on the one hand, result in higher returns to the landowner and make the investment in switchgrass more attractive while mitigating some of the consequences of on-farm activities on human and aquatic systems.

Future work could evaluate the impact of credit constraints and cost of capital on the feasibility of investments in switchgrass. Potential for preordained contracts between biofuel producers and farmers and insurance programs could be examined. This analysis can be extended to compare the feasibility of investments in switchgrass vis-à-vis other energy crops or also for alternatives including agroforestry options where energy grasses can be cultivated with other species. Finally, since switchgrass is not widely cultivated, there is limited data availability. Cultivation and processing cost estimates from other states in the US could be extremely useful to analyze investments in switchgrass and extend research in this area.

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3 Factors affecting farmer willingness to cultivate switchgrass in Missouri[2]

3.1 Introduction

The United States (U.S.) government, through policies such as the 2007 Energy Independence and Security Act (EISA) increased the renewable fuel standards (RFS) target to 36 billion gallons by 2022, while capping the contribution of corn-based ethanol to 15 billion gallons. The remaining 21 billion gallons would constitute cellulosic ethanol and other advanced biofuels. While these targets have since been revised on multiple occasions, owing to a host of factors, emphasis on the need to develop alternate energy sources remains a cornerstone of U.S. energy policy.

Cellulosic biomass feedstocks, including switchgrass and other energy grasses, are expected to become important sources of raw material for biofuel production. On the one hand, feedstocks such as switchgrass partially obviate the food vs. fuel debate surrounding biofuel production. On the other hand, switchgrass has been identified as a high potential bioenergy feedstock given its high biomass yield and ethanol conversion potential, among other factors (Wright, 2007). It is native to the U.S., has a deep-root system that helps with erosion control and substantial below-ground carbon sequestration, requires limited use of fertilizers, and can serve as a wildlife habitat. Switchgrass and other energy grasses and woody feedstocks also provide a suitable opportunity to diversity the feedstock mix away from an over reliance on corn-based

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[2] A modified version of this chapter has been submitted to the Energy Economics Journal - Burli et al. *Factors affecting willingness to cultivate switchgrass: Evidence from a farmer survey in Missouri* and is currently under review.

ethanol. Additionally, switchgrass can be used for co-firing with coal to produce electricity (Rasnake et al., 2013)

Multiple factors have held back the commercial deployment of cellulosic biofuels so far, including slower than anticipated technological advancements in the conversion processes associated with producing fuels from cellulosic biomass, improved fuel efficiency which lowers demand for ethanol, capital constraints etc. However, one of the major obstacles associated with large-scale development of cellulosic biofuels pertains to the lack of assured year-round feedstock supply (Uden et al., 2013). The challenges faced by the cellulosic bioenergy industry are often described as a chicken and egg problem, where adequate investment and infrastructure for feedstock conversion is not forthcoming owing to a lack of assured feedstock supply and farmers are unwilling to cultivate dedicate bioenergy feedstocks until a steady market is established and adequate demand is created (Luo and Miller, 2017). As a result, understanding farmer preferences and the underlying factors that inform their decisions is paramount to evaluate the supply side bottlenecks in the bioenergy industry.

There have been a few studies that have analyzed the factors that influence farmer willingness to grow feedstocks for biofuel production. While the benefits associated with switchgrass including erosion control, wildlife habitat, soil conservation, and improvements in water quality are likely to encourage cultivation; factors such as lack of information, long establishment periods, and absence of a reliable markets for the produce are crucial impediments (Hipple and Duffy, 2002). Jensen et al. (2007)

conducted a survey of farmers in Tennessee to evaluate their willingness to supply switchgrass. They found that a majority of respondents had not even heard of growing switchgrass for energy production and identified lower age, higher education, and off-farm income as factors that positively influenced willingness to cultivate switchgrass while farm size, higher farm incomes and use of leased farmland had a negative influence on share of farmland likely to be converted to switchgrass. Additionally, other factors such as erosion problems, desire to provide wildlife habitat, views about on-farm issues, and national policy issues were also studied in their research (Jensen et al. 2007).

Given the relatively long establishment period for switchgrass, and the time lag between planting and harvesting the feedstock, investments in switchgrass tend to be impacted by various types of risks including biophysical, financial, climatic, and policy uncertainty. Therefore, investments in perennial bioenergy crops are often considered to be more risky than other bioenergy feedstocks (Pannell et al. 2006, Song et al. 2011). Meanwhile, Bergtold et al. (2014) assessed farmers` willingness to produce cellulosic feedstocks under contractual arrangements. The authors adopted stated choice experiments and a random utility model framework to examine farmer decisions to find that contract length, cost share, financial incentives, insurance, custom harvest options, and net returns above the next best alternative land use are important attributes that could influence choices.

Using a survey of farmers in 12 southern states of the US, Qualls et al. (2012) delineated that factors such as farm size, raising beef cattle, age, location, concern about having the necessary financial resources and equipment negatively influenced interest in cultivating switchgrass. On the other hand, ownership of hay equipment and the possibility of lowering fertilizer and herbicide applications led to higher likelihood of interest in cultivating switchgrass. Their research found that the above-mentioned factors also influenced the share of land farm managers were willing to convert to switchgrass cultivation. Lynes et al. (2016) examined farmer willingness to harvest crop residue and grow a dedicated annual or perennial bioenergy feedstock in Kansas. They found that only 44% of the respondents were willing to grow a perennial bioenergy crop, and were willing to devote on average 97 acres for this purpose. The location of the farms, percentage of land under the conservation reserve program (CRP), and proportion of leased farmland were significant variables that explained farmer willingness. Furthermore, farm managers who had conservation plans were also more likely to produce perennial cellulosic feedstocks.

Research from other countries and varied types of cellulosic feedstock also identify a similar set of factors that can potentially influence farmer or landowner willingness to cultivate feedstocks. An analysis of Swedish farmers by Paulrud and Laitila (2010) identified age of the farmer, size of the farm, and geographical area as significant characteristics that may influence the willingness to grow bioenergy crops. Furthermore, opportunity costs associated with committing land to perennial energy crops, reversibility of decisions, returning the land to other uses, and policy environment appear to be some of the barriers to adoption in the U.K. (Sherrington et al. 2008). Finally, for woody bioenergy feedstocks such as pine, price, preference for producing non-timber products, and lower dependence on the land for income resulted in higher likelihood of forestland allocation for growing dedicated bioenergy feedstocks (Wolde et al., 2016).

Together these studies provide useful insights on some of the most important issues around the cultivation of switchgrass, and other feedstocks, for bioenergy. We build on these studies and extend the research by analyzing farmer willingness to grow switchgrass in the state of Missouri, evaluating a broader set of variables, and using rigorous economic modeling and data analysis frameworks.

3.2 Study Area

3.2.1 Data and Survey Design

A database of 5000 farmer addresses in Missouri was obtained from ListGiant, a company that provides targeted mailing lists. We randomly selected a sample of 1000 farmers from aforementioned list to participate in the study and mailed them a survey in the month of March and April 2017. As we did not have reliable metrics such as those based on farm size or minimum value of agricultural sales, we did not use any exclusion restrictions in our sample selection procedure as used in previous studies (Jensen et al. 2007; Qualls et al. 2012). The survey packet included a cover letter, forms seeking the respondent's consent to utilize their data for the survey, a copy of the survey, and a self-addressed postage-paid return envelope.

The survey instrument contained a brief background about switchgrass and its use as a bioenergy feedstock and 33 questions spanning (i) farm size, characteristics, and current farming practices; (ii) knowledge of and interest in cultivating switchgrass; (iii) price requirements and potential acres that would be devoted to switchgrass under favorable conditions; (iv) opinions about cultivation decisions, environment, society, and policies; (v) individual characteristics and demographic attributes of the respondents.

The initial mailing was followed by a reminder postcard a week later. About 3 weeks later, a second survey packet was mailed out to non-respondents. The follow-up mailing also included a cover letter urging the recipients to participate in the survey, consent forms, a copy of the survey questionnaire, and a self-addressed postage-paid return envelope.

3.2.2 Survey Responses

Out of the 1000 surveys mailed, 72 were returned as undeliverable due to incorrect addresses. 115 respondents indicated that they were unwilling to participate in the survey, owing to a host of reasons ranging from personal situations, age, farm characteristics, or by sending a return note/ a blank survey. 135 respondents completed the survey. Based on the above, the survey response rate was 26.9% i.e. [(135 +115)/(1000-72)]. Out of the 135 respondents who completed the survey, 105 responses were usable for performing our analysis examining farmer willingness in response to farm-level characteristics, risk preferences, information and demographic attributes. The lower number of responses is because not all respondents answered all the questions, and we have considered only the most complete responses. Similar approaches have been used in previously published literature (Jensen et al., 2007; Qualls et al., 2012; Lynes et al., 2016).

A comparison with the 2012 Agricultural Census for Missouri published by the United States Department of Agriculture (USDA, 2014) highlights the following similarities and differences compared to our research sample. A majority of the farmers in the state of Missouri report their ethnicity as white or Caucasian with 97.3% of all farmers representing this ethnic category. In our survey sample, the proportion of respondents reporting their ethnicity as Caucasian was 99.0%. While proportion of male and female principal farm operators in Missouri is 88.8% and 11.2% respectively, our research sample had 86.7% male respondents and a marginally higher representation of female farmers with 13.3% female respondents. In terms of land holdings, the average farm size in Missouri is 285 acres whereas the average farm size for our survey sample came in at 208.4 acres. The distribution of survey respondents by farm size is provided in Table 3.1.

Table 3.1: Comparison of land holdings by respondents

Acreage	Proportional land holdings in Missouri	Proportional land holdings in sample
1-9	3.6%	3.8%
10-49	21.9%	39.0%
50-179	37.3%	25.7%
180-499	23.5%	21.9%
500 or more	13.7%	9.5%

Source: USDA Agricultural Census 2014 and survey data

Compared to the statewide data, we received a higher response from farmers in the 10-49 acres category, and a somewhat lower response from farmers in the 50-179 acres category. The distributions in the other categories are fairly in line with the 2012 Missouri Agricultural census data. With regard to the age of the survey respondents, our sample had the highest number of responses, 54.3%, for the above 60 years age category followed by 23.8% in the 51-60 years category. The other age categories < 30 years, 31-40 years, and 41-50 years had 1.0%, 6.7% and 13.3% respondents respectively. The distribution of respondent age is similar to the age distribution of farmers in the state of Missouri, although the specific age categories are slightly different. The average age of a farmer in Missouri in 2012 was 58.3 years.

