Contracting for Energy Crops: Effect of Risk Preferences and Land Quality

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Abstract