Finally, the survey responses arrived in three waves following from the initial mailings of the survey, a reminder postcard sent one week after the initial mailing, and a second mailing about three weeks later. We evaluated variables such as size of land holding as well as demographic characteristics such as gender, age, and education for the survey respondents' based on the time their responses were received and did not find statistically significant differences in the respondents.

3.3 Analytical Framework

3.3.1 Logistic regression

The dependent variable (Y) for this analysis is farmer "willingness to cultivate switchgrass", which is binomial in nature. Thus, we use logistic regression to analyze our data. In a logistic regression, the model estimates the probability of a "yes" response occurring given the values of the independent variables (X's) (Wooldridge, 2015). In its simplest rendering with one explanatory variable the probability of Y, P(Y), can be expressed as

$$P(Y) = \frac{1}{1 + e^{-(\beta_0 + \beta_1 X)}}$$

and this framework can be easily extended to the n variable case where

$$P(Y) = \frac{1}{1 + e^{-(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n)}}$$

For our analysis, the X's represent the various variables in classified as farm characteristics, risk, and demographic variables. The logit model ensures that the probabilities are always between 0 and 1, and the link function G(z) , where z is the composite index of all the explanatory variables, has a cumulative distribution function (CDF) given by $G(z) = \frac{e^z}{1+e^z}$.

3.3.2 Weighting Survey Responses

Assigning weights to survey responses is a technique used for survey data analysis to ensure that the survey data is representative of the population being studied and common issues such as non-response can be adequately addressed (Kalton and Flores-Cervantes, 2003). Using survey weights is considered an important element for arriving at population estimates and regression parameters that are not just valid for the sample data alone (Valliant et al., 2013). However, as regression models are primarily used to unravel relationships between the dependent and independent variables, it is argued that it should be possible to arrive at these estimates without the use of sampling weights (Lumley, 2011). Overall, one must proceed with caution when using sample weights in the analysis of survey data as weighting to make estimates less efficient. A conservative approach is to compare results from both analyses and if the results are similar, the unweighted analysis could be favored from an efficiency perspective for associational parameters whereas weighted estimates could be used for population-level parameters (Platt and Harper, 2013).

Adjustments for non-response can be accomplished through simple tabulation of responses and creating classes with different weights or employing more sophisticated techniques, which require information or assumptions pertaining to the marginal distributions of the variables and interactions (Kalton and Flores-Cervantes, 2003; Valliant et al., 2013). For our survey, the respondent characteristics are a good representation of the population of farmers in Missouri on several key variables including gender, ethnicity and age as described in Section 3.2.2 above. However, our sample has a higher representation of individuals with smaller land holdings. We assign proportional weights to the survey responses using the distribution of land holdings from the 2012 Missouri Agriculture Census in order to make our survey sample more representative and correct for any non-response bias that may be present in the data owing to lower responses from farmers with larger land holdings. We present results from the weighted and unweighted regressions.

3.3.3 Transformation of variables and recursive partitioning

Some of the variables pertaining to land characteristics had skewed distributions. A usual method of dealing with skewed distributions with positive values is to consider logarithmic transformations of the variables. While this method was suitable for the land holding variable 'acres', the other variables which depicted land holdings in specific land use categories such as cropland, grazing land, woodland or non-agricultural land had several 'zero' values. In order to transform these variables for our analysis we utilized the Box-Cox transformations wherein the variable is transformed as

$$g(x;\ \lambda_1, \lambda_2) = \frac{(x +\ \lambda_2)^{\lambda_1}\ - 1}{\lambda_1}\ when\ \lambda_1 \neq 0$$

and

$$g(x;\ \lambda_1, \lambda_2) =\ \log(x + \lambda_2)\ when\ \ \lambda_1 =\ 0$$

A common choice in the two-parameter version is to have $\lambda_1 = 0$ and $\lambda_2 = 1$, a convenient property of which is that it maps the zeros to zero (Hyndman and Grunwald, 2000; Hyndman, 2010). We anticipated that a log-transformation of these continuous variables would best capture the relationship between farmer willingness and the land holding under various types of land use and log-transformations would also correct for the skewness in the distribution of the data.

Recursive partitioning is a technique used to split data into categories, wherein observations that belong to the same group exhibit similar characteristics (Strobl et al., 2009). We utilize this approach to partition some of the variables in the risk and demography categories as we anticipated responses to vary depending on specific thresholds. Dividing the respondents into specific categories based on their responses to questions with Likert-scale responses allows us to study their statistical significance on the dependent variable. Similarly, demographic variables that solicited responses based on some interval scale are classified into optimal clusters for enhancing their predictive capabilities within the model framework. The recursive partitioning analysis performed using the 'rpart' package in R (Therneau et al., 2012), Based on the results of the recursive partitioning analysis, categorical/dummy variables are created to appropriately represent the specific categories.

3.3.4 Odds ratio

Odds ratio is extremely important to interpret the coefficients of the logistic regression. The ratio expressed as the probability of success over the probability of failure indicates the resulting change in odds due to a one-unit change in the predictor (Field et al. 2012). The odds ratio is expressed as

$$odds = \frac{P(Y)}{1 - P(Y)}$$

and is equivalent to the exponential of the β coefficients from the logistic regression.

3.4 Variable Descriptions and Hypothesized Effects

Previous studies have shown that land size and land use pattern tend to influence decisions pertaining to adoption of biofuel feedstock cultivation (Jensen et al., 2007). We hypothesized that the size of land holding has a positive influence on the decision to adopt switchgrass as farmers may be more likely to plant switchgrass on part of their land to benefit from the upcoming market opportunities. We used logarithmic transformations for the landholding variables to evaluate their influence on willingness to cultivate switchgrass.

Table 3.2: Variable Descriptions and Hypothesized effects

Variable	Variable Type	Hypothesized effect
Land Characteristics		
logacres	Continuous	(+)
logacres.cropland	Continuous	(–)
logacres.grazing	Continuous	(+)
logacres.woodland	Continuous	(+)
flood	Factor 0: No 1: Yes	(+)
drought	Factor 0: No 1: Yes	(+)
crp	Factor 0: No 1: Yes	(+)
erosion	Factor 0: No 1: Yes	(+)
Risk and Information		
risk	Ordinal 1 : Strongly Disagree 2 : Disagree 3 : Neutral 4 : Agree 5 : Strongly Agree	(+)

univ.ext	Ordinal 1 : Strongly Disagree 2 : Disagree 3 : Neutral 4 : Agree 5 : Strongly Agree	(+) / (–)
follow.others	Ordinal 1 : Strongly Disagree 2 : Disagree 3 : Neutral 4 : Agree 5 : Strongly Agree	(+) / (–)
awareness	Factor 0: No 1: Yes	(–)
Demographic Characteristics		
gender	Factor 0 : Female 1 : Male	(+)
education	Ordinal 1 : < Middle School 2 : High School 3 : Some College 4 : College Graduate or above	(+)
residence.property	Factor 0 : Not on Property 1 : On Property	(+)

Since land under crop cultivation is unlikely to be diverted for switchgrass cultivation, we hypothesized that the variable would likely have a negative influence on the farmers' adoption decision. Furthermore, as switchgrass can be a close substitute for hay as well as being well suited for agroforestry, we hypothesized that landholding in grazing land and woodland would positively influence farmer willingness decisions.

Switchgrass is known to grow well in nutrient deficient systems, so it is possible that land that is considered marginal for traditional row crops or left uncultivated due to flooding/arid conditions could be diverted to cultivate switchgrass. Similarly, lands that are prone to soil erosion can be planted with switchgrass as its deep-root system can help reduce erosion. In addition, the USDA's CRP pays a yearly rental payment to farmers for removing land that is considered environmentally sensitive from agricultural production. Such land can be planted with switchgrass, which can help enhance the environmental quality of the soil. As a result, we hypothesized that farmers who have fallow land, land under CRP, or face erosion problems on their lands would be more willing to cultivate switchgrass. We hypothesized that farmers who experienced flooding or drought-like conditions on their farmland, have land under the CRP program, and farmers facing erosion problems on their lands would all be more willing to consider planting switchgrass.

In order to gauge risk preferences, respondents were provided with a statement and were asked to indicate their level of agreement. The statement presented to the survey respondent was "I am willing to take risks in farming if there is a possibility of earning high profits" and a 5-point Likert-scale schematic wherein a score of 1 indicates strong disagreement whereas a score of 5 indicates strong agreement was provided. Respondents selecting 'Agree' or 'Strongly Agree' to the statement were considered to have a higher risk-taking propensity.

The recursive partitioning analysis also resulted in a grouping of the responses into two categories, namely those who indicated agreement with the statement and those who were neutral or indicated disagreement. In the analysis, the variable ‘risk’ was used as a 2-level factor variable. Given that the cellulosic bioenergy industry is still in its nascent stages of development, investments in switchgrass are considered relatively riskier than traditional choices.

Table 3.3: Proportional distribution of responses for risk and information related variables

Statement	Levels	1	2	3	4	5
I am willing to take risks in farming if there is a possibility of earning high profits	1 : Strongly Disagree 2 : Disagree 3 : Neutral 4 : Agree 5 : Strongly Agree	5.71%	7.62%	36.19%	42.86%	7.62%
I prefer to adopt new crops after seeing them on demonstration plots at University Extension meetings	1 : Strongly Disagree 2 : Disagree 3 : Neutral 4 : Agree 5 : Strongly Agree	6.67%	7.62%	54.28%	24.76%	6.67%
I prefer to adopt new crops after seeing them adopted by other farmers	1 : Strongly Disagree 2 : Disagree 3 : Neutral 4 : Agree 5 : Strongly Agree	7.62%	9.52%	46.67%	29.52%	6.67%

For the variables 'univ.ext' and 'follow.others' the survey asked for responses to the statements "I prefer to adopt new crops after seeing them on demonstration plots at University Extension meetings" and "I prefer to adopt new crops after seeing them adopted by other farmers" respectively. In this case too, the recursive partitioning approach clustered the responses in to two distinct categories with one category comprising of respondents who agreed with the statements whereas the other category comprising respondents who were neutral or showed disagreement with the statements.

However, the interpretation of the effects of the two variables is more nuanced. On the one hand, a preference to adopt new crops only after seeing them at demonstrations by university extension services or other farmers indicates some level of risk aversion or a reluctance to be an early adopter. On the other hand, agreement with the statements could also indicate that the respondents prefer to have more information to be better equipped at making a farming decision, even if the decision may entail risks that are relatively larger than their traditional cultivation choices. To that effect, the influence of university extension services and local social networks with other farmers could also influence farmer cultivation decisions. While risk aversion could have a negative influence on farmer willingness to adopt switchgrass, attending university extension meetings to gather new information and seeing others adopt switchgrass could have a positive influence on cultivation choices.

While the survey document contained some information about switchgrass, its potential as a bioenergy feedstock, and associated ecosystem services benefits, respondents were asked whether or not they were aware of switchgrass before taking the survey. We hypothesized that the farmers who were aware of switchgrass could likely be less willing to cultivate owing to the long establishment period for switchgrass and the uncertainties associated with price and demand for the feedstock at this point.

Several studies have tried to explore differences in male and female behavior for a variety of research questions. Doss and Morris (2002) investigated whether men and women tend to adopt agricultural innovations at different rates as they felt that if such differences indeed exist it may be necessary to design research and policies that meet their specific needs. In our context, gender can play a role in influencing a farmer’s willingness to cultivate switchgrass if men and women have intrinsically different preferences. As men and women tend to demonstrate varied risk assessments, we hypothesized that men could be more willing to cultivate switchgrass for bioenergy.

The variable for education was recursively partitioned into two groups: respondents educated up to high school or less and respondents with some college education or college graduates. We anticipated that such a classification would allow us to unravel any relationships between switchgrass willingness and educational levels. Previous studies have found that educational attainment has a positive effect on farmer willingness (Jensen et al. 2007; Kelsey et. al 2009), and we hypothesized that education would positively influence farmer willingness to adopt switchgrass.

Finally, we included a variable that demonstrated whether the respondent’s residence was on the farmland itself. Wolde et al. (2016), studying the willingness to allocate non-forested land for pine plantation, found that individuals with a primary residence on their forested property were more willing to adopt a bioenergy feedstock. Having their primary residence on the farmland could indicate more active involvement in farming or on-farm decisions than if the individuals were living elsewhere. We hypothesized that the variable 'residence.property' could positively influence farmer willingness to cultivate switchgrass.

3.5 Results and Discussion

In our survey sample, 54.3% of the respondents indicated that they were unwilling to cultivate switchgrass and 45.7% indicated they were willing. Using a univariate analysis, we were able to evaluate our theoretical hypotheses and understand the relationship between our explanatory variables and the dependent variable 'willingness to cultivate switchgrass'. Many of the results were in line with our prior hypothesis in terms of direction of the influence of the independent variable on the willingness to cultivate switchgrass. Out of the fifteen variables considered for the analysis, the univariate analysis indicated that ten variables had a statistically significant influence on the dependent variable. However, the coefficients in these regressions may not be very useful as univariate regression models are often affected by omitted variable bias. Consequently, we extend our logistic regression model to evaluate a broader set of variables described above. Since the overall land holdings correlated with land holdings under different land uses, we excluded the variable representing the overall land holdings 'logacres' from the multivariate logistic regression analysis to avoid potential multicollinearity. Table 3.4

shows results from the multivariate logistic analyses, for the unweighted and weighted regressions.

Given that the results of the weighted and unweighted regressions are quite similar, we discuss the coefficients of the unweighted regression to compute the corresponding odds ratios as these estimates are known to be more efficient (Platt and Harper, 2013).

Table 3.4: Estimation results for the willingness model using multivariate logistic regressions

Variable	Coefficients and p-values for unweighted regression	Coefficients and p-values for weighted regression
logacres.cropland	-0.024 (0.876)	-0.020 (0.888)
logacres.grazing	0.384 (0.032 **)	0.356 (0.036 **)
logacres.woodland	0.331 (0.063*)	0.366 (0.030**)
flood	-0.543 (0.478)	-0.502 (0.464)
drought	-0.216 (0.726)	-0.373 (0.545)
crp	0.346 (0.510)	0.606 (0.370)
erosion	0.622 (0.118)	-0.107 (0.863)
risk	1.978 (0.004***)	1.964 (0.006***)
univ.ext	1.330 (0.066*)	1.448 (0.043*)
follow.others	0.602 (0.341)	0.625 (0.320)
awareness	-1.248 (0.066*)	-1.222 (0.070*)
gender	1.825 (0.125)	1.404 (1.167)
education	-0.796 (0.279)	-0.921 (0.183)
residence.property	0.132(0.859)	0.287 (0.705)
constant	-4.223 (0.007***)	-3.736 (0.009***)
Observations	105	105
Log Likelihood	-44.984	-45.575
Akaike Inf. Crit.	119.967	121.149
Pseudo R^2	0.379	0.365

Signif. codes: '***' 0.01 '**' 0.05 '*' 0.1

The coefficients for land use related variables pertaining to land holding in grazing land and wood land were positive and significant, in line with our expectations. However, we did not find evidence to support our hypothesis that the coefficient for land use under crop production would be negative. The coefficient for this variable was not statistically significant.

Of the other variables related to the land characteristics, particularly whether the respondent had experience flooding or drought like conditions on their land during the previous five years was not statistically significant. Similarly, we did not find evidence to support our hypothesis that farmers with land under the CRP and farmland faced with erosion problems would be more likely to indicate willingness to cultivate switchgrass.

The relationship between farmer willingness and their preference for risk was both positive and significant. This result supports our hypothesis suggesting that farmers with higher willingness to take on risks would be more likely to indicate willingness to cultivate switchgrass. In the case of the variables pertaining to first seeing switchgrass being grown on university extension demonstration plots or other farmers, this variable suggests that farmers who prefer additional information regarding the crop and are more likely to indicate willingness. This result highlights a role for engagement of university extension services in wider dissemination of information pertaining to switchgrass and the value for demonstrations and exhibitions of successful switchgrass establishment.

Additionally, while we hypothesized that local farmer networks could also play an important role for information sharing, we did not find evidence to support this hypothesis. Finally, prior awareness of switchgrass has a negative and statistically significant influence on farmer willingness to cultivate switchgrass. This result suggests that farmers might have the perception that switchgrass is unlikely to be profitable and may not be a viable alternative. Furthermore, they might be concerned about the long establishment period and limited cash flows in the early years of cultivation. As a result, more specific information about farmer concerns and perceptions of switchgrass cultivation should be collected to address their concerns.

Among the demographic variables, gender did not have a significant influence on farmer willingness to adopt switchgrass. Furthermore, the coefficients for education was statistically insignificant, contrary to our expectations. Similarly, having a primary residence on the farmland also did not have a statistically significant influence on farmer willingness to cultivate switchgrass for bioenergy.

In Table 3.5, we present the odds ratio for the statistically significant variables in the multivariate logistic regression. The variable for risk preference of farmers indicates that individuals who identify themselves as those who are willing to take risks if there is a possibility of earning profits have higher odds of saying “yes” to the willingness question and the results indicate an odds ratio around 7.2. Similarly, preference for first seeing a crop being grown on extension services demonstration plots also results in higher willingness odds. Furthermore, being aware of switchgrass prior to the survey has a negative and statistically significant coefficient indicating lower odds of willingness to cultivate switchgrass. These two results highlight the role of information sharing, demonstration, and dissemination of best practices pertaining to cultivation techniques that will ensure successful establishment of switchgrass and maximized yields.

Table 3.5: Odds ratio for significant variables (unweighted regression)

Variable	Odds Ratio
logacres.grazing	1.468
logacres.woodland	1.392
risk	7.228
univ.ext	3.782
awareness	0.287

Signif. codes: ‘***’ 0.01 ‘**’ 0.05 ‘*’ 0.1

Having land under grazing as well as woodlands also positively influences farmer willingness to adopt switchgrass and thereby increases the odds of saying “yes”. These results confirm our hypothesis that switchgrass, being very similar to hay, appears to be a favorable substitute crop. Furthermore, since switchgrass is also an attractive agroforestry alternative, individuals owning woodlands are also more likely to exhibit willingness to cultivate switchgrass.

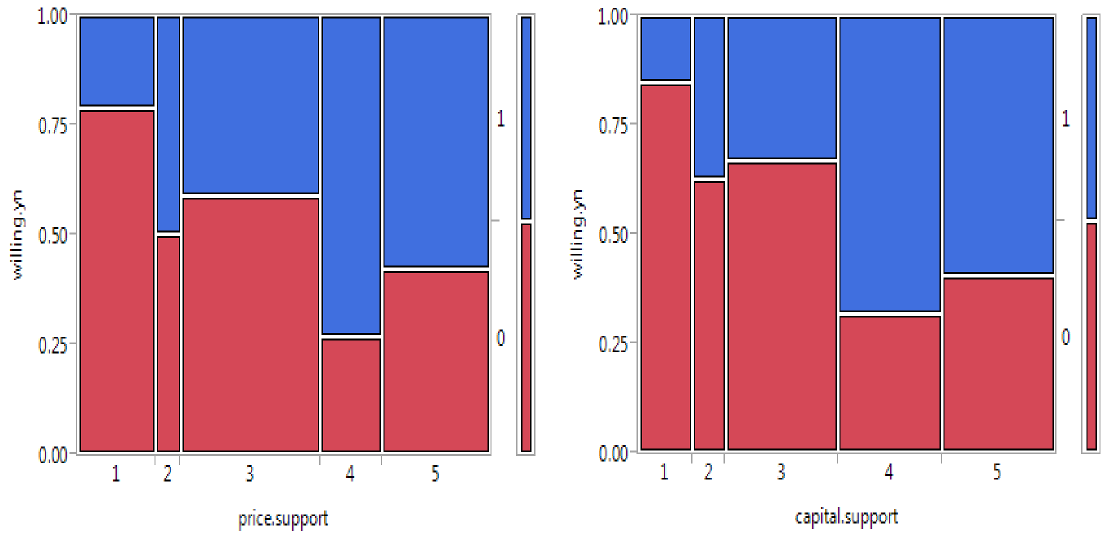
The survey also included some questions requesting the respondents to indicate the importance of some policy alternatives. Respondents were asked to specify the relative importance they attached to policy support in the form of price support for the produce, support for meeting capital needs during the initial 3-year period until switchgrass establishment, loan support for harvesting and marketing of produce. We evaluated the responses to these policy related questions against the backdrop farmer willingness to cultivate switchgrass. Table 3.6 provides the distribution of responses to these questions (N = 100).

Table 3.6: Proportional distribution of responses indicating importance of policy alternatives

Statement	Levels	1	2	3	4	5
Price support for switchgrass similar to other agricultural products	1 : Not Important 2 : Slightly Important 3 : Moderately Important 4 : Important 5 : Very Important	19.0%	6.0%	34.0%	15.0%	26.0%
Capital support program that would help finance initial costs and provide income for first 3 years until crop attains full yield	1 : Not Important 2 : Slightly Important 3 : Moderately Important 4 : Important 5 : Very Important	13.0%	8.0%	27.0%	25.0%	27.0%
Commodity loans such as the Marketing Assistance Loan to meet cash flow needs during harvest	1 : Not Important 2 : Slightly Important 3 : Moderately Important 4 : Important 5 : Very Important	17.0%	11.0%	36.0%	17.0%	19.0%

Figure 3.1 shows results of the contingency analysis for the questions pertaining to price support and capital support. The differences in the responses indicating the relative importance of the policy alternatives were statistically significant for the respondents

who answered ‘Yes’ or ‘No’ to the willingness question. The results indicate that individuals who were willing to cultivate switchgrass were more likely to place importance on price support and capital support.



(a) (b)

Figure 3.1: Contingency tables evaluating farmer willingness to cultivate switchgrass and the importance attached to price support and capital support as policy alternatives in panels (a) and (b) respectively.

On one hand, individuals who are unwilling to cultivate switchgrass might not be induced to enter the market for switchgrass merely due to incentive programs. On the other hand, individuals who are willing to cultivate switchgrass could benefit from potential safety nets provided by such policy support. Evaluating the relative importance to the question related to loans to meet harvesting and marketing needs vis-à-vis the willingness to cultivate switchgrass yielded a result that was statistically insignificant.

3.5 Conclusions

Switchgrass has been identified as a high potential energy feedstock by the U.S. Department of Energy and can contribute towards reducing the country's consumption and dependence on non-renewable energy sources. This research contributes by providing insights about farmer characteristics and preferences that can unravel some of the factors that influence farmer willingness to cultivate switchgrass. An assured year-round supply of feedstocks is one of the most important steps towards the establishment of a robust cellulosic bioenergy sector. It is likely that the other infrastructure such as the conversion facilities, transportation, and other supply chain aspects associated with cellulosic biofuel production will develop as the initial supply-side challenges are addressed.

This research is able to identify several key variables that can be used to develop and design policies that will enable the farming community to adopt switchgrass cultivation and thereby contribute towards the development of this industry. We are able to highlight the role of risk preferences that influence farmer decisions to cultivate a bioenergy feedstock. Farmers who are willing to undertake some risks with the potential of earning profits from switchgrass cultivation are more likely to participate in this market. We also found that information plays a key role in that farmers would like to see switchgrass being cultivated on university extension demonstration plots before they adopt it themselves. These insights could be used to ensure that techniques for successful establishment and management are disseminated to other farmers through newsletters, farm bureau meetings, or university extension services. Having access to the right information could allow farmers to make well-thought-out decisions and encourage them to actively seek new agricultural opportunities.

Furthermore, we also observe that policy incentives such as price support programs for switchgrass or capital support programs during the initial years until establishment could be important policy tools. However, individuals who are already willing to cultivate switchgrass would more likely benefit from them. In order to incentivize individuals to enter the market for switchgrass cultivation, policymakers might need to develop programs that not only provide financial support in a market that is in its nascent stages of development, but also engage with university extension services along with other information dissemination pathways to educate and encourage potential adopters.

Farmers with tracts of grazing land might find it relatively easier to substitute their current choices, such as hay, with switchgrass. The environmental benefits of cultivating switchgrass are myriad. Although variables that capture the influence of erosion, flood, drought etc. did not yield statistically significant results in the model as drivers for switchgrass adoption, disseminating these environmental benefits is necessary to inform the farming community about switchgrass.

This study adds to the existing body of research in the area of bioenergy research, specifically for farmer participation in bioenergy markets. While the results provide important insights, further research is required to determine whether or not these conclusions are generalizable in varied contexts and geographies. Extensive primary surveys covering a larger section of the farming community in the state of Missouri and beyond are necessary to build upon the results of this survey. Additionally, research pertaining to other variables such as land tenure, financial constraints, prior experiences, and cultivation under contracts to safeguard farmers from downside risks could be valuable. Studies that delve into the potential land use change implications of farmer decisions to cultivate switchgrass for bioenergy can evaluate the local and regional level changes emanating from dedicated bioenergy cultivation. The net benefits from enhanced ecosystem services provided by switchgrass could also extend this research. Finally, the absence of a market for switchgrass translates into very limited information regarding the price of the feedstock. Future research can aim to address these myriad issues.

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4 Farmer perceptions about switchgrass and land allocation decisions

4.1 Introduction

In July 2017, the US Environmental Protection Agency proposed to lower the requirements for cellulosic ethanol in 2018 to 238 million gallons, down from 311 million gallons in 2017 (EPA, 2017). Meanwhile, the target for corn-based ethanol was maintained at 15 billion gallons. It was not the first time that the targets for cellulosic ethanol under the Renewable Fuels Standards (RFS) were lowered. Factors ranging from decline in demand for fuel (owing to improved fuel efficiency), slower than anticipated improvements in conversion technology for cellulosic feedstock to fuel processes, input and output prices, and government policies have all contributed to the pace of cellulosic biofuel production in the United States (Lynes et al., 2016).

The biofuels industry faces a challenge commonly referred to as the “chicken-and-egg” problem, wherein capital for investment in bio-refineries is not easily available until there is an adequate supply of feedstock, and farmers are unwilling to cultivate bioenergy feedstocks until there is an established market and assured demand for their produce (Luo & Miller, 2017). Against the backdrop of an evolving biofuels policy environment, a point of interest pertaining to cultivation of a perennial feedstock such as switchgrass is to study the land allocation decisions of the farmers. In a survey of farmers in Kansas, Lynes et al. (2016) found that the unconditional mean acres allocated to a perennial bioenergy crop that farm managers were willing to adopt was 97.0 acres. Meanwhile, farmers surveyed in Southern Lower Michigan were uninterested to allocate land for bioenergy crops even if rental rates were higher than current levels (Skevas et al., 2016). The authors also found that landowners who indicated a preference to grow energy crops were willing to cultivate them on cropland as opposed to marginal land, leading the authors to infer poor prospects for biomass supply from marginal land.

Several studies have investigated and delineated the factors that influence farmer and landowner willingness to cultivate bioenergy feedstocks on their land (Hipple and Duffy, (2002); Qualls et al. (2012); Wolde et al., (2016)). The factors that influence willingness have ranged from lack of information about bioenergy crops, high establishment costs, and farm size to demographic factors such as age, education, and off-farm incomes, among others.

Jensen et al. (2007) studied the willingness of farmers in Tennessee to cultivate switchgrass. Their survey results indicated that many farmers were not familiar with switchgrass and less than 30 percent would be willing to grow switchgrass were it to be profitable. Farmers in Tennessee also felt that they needed technical assistance to be able to successfully cultivate switchgrass and that markets for switchgrass were still not sufficiently developed. Among other findings, their results also suggested that farmers with higher net incomes per farm would convert smaller shares of their land emphasizing the opportunity cost/ alternate land use aspect associated with switchgrass cultivation. Paulrud and Laitila (2010) utilized the choice experiment method to analyze farmer willingness to cultivate energy crops in Sweden. The authors concluded that factors such as age of the farmer, farm size, geographical area were significant in explaining farmer willingness whereas factors such as leased land, rented land and type of farming were statistically insignificant.

Farmer willingness to plant energy grasses in central Illinois was found to be tied to their understanding of land suitability as well as social barriers including tenancy arrangements, market constraints, and transportation considerations (Cope et al., 2011). Bergtold, Fewell, and Williams (2014) assessed farmer willingness to cultivate cellulosic bioenergy feedstocks under contract in Kansas and found that factors such as next best alternate land use, contract length, cost share, financial incentives, insurance, and custom harvest options were important contract attributes. They also claimed that farmer willingness to adopt and pay for alternate contract attributes varied across regions and feedstock choices. Caldas et al. (2014) also conducted their study in Kansas and indicated that regional differences play an important role in crop selection, which included crop residues, annual and perennial bioenergy crops.

Tyndall, Berg and Colletti (2011) surveyed farmers in Iowa to understand their perceptions regarding supplying corn stover to a biorefinery. They found that farmers who indicated interest in supplying stover were younger, somewhat knowledgeable about stover, have large amounts of land, and currently have land in continuous corn rotations. Further, their results suggest that farmers who have environmental concerns, specifically the negative impacts of stover removal on environmental quality, were less willing to harvest corn stover.

For other sources of cellulosic materials such as woody biomass, in the case of nonindustrial private forests (NIPF) landowners in the southern United States, Joshi and Mehmood (2011) concluded that willingness to harvest woody biomass was influenced by ownership objectives of landowners, size of holdings, composition of tree species, and demographic characteristics. Meanwhile, Aguilar, Cai, and D'Amato (2014) suggested that timber prices are the most important factor behind NIPF owners' willingness to harvest woody biomass and that policy tools could be more effective by targeting timber rather than woody biomass revenues. Additionally, previous studies have used remote sensing land cover data and vegetation modeling techniques to identify suitable land and estimate land availability for cultivating bioenergy feedstocks (Cai et al., 2010; Gelfand et al., 2013).

Large-scale cultivation of biofuel feedstocks as a response to government mandates or favorable market conditions could result in both direct and indirect land use changes. Searchinger et al., (2008), highlighted that failing to account for conversion from existing land use to bioenergy crops tends to misrepresent the greenhouse gas emission reductions attributed to switching from fossil fuels to bioenergy. Similarly, the impact of biofuel policies on food prices and agricultural commodities has also garnered economic interest over the past several years (Ciaian, 2011; Zilberman et al., 2012). Finally, researchers argue that growing bioenergy crops on marginal land could obviate competition for cropland, thereby mitigating some of downside risks pertaining to the influence of bioenergy feedstock cultivation on food prices (Campbell et al., 2009; Swinton et al., 2011).

In this chapter, we evaluate the importance of farmer perceptions about the suitability of switchgrass cultivation on their lands and their willingness to grow it on their farmland. We look at an important dimension pertaining to the supply of bioenergy by analyzing the land allocation decisions of the farmers. Additionally, we also evaluate the type of lands that the farmers are willing to convert to switchgrass to assess potential land-use change implications.

4.2 Study Area

4.2.1 Data and Survey Design

The survey instrument used to collect data for the analysis for this chapter is the same as that described in Chapter 3 earlier. The survey administration and data collection procedures have been described in Chapter 3 as well.

The survey instrument contained some basic information about switchgrass and its potential for use as a bioenergy feedstock. The respondents were asked to answer questions pertaining to their (i) farm size, characteristics, and current farming practices; (ii) knowledge of and interest in cultivating switchgrass; (iii) price requirements and potential acres that would be devoted to switchgrass under favorable conditions; (iv) opinions about cultivation decisions, environment, society, and policies; (v) individual characteristics and demographic attributes.

4.2.2 Survey Responses

The survey response rate is the same as described in the previous chapter. However, out of the 135 respondents who completed the survey, 102 responses were usable for performing our analysis for this chapter on farmer perceptions and land allocation decisions, as we considered only the most complete responses for our analysis, an approach similar to previously published literature (Jensen et al. 2007; Qualls et al. 2012; Lynes et al. 2016).

Furthermore, similar to the previous chapter, the sample is a relatively good representation of farmers in the state of Missouri. Based on a comparison with the 2012 Agricultural Census for Missouri published by the United States Department of Agriculture (USDA, 2014), we delineate the similarities and differences between our sample data and the census data. While proportion of male and female principal farm operators in Missouri is 88.8% and 11.2% respectively, our research sample had 86.3% male respondents, and a marginally higher representation of female farmer than the census data with 13.7% female respondents. Approximately 97.3% of the farmers in the state of Missouri report their ethnicity as white or Caucasian. For our survey sample, the proportion of respondents reporting their ethnicity as Caucasian was 99.0%.

Compared to the statewide data for Missouri, we received a higher response from farmers in the 10-49 acres category, and a somewhat lower response from farmers in the 50-179 acres category. The distributions in the other categories based on size of land holdings were in line with the 2012 Missouri Agricultural census data. As a result, in terms of land holdings, the average farm size for our survey sample came in at 208.7 acres whereas the average farm size in Missouri as per the 2012 Census data was 285 acres.

Evaluating the age of our survey respondents, we found that the highest number of responses, 55.9%, were in the above 60 years age category followed by 22.5% in the 51-60 years category. The other age categories < 30 years, 31-40 years, and 41-50 years had 1.0%, 6.9% and 12.7% respondents respectively. Comparing the distribution of ages in our survey sample to that of the 2012 Agricultural Census for Missouri, we find that the distributions are comparable; the average age of a farmer in Missouri in 2012 was 58.3 years.

4.3 Analytical Framework

We follow the methodological framework described in Miller and Platinga (1999) and Lynes et al. (2016) and adapt it for our analysis. This approach combines discrete choice modeling techniques with selection models to identify the influence of farmer preferences on their willingness to participate in switchgrass cultivation followed by an analysis of acreage allocated for cultivating switchgrass. We posit that the farmer engages in a sequential decision-making process wherein the first stage involves the decision to cultivate switchgrass and the second stage involves a decision to allocate his/her land or part thereof for cultivation.

Let U_i represent the expected utility function for farmer i. Under this framework the utility derived by the farmer by cultivating switchgrass and participating in the bioenergy market can be given by

$$U_{i,s}(\pi_i(X_i), P_i, Z_i)$$

where the index s = 1 indicates that the farmer indicates willingness to cultivate switchgrass and s = 0 indicates unwillingness to adopt switchgrass cultivation for bioenergy. The function, $\pi_i(X_i)$, denotes the restricted expected profit from cultivating switchgrass and is dependent on as set of explanatory variables X_i that influence the returns from producing switchgrass. This set of variables includes variables such as size of land holding, and access to equipment for harvesting switchgrass. We also assume that U_i monotonically increasing in π_i, which implies that maximizing the expected profit will increase expected utility for the farmer.

P_i constitutes a set of variables that capture the perceptions of the farmers with regard to switchgrass cultivation and includes their perceptions about whether switchgrass can create a habitat for wildlife on their farm, can help reduce soil erosion on their lands, and whether the switchgrass-based bioenergy industry can help create jobs in their community. Finally, Z_i includes demographic variables such as gender, ethnicity, on-farm residence, etc.

We hypothesize that a farmer would choose to cultivate switchgrass if the expected utility from cultivating the feedstock is greater than the expected utility in the scenario that it is not cultivated, as represented by the following:

$$U_{i,1}(\pi_i(X_i), P_i, Z_i) > \; U_{i,0}(\pi_i(X_i), P_i, Z_i)$$

Perennial bioenergy crops, such as switchgrass, are considered suitable for marginal lands, lands prone to flooding/erosion, or lands in similar use such as those used for growing hay or forage crops. Given that the farmer is willing to cultivate switchgrass, we analyzed the allocation of land for switchgrass cultivation. We assume that the farmer will allocate land for switchgrass cultivation with an overall objective of maximizing the total restricted profit function (Miller and Platinga, 1999) and that the initial allocation does not depend on Z_i (Lynes et al. 2016). This objective can be described as:

$$\text{Max } \pi_{i,s}(A_s, X_i, P_i) + \pi_{i,o}(A_o, \bar{X}, \bar{P})$$

subject to

$$A_s + A_o = L$$

where A_s is the allocation for switchgrass cultivation and A_o is the land allocated for other crops/uses. $\bar{X}$ and $\bar{P}$ are the factors and preferences affecting the choice of other crops/uses and L is the total land holding of each farmer. Following from the modeling approach described in Miller and Platinga (1999), the Kuhn-Tucker solution to the above maximization problem is given by $A^* = f(X_i, P_i)$, i.e. the optimal land allocation to plant switchgrass.

In a class of models commonly referred to as sample selection models, we are unable to observe the value of the dependent variable for a nonrandom sub-sample of the data (Wooldridge, 2016). The empirical model is set up using the framework described above wherein we first consider the willingness to cultivate switchgrass and subsequently evaluate the acreage allocation decision. The farmer's response to the question pertaining to the willingness to cultivate is observed from the survey data. We consider, if $\Delta U > 0$ $i.e.$ $U_{i,1}(\pi_i(X_i), P_i, Z_i) > U_{i,0}(\pi_i(X_i), P_i, Z_i)$, s = 1 and 0 otherwise. For notational convenience we suppress the index i. Further, let W represent the collection of variables in X, P, Z and M contain a subset of W such that it includes only the variables in X, P. Farmer willingness is modeled as:

$$\Delta U = \Upsilon W + \varepsilon$$

where $\varepsilon \sim N(0, \sigma_\varepsilon^2)$ and γ represents parameters. Given that s is observed and ε is normally distributed, the above model can be estimated as binary Probit model (Lynes et a., 2016).

Given that the optimal allocation of land for switchgrass if given by $A^* = f(M)$ and the functional relationship is linear, the allocation decision can be given as:

$$A_s = \beta M + v$$

Where v is the unobserved error and $v \sim N(0, \sigma^2)$. Furthermore, since the allocation decision is only observed for individuals for who indicate willingness to cultivate switchgrass, we utilize the 2–step Heckman selection model (Heckit method) to estimate the conditional mean of A_s (Heckman, 1977; Wooldridge, 2015);

$$E(A_s|M, s = 1) = \beta M + E(v|M, s = 1)$$

Since the variables included in M are a subset of W, we are able to adhere to the exclusion restriction described in the Heckman selection model. Thus while we hypothesize that the demographic variables in Z can influence the willingness to cultivate switchgrass, we also assume that once the willingness is established, the allocation decision is not affected by demographic attributes and is determined by the restricted expected profit function and perceptions. Following Wooldridge (2015) and Greene (2003) we can represent the equation for the allocation decision as

$$E(A_s|M, s = 1) = \beta M + \rho\lambda(\Upsilon W)$$

where $\lambda(\Upsilon W)$ is the inverse Mills ratio. If the parameter ρ = 0, then there is no selection bias in the model (Greene, 2003; Wooldridge, 2016). We use the sample selection package in R to perform our analysis for the Heckman model (Henningsen and Toomet, 2011; Henningsen and Toomet, 2015).

For the questions with Likert-scale responses, we utilize the recursive partitioning technique to classify the respondents in to distinct categories. Recursive partitioning is a technique used to split data into categories, wherein observations that belong to the same group exhibit similar characteristics (Strobl et al., 2009). We utilize this approach to partition the variables in the preference and demography categories as we anticipated responses to vary depending on specific thresholds. The recursive partitioning analysis performed using the ‘rpart’ package in R (Therneau et al., 2010), Based on the results of the recursive partitioning analysis, categorical/dummy variables are created to appropriately represent the specific categories.

In our analysis in Chapter 3, we used weights based on size of land holdings to correct for any non-response bias and to make our sample more representative. However, we found that the analytical results for the weighted and unweighted regressions were similar. In this chapter, we only report results of the unweighted analysis, as they are be more efficient (Platt and Harper, 2013).

4.4 Results and Discussion

We utilized the partitioning technique to classify responses for the questions with Likert-scale responses. While partitioning does tend to result in some loss of information, it is extremely useful to collate responses into distinct categories. Variables that were already in binary form, such as gender, whether the farmer's residence was on the farm or whether they benefited from state or federally sponsored support programs, cannot be partitioned. Continuous variables – particularly land holdings under various land use types – were also not partitioned to minimize the loss of information. Table 4.1 delineates the set of variables included in the analysis and includes the results of the partitioning analysis.

Table 4.1: Variable Description and Hypothesized effects

Variable	Variable Type	Hypothesized effect	Partitioning
acres.grazing	Continuous	(+)	
acres.woodland	Continuous	(+)	
acres.cropland	Continuous	(–)	
acres.other	Continuous	(+)	
gender	Factor 0 : Female 1 : Male	(+)	
residence.property	Factor 0 : Not on Property 1 : On Property	(+)	

education	Ordinal 1 : < Middle School 2 : High School 3 : Some College 4 : College Graduate or above	(+)	0 : {1,2} 1 : {3,4}
equipment	Ordinal 1 : Strongly Disagree 2 : Disagree 3 : Neutral 4 : Agree 5 : Strongly Agree	(+)	0 : {1,2,3} 1 : {4,5}
conflict	Ordinal 1 : Strongly Disagree 2 : Disagree 3 : Neutral 4 : Agree 5 : Strongly Agree	(–)	0 : {1,2} 1 : {3,4,5}
diversify	Ordinal 1 : Strongly Disagree 2 : Disagree 3 : Neutral 4 : Agree 5 : Strongly Agree	(+)	0 : {1,2,3} 1 : {4,5}
reduce.erosion	Ordinal 1 : Strongly Disagree 2 : Disagree 3 : Neutral 4 : Agree 5 : Strongly Agree	(+)	0 : {1,2,3} 1 : {4,5}
livestock.feed	Ordinal 1 : Strongly Disagree 2 : Disagree 3 : Neutral 4 : Agree 5 : Strongly Agree	(+)	0 : {1,2,3} 1 : {4,5}
reduce.fertilizer	Ordinal 1 : Strongly Disagree 2 : Disagree 3 : Neutral 4 : Agree	(+)	0 : {1,2,3} 1 : {4,5}

	5 : Strongly Agree		
wildlife.habitat	Ordinal 1 : Strongly Disagree 2 : Disagree 3 : Neutral 4 : Agree 5 : Strongly Agree	(+)	0 : {1,2,3} 1 : {4,5}
create.jobs	Ordinal 1 : Strongly Disagree 2 : Disagree 3 : Neutral 4 : Agree 5 : Strongly Agree	(+)	0 : {1,2,3} 1 : {4,5}

Barring land holdings used for crop cultivation, we anticipate other types of land holdings such as woodlands, grazing lands and other land uses to have a positive impact on both willingness to cultivate switchgrass and the allocation of land for switchgrass cultivation. Land under the Conservation Reserve Program (CRP) or lands currently left fallow are recorded under the 'other uses' category. Switchgrass is considered a suitable agroforestry alternative and can be cultivated on lands that are classified as marginal or unsuitable for traditional row crops.

Men and women could have varied preferences and perceptions about bioenergy and cultivating a dedicated feedstock for bioenergy production. Given that the market for switchgrass is currently underdeveloped and switchgrass cultivation involves large up-front establishment costs with limited price certainty for the product, participating in switchgrass cultivation is inherently more risky. Additionally, men and women could exhibit distinct responses to risk and we hypothesize that male farmers could be more willing to cultivate switchgrass for bioenergy.

Earlier studies, including, Jensen et al. (2007) and Kelsey et. al (2009), have found evidence to indicate that educational attainment has a positive effect on farmer willingness. We also hypothesize the same. However, the variable for education was recursively partitioned into two groups namely those with relatively low education and other with high education. The former group comprised of respondents educated up to high school or less while the latter comprised of respondents with some college education or college graduates. We anticipated that such a classification would allow us to unravel any relationships between switchgrass willingness and educational levels.

In a study of forestland owners, Wolde et al. (2016) found that individuals with a primary residence on their forested property were more willing to adopt a bioenergy feedstock. A variable capturing the location of the respondent's primary residence was included in our analysis as well. We hypothesized that having a residence on the farmland could positively influence farmer willingness to cultivate switchgrass as it could indicate more active involvement in farming and enhance on-farm decision making. While these demographic variables were included in the selection equation for willingness to cultivate switchgrass, they were excluded from the outcome equation evaluating the land allocation decision.

The survey included several questions that requested responses on a 5-point Likert scale ranging from 'Strongly Disagree' to 'Strongly Agree'. Farmers responded indicating their agreement to statements pertaining to switchgrass cultivation decisions and statements about the influence of switchgrass cultivation on the environment and community. One of the variables that could influence the willingness and allocation decisions around switchgrass pertains to access to equipment used for harvesting switchgrass. The recursive partitioning technique classified the responses to the statement “I have access to equipment needed for harvesting switchgrass” into two categories. Respondents who indicated disagreement or neutrality were categorized into one group while respondents who indicated agreement or strong agreement were categorized into the second group.

Individuals who indicated disagreement with the statement “The planting/harvesting period for switchgrass will conflict with the planting/harvesting period for my other crops” were hypothesized to be more likely to be willing to cultivate switchgrass. This hypothesis is consistent with the argument that switchgrass cultivation could entail opportunity costs and if the current cultivation alternatives were valuable, individuals would be less likely to switch.

We hypothesized that individuals who perceived that switchgrass cultivation would help them reduce their fertilizer use, and those who felt that switchgrass cultivation could help reduce soil erosion on their land were more likely to indicate willingness to cultivate switchgrass. Similarly, individuals who thought that switchgrass cultivation could help them diversify their crop mix as well as those who felt they could use/sell switchgrass as a livestock feed could be more willing to cultivate switchgrass.

Finally, we also hypothesized that agreement with the statements “Switchgrass can create a wildlife habitat on my farm” and “Switchgrass-based bioenergy can create jobs in my community” could also positively influence farmer willingness and allocation decisions. Based on the recursive partitioning analysis, individuals who indicated agreement or strong agreement for statements capturing the above-mentioned variables were categorized into one group whereas farmers who were neutral or disagreed with the statements comprised the other group.

Table 4.2 reports the results of step-1 of analysis, i.e. the estimation of the Probit selection model. We evaluate the influence of the variables on farmer willingness to cultivate switchgrass. Out of the 102 responses included in the analysis, 57 respondents (approximately 56%) indicated that they were unwilling to cultivate switchgrass, whereas 45 (approximately 44%) were willing to cultivate switchgrass.

Out of the fifteen variables considered in the analysis, six were significant. Land holdings in woodland use and the perception about cultivating switchgrass in order to diversify their crop-mix were significant at the 1% level of significance. Perceptions that the cultivation/harvesting period for switchgrass would conflict with that of their existing crops had a negative and significant influence on willingness to cultivate switchgrass.

Furthermore, ability to create a wildlife habitat by cultivating switchgrass on their farm was significant in explaining farmer willingness. Finally, gender and the perception that switchgrass could be used or sold as a livestock feed were significant, albeit at the 10% level of significance. Furthermore, the direction of influence for the significant variables on the dependent variable 'willingness to cultivate' were also in line with our a priori hypotheses.

Table 4.2: Estimation results for the willingness to cultivate switchgrass (Probit selection equation)

Variable	Coefficients and (standard errors)	p-values
acres.grazing	-0.002 (0.001)	0.119
acres.woodland	0.017 (0.005)	0.004 ***
acres.cropland	-0.002 (0.002)	0.281
acres.other	0.001 (0.001)	0.328
gender	1.618 (0.920)	0.083*
residence.property	0.708 (0.558)	0.209
education	-0.821 (0.569)	0.153
equipment	-0.190 (0.454)	0.676
conflict	-1.086 (0.419)	0.012**
diversify	1.573 (0.494)	0.002***
reduce.erosion	-0.652 (0.531)	0.223
livestock.feed	0.882 (0.445)	0.051*
reduce.fertilizer.use	-0.294 (0.498)	0.556
wildlife.habitat	1.407 (0.558)	0.014**
create.jobs	0.371 (0.444)	0.407
constant	-3.360 (1.170)	0.005***
N Censored Observed	102 57 45	

Signif. codes: '***' 0.01 '**' 0.05 '*' 0.1

Table 4.3 delineates the results of the 'Outcome Equation', wherein the dependent variable is the number of acres allocated for switchgrass cultivation. The land use variables, barring acres under crop use, are positive and significant. The other variables in the model are not statistically significant.

Table 4.3: Estimation results for the land allocation model (Outcome equation)

Variable	Coefficients and (standard errors)	p-values
acres.grazing	0.155 (0.049)	0.002***
acres.woodland	0.129 (0.027)	1.16e-05 ***
acres.cropland	0.034 (0.075)	0.656
acres.other	0.351 (0.036)	6.08e-15***
equipment	14.871 (13.633)	0.279
conflict	-0.782 (14.735)	0.958
diversify	25.565 (17.793)	0.155
reduce.erosion	-7.947 (15.781)	0.616
livestock.feed	14.194 (14.977)	0.346
reduce.fertilizer.use	-6.601 (16.622)	0.692
wildlife.habitat	19.068 (19.417)	0.329
create.jobs	10.090 (14.590)	0.491
constant	-13.833 (32.193)	0.669
Inverse Mills Ratio	-11.743 (20.874)	0.575
rho	-0.282	
N R-squared Adj. R-squared	102 0.85 0.79	

Signif. codes: '***' 0.01 '**' 0.05 '*' 0.1

Yet, with an adjusted R-square of 0.79, the model has a very high explanatory power. However, the correlation between the land use variables is not very high and the variance inflation factors (VIF) in the outcome equation are within reasonable limits. The coefficient of the Inverse-Mills-ratio is not statistically significant, indicating that there is no selection bias in our model.

The significance of the land use variables, specifically that of land under other uses, strongly supports our hypothesis. Since, other land use includes lands that are left fallow or are under the CRP, this result indicates that farmers with land use under these categories could become early adopters of switchgrass. Additionally, the magnitude of the coefficient of the variable depicting land under other uses is the largest among other land use variables. Anand et al. (2011), indicated that a perennial bioenergy crop could be a good alternative for marginal land and land under hay or grassland. Our results also indicate that land allocation for switchgrass is positively influenced by farmer's land holding of grazing lands. Finally, the coefficient of woodland acres is also positive and significant. The unconditional mean acres that the farmers are willing to allocate to switchgrass is 32.35. While this initial allocation in our study is lower than the 97.0 acres reported in Lynes et. al, (2016) for Kansas, the average size of landholding in their survey was also much larger at 2172 acres.

The Heckman's two step procedure is widely used owing to its ease of implementation and applicability to wide range of models the model is sensitive to the distributional specification of the errors (Cameron & Trivedi, 2005; Wojtys, Marra & Radice, 2016). The method developed in Zhelonkin, Genton, and Ronchetti (2016) relaxes the assumption of bivariate normality and provides a robust estimator using the Heckman's two-step estimation procedure (Zhelonkin, Genton, & Ronchetti, 2016; Wojtys, Marra & Radice, 2016). This method provides a middle way to derive estimators that are reliable, yet maintain the benefits of computational simplicity and interpretability. We utilize this approach to arrive at robust estimates for our model using the "ssmrob" package in R (Zhelonkin, Genton, & Ronchetti, 2015; Zhelonkin, Genton, & Ronchetti, 2016), the results of which are presented in Tables 4.4 and 4.5.

Table 4.4: Estimation results for the willingness to cultivate switchgrass (Selection equation – Robust Heckit)

Variable	Coefficients and (standard errors)	p-values
acres.grazing	-0.002 (0.001)	0.160
acres.woodland	0.016 (0.006)	0.007***
acres.cropland	-0.002 (0.002)	0.228
acres.other	0.001 (0.001)	0.351
gender	1.564 (0.932)	0.094*
residence.property	0.552 (0.559)	0.323
education	-0.672 (0.587)	0.252
equipment	-0.046 (0.470)	0.922
conflict	-1.257 (0.482)	0.009***
diversify	1.518 (0.534)	0.004***
reduce.erosion	-0.526 (0.546)	0.335
livestock.feed	0.840 (0.467)	0.072*
reduce.fertilizer.use	-0.613 (0.552)	0.266
wildlife.habitat	1.493 (0.635)	0.019**
create.jobs	0.496 (0.474)	0.296
constant	-3.212 (1.216)	0.008***
N Censored Observed	102 57 45	

Signif. codes: ‘***’ 0.01 ‘**’ 0.05 ‘*’ 0.1

Comparing the results of the selection equation for the robust model with the results obtained from the simple two-stage Heckit indicate that the same variables that were identified as significant in the earlier model are significant in the robust Heckit model as well, albeit the coefficients are slightly different.

Table 4.5: Estimation results for the land allocation model (Outcome equation – Robust Heckit)

Variable	Coefficients and (standard errors)	p-values
acres.grazing	0.150 (0.069)	0.003***
acres.woodland	0.147 (0.032)	4.14e-06***
acres.cropland	0.056 (0.046)	0.231
acres.other	0.370 (0.018)	9.49e-96***
equipment	8.387 (11.407)	0.462
conflict	-8.061 (11.129)	0.469
diversify	20.443 (8.316)	0.014**
reduce.erosion	-10.076 (10.908)	0.356
livestock.feed	21.630 (12.791)	0.091*
reduce.fertilizer.use	-15.447 (10.671)	0.148
wildlife.habitat	12.391 (14.998)	0.409
create.jobs	17.536 (13.126)	0.182
constant	-21.154 (18.095)	0.242
Inverse Mills Ratio	10.524 (11.320)	0.353
N	102	

Signif. codes: ‘***’ 0.01 ‘**’ 0.05 ‘*’ 0.1

Akin to the simple model, the robust Heckit model for the outcome equation identifies land holdings in grazing land, woodland, and other land as significant variables for explaining the initial allocation for switchgrass cultivation. The magnitudes of the coefficients are similar too. However, the outcome equation in the robust model also identifies variables capturing the perception that switchgrass will help farmers diversify their crop mix and that switchgrass can be used as a feedstock for livestock as significant variables in explaining land allocation toward switchgrass.

Respondents who provided information for initial allocations for switchgrass cultivation, also indicated the type of land they would convert out of its existing use to switchgrass. Based on our survey responses, around 45% of the land allocated to switchgrass is likely to come out of hay cultivation. Land under other uses would contribute approximately 40% to the land allocated for switchgrass and crops such as corn, soy, and sorghum together comprise less than 15%.

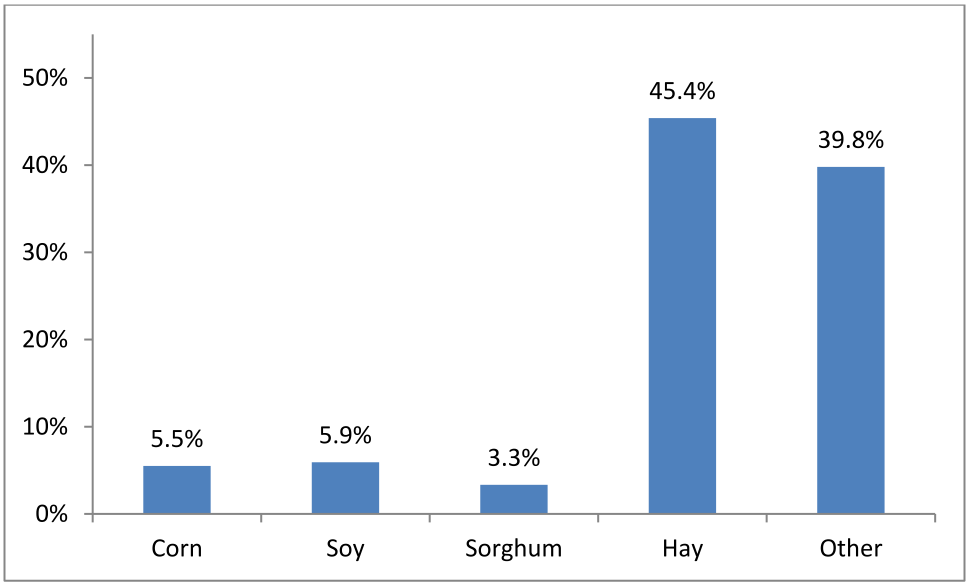

Figure 4.1: Proportion of land likely allocated for switchgrass cultivation.

4.5 Conclusions

In this chapter, we evaluated a sequential decision-making process. In the first step, we analyzed the willingness of farmers in Missouri to cultivate switchgrass on their lands by studying their perceptions about switchgrass and its suitability in supporting their cultivation, environmental, and social objectives. In the second step, we focused our attention to the land allocation decision to unravel the potential land use implications of switchgrass cultivation. We utilized the framework of expected utility to describe the theoretical model and used the 2-step Heckman selection model for out empirical analysis.

If a farmer perceives that cultivating switchgrass will help them diversify their crop mix, they are more likely to be willing to cultivate switchgrass. This result could have important implications for risk mitigation policies especially in the face of changing climatic conditions and extreme weather events. By diversifying the types of crops being cultivated through the adoption of switchgrass, a farmer could potentially reduce financial losses stemming from crop damage, erosion following high-rain events, pest outbreaks in monoculture cultivation systems, etc. Furthermore, switchgrass could also help in improving the quality of the soil on degraded lands and prove to be a suitable alternative on lands that are not usable for traditional crops.

We also found evidence to support the claim that land owners with forestland or woodland are more likely to be willing to cultivate switchgrass. This result suggests that the potential for switchgrass as a viable agroforestry alternative must be explored further and the most suitable mix of trees and switchgrass based on land-type and location should be determined. Farmers who think that switchgrass could help create a wildlife habitat on their lands are also more likely to cultivate switchgrass. As such, switchgrass is known to provide a suitable winter habitat for several bird species and bedding for deer. This result could help policy makers to evaluate the potential for switchgrass cultivation on farms where the farmers are members of hunting or conservation groups. This could also help farmers to obtain additional revenues from hunting permits or revenues in the form of payments for ecosystem and conservation services associated with switchgrass cultivation.

Farmers who perceive that switchgrass cultivation is likely to create conflicts with their existing crops, from a planting and/or harvesting perspective are less willing to consider adoption. Furthermore, in our land allocation analysis we found that lands that are currently fallow, maintained under CRP guidelines, or used as grazing lands and woodlands contribute significantly to land being allocated to switchgrass. This result is in line with published literature that emphasizes the need to consider cultivation of dedicated bioenergy feedstocks on land that is not used for cultivation of food crops to obviate any conflicts that could arise from competing land uses.

The adoption of switchgrass and allocation of land are crucial to ensure a steady supply of feedstock for the economically vitality of the cellulosic bioenergy industry. The future of this sector depends critically on the cultivation decisions of the landowners. Therefore, the policy framework ought to take into consideration the preferences, perceptions, and concerns of the farming community to support rural economies and the development of the biomass-based renewable energy. Policies that incorporate regional heterogeneities, differences in feedstock types, and address the inherent uncertainties associated with a nascent industry will likely have a more positive influence on the cellulosic bioenergy sector as a whole.

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5 Conclusions, limitations, and future work

5.1 Conclusions

Adoption under uncertainty

Switchgrass has been identified as a high potential energy feedstock by the US Department of Energy for producing cellulosic biofuels, which can contribute towards reducing the country's consumption of and dependence on non-renewable energy sources. Compared to earlier models that rely on a continuous-time modeling framework, this research developed a more realistic model to evaluate the economic value of switchgrass investments under price uncertainty. By adopting a discrete-time model, we are able to incorporate biological attributes of switchgrass cultivation, such as yield variability, in in conjunction with dynamic decision making, to analyze the conditions under which a farmer would prefer to enter, expand, or abandon an investment in switchgrass. Furthermore, we are also able to incorporate the time-to-establishment attributes of switchgrass cultivation and variations in operational costs during the project life-span. We computed boundary conditions for switchgrass price to ascertain threshold values, where the agricultural producer should opt to enter the switchgrass market and invest resources for cultivating the feedstock. We are able to simulate various price transition paths and the corresponding project net present values to indicate time-thresholds that ensure a positive return on investment.

Additionally, we evaluate the relationship between risk and profitability by computing the odds of profit under varying price transition paths for the feedstock. The analysis of option values highlights the relationship between the value of the option to expand or abandon the investment and the timing of the decision. We demonstrate the sensitivity of the option value, which underscores the importance of active on-farm management and timing of decisions.

The decision to invest in switchgrass is unlikely to be guided by profitability of the investment alone, but rather depends on the profitability of the existing land use, among other factors. Earlier studies have demonstrated the role of other crops, such as corn, that can influence investments in energy crops. Our analysis considered hay as an alternate crop and demonstrated the sensitivity of investment decisions under multiple price scenarios.

This research allows us to identify a policy dimension, namely government subsidies, around switchgrass cultivation. We note that a lower subsidy influences model parameters not only in the form of lower average price estimates, but also in the estimated volatility of future price moves. Additionally, project profitability is higher in the high-subsidy scenario.

Factors influencing farmer willingness to cultivate switchgrass

In Chapter 3, we evaluated the factors that influence farmer willingness to cultivate switchgrass. An assured year-round supply of feedstocks is one of the most important pre-conditions that will encourage the establishment of a cellulosic bioenergy industry. We not only looked at the role of land holdings under various uses such as cropland, grazing land, woodland, and land under the conservation reserve program, but also investigated the role of risk and information along with certain demographic characteristics to delineate their influence on farmer willingness to cultivate switchgrass. This research provides interesting insights and confirms some of our prior hypotheses.

We identified several key variables that can be used to develop and design policies that will enable the farming community to adopt switchgrass cultivation and contribute towards the development of the bioenergy industry as a whole. It is well known that investment in switchgrass is subject to a host of uncertainties ranging from biological vagaries associated with crop growth, to the lack of deep markets and an ever-changing regulatory/policy environment. Our analysis indicates that farmers who have a higher risk tolerance and are willing to take on investments, such as those commonly associated with long-duration crops, and are therefore more likely to be willing to cultivate switchgrass. Thus, the underlying risk preferences of farmers and the potential of earning profits by assuming higher risk was one of the factors that influence participation in this market.

Additionally, information plays an important role in influencing farmer willingness. Farmers who were already aware about switchgrass prior to taking the survey were less likely to be willing to cultivate switchgrass. This could suggest that farmers perceive that the economic prospects from switchgrass cultivation are unlikely to be favorable or that their information set is replete with instances wherein switchgrass cultivation has resulted in adverse outcomes, such as financial loss. It is also possible that the farmers are convinced that switchgrass is not suitable for their lands and or their current farming practices. As a result, an important aspect of encouraging farmer participation in this market would necessitate better access to information and address the specific concerns of the farming community with regard to switchgrass cultivation.

We also found farmers who were more likely to be willing to cultivate switchgrass indicated a preference to see switchgrass being cultivated on university extension demonstration plots before they adopt it themselves. This insight complements the earlier discussion about information sharing and addressing farmer concerns. Policy makers should ensure that techniques for successful establishment and management are disseminated to farmers through newsletters, farm bureau meetings, or university extension services. Having access to the right information could allow farmers to make educated decisions and encourage them to actively seek new agricultural opportunities.

We find evidence to confirm that farmers with tracts of grazing land might find it relatively easier to substitute their current choices, such as hay or other forage crops, with switchgrass. We also found evidence to support the claim that land owners with forestland or woodland are more likely to be willing to cultivate switchgrass. While switchgrass is considered to be tolerant to water stress and could be grown on lands that experience floods and droughts, it is also known to produce a host of environmental benefits, including erosion control and carbon sequestration. However, in our analysis, variables such that captured the influence of these environmental benefits did not yield statistically significant results in the model as drivers for switchgrass adoption.

It is possible that other infrastructure such as the conversion facilities, transportation, and various supply chain aspects associated with cellulosic biofuel production will develop as the initial supply-side challenges are addressed.

Farmer perceptions and land allocation decisions

Farmer perceptions plays an important role in influencing willingness to cultivate switchgrass. If a farmer perceives that cultivating switchgrass will help in diversifying their existing crop mix, they are more likely to be willing to cultivate switchgrass. Crop diversification could have important implications from a risk mitigation perspective, especially in the face of changing climatic conditions and extreme weather events. By diversifying the types of crops being cultivated through the adoption of switchgrass, a farmer could potentially reduce financial losses stemming from crop damage, erosion following high-rain events, and pest outbreaks in monoculture cultivation systems, among other factors. Switchgrass could also help in improving the quality of the soil on degraded lands, and prove to be a suitable alternative on lands that are not usable for traditional crops.

Hunting is a popular recreational activity in the US, previous studies have found that farmers who perceive that switchgrass cultivation could help create a wildlife habitat on their lands are also more likely to cultivate switchgrass. Our analysis also finds evidence to support this claim. Switchgrass is known to provide a suitable winter habitat for several bird species, and therefore may make cultivation more valuable. This result could help policy makers evaluate the potential for switchgrass cultivation on farms where the farmers are members of hunting or conservation groups. This could also help farmers to obtain additional revenues from hunting permits or revenues in the form of payments for ecosystem and conservation services associated with switchgrass cultivation.

On the other hand, farmers who perceive that switchgrass cultivation is likely to create conflicts with their existing crops from a planting and/or harvesting perspective are less willing to consider adoption. While competition with food crops is one of the main criticisms of bioenergy feedstock cultivation, based on our analysis we did not find any evidence to suggest that displacement of food crops is likely for our study area.

In our land allocation analysis, we found that lands that are used as grazing lands, woodlands, are currently fallow or being maintained under conservation reserve program guidelines, contribute significantly to land that could potentially be allocated to switchgrass. This result is in line with previously published literature and supports the argument that cultivation of dedicated bioenergy feedstocks is most likely on land that is either not being used for cultivation of food crops, or marginal lands, which will also obviate any conflicts that could arise from competing land uses. Furthermore, our result suggests that the potential for switchgrass as a viable agroforestry alternative ought to be explored further, and the most suitable mix of trees and switchgrass based on land-type and location should be determined.

5.2 Limitations and Future Work

In our model in Chapter 2, we assumed a relatively conservative yield assumption at 6 tons per acre. It is likely that commercial cultivation of switchgrass could result in higher per acre yields and therefore translate into higher returns on investment. Furthermore, a low interest rate regime and improved access to finance could boost profitability of investments in switchgrass cultivation. Finally, technological advancements in conversion processes could increase overall profitability in the bioenergy industry translating to higher prices for switchgrass.

Based on the results of our model, it is evident that returns on switchgrass cultivation exhibit high volatility. This problem is accentuated by the relatively large up-front costs and lengthy period of establishment until the crop reaches potential yield levels. For our computations, we only considered a single discount rate and we assumed no borrowing requirements for both initial capital costs and operating expenses. Future work could evaluate the impact of credit constraints and cost of capital on the feasibility of investments in switchgrass. In addition, preordained contracts between biofuel producers and farmers, and insurance programs to protect the farmer from downside risks in a relatively nascent bioenergy industry. This analysis can be extended to compare the feasibility of investments in switchgrass vis-à-vis other energy crops, and for alternatives including agroforestry options where energy grasses can be cultivated with other species. Since switchgrass is not widely cultivated, there is limited data availability. Cultivation and processing cost estimates from other states in the US could be extremely useful to analyze investments in switchgrass and extend research in this area.

The discrete-time model can be extended into a continuous-time stochastic framework to evaluate other bioenergy feedstocks. For a fast growing bioenergy feedstock such as loblolly pine, willow, or slash pine, the evolution of prices can be represented as a stochastic process and the entry, harvest, and exit decisions can be evaluated in a continuous-time framework.

Previous research suggests a wide range of policy alternatives, ranging from subsidies linked to the price of crude oil, subsidies for energy content or reductions in GHG emissions or some combination thereof. However, our research did not delve into the precise nature of the subsidies. We found evidence to suggest that policy alternatives such as price support for switchgrass or capital support programs in the initial years of establishment are considered important among the farming community. Federal and state governments have at their disposal all the aforementioned alternatives as well as payment mechanisms such as the BCAP. In addition, alternate arrangements for lands under the Conservation Reserve Program could be considered. Furthermore, the potential for a subsidy that compensates for the market value of the direct and indirect ecosystem services of switchgrass cultivation could be examined. This may result in higher returns to the landowner and make the investment in switchgrass more attractive while mitigating some of the consequences of on-farm activities on human and aquatic systems. Future research could explore the influence of specific programs in greater depth, in order to design policy alternatives that would be most effective to incentivize adoption of bioenergy feedstock cultivation.

Our results from the farmer survey contribute to the existing body of research in the area of bioenergy research, and specifically farmer participation in bioenergy markets. While the results provide important insights, additional research is required to determine whether or not these conclusions are generalizable in varied contexts and geographies. While our survey response data showed a reasonable representation of the farm population in Missouri, additional primary surveys covering a larger section of the farming community in the state of Missouri and beyond are necessary to build upon these results. Additionally, stated preference survey methods including choice experiments, conjoint analysis, and best-worst scaling can be applied to study questions pertaining to willingness to cultivate bioenergy crops to identify key attributes that influence farmer/landowner decisions.

Research pertaining to other variables such as land tenure, financial constraints, prior experiences, and cultivation under contracts to safeguard farmers from downside risks could also be extremely valuable. The absence of a market for switchgrass translates into very limited information regarding the price of the feedstock. Questions related to the benefits of existing policy programs and the importance of tailor-made programs to cater to the specific requirements of perennial bioenergy crops such as switchgrass have not be studied adequately in the existing literature. Furthermore, consumer perceptions and preferences for clean energy as well as willingness to pay for energy produced from sustainable sources are important areas for future research.

In Chapter 4, we delved into the potential land use change implications of farmer decisions to cultivate switchgrass for bioenergy, which can evaluate the local and regional level changes emanating from dedicated bioenergy cultivation. The net benefits from enhanced ecosystem services provided by switchgrass could extend this research. Evaluating the behavioral triggers for adoption of switchgrass cultivation using experimental research techniques could also be an important area for future work.

The adoption of switchgrass and allocation of land are crucial to ensure a steady supply of feedstock for the economically vitality of the cellulosic bioenergy industry. Federal and state policies are important factors that influence the cellulosic biofuels industry in the United States; understanding the dynamics of this industry is extremely important from both private sector and policy perspectives. The future of this sector depends critically on the cultivation decisions of the landowners. Therefore, the policy framework must take into consideration the preferences and concerns of the farming community in order to support rural economies and the development of the biomass-based renewable energy. Policies that incorporate regional heterogeneities, differences in feedstock types, and address the inherent uncertainties associated with a nascent industry will likely have a more positive influence on the cellulosic bioenergy sector as a whole.

Biomass yields and overall production costs are likely to vary by geography owing to variations in climatic conditions, land type, soil quality etc. Furthermore, changes in management techniques, including use of fertilizers, time of the year when seeding is done, depth of planting, crop establishment, and adherence to harvesting guidelines will influence both costs and yields resulting in variations in profitability. As more growers cultivate switchgrass, learnings in terms of best agronomic practices are likely to emerge, which will influence information sharing and future adoption of switchgrass.

Finally, evaluating farmer perceptions about the sustainability of switchgrass cultivation and engaging them into the policy process as key stakeholders is critical for the success of this industry. The development of widely acceptable sustainable cultivation practices around bioenergy feedstock cultivation could not only benefit the society, but also create greater benefits for all those who directly and indirectly participate along the cultivation, transportation, conversion, and consumption processes of the product life cycle. Switchgrass-based cellulosic bioenergy has not yet delivered on the initial promise. However, understanding these crucial bottlenecks through future research could help this industry deliver benefits to not only the agricultural community through job creation and revitalization of rural economies, but also diversify the energy mix, reduce dependence on fossil fuels, and contribute to the environmental goals of the country.

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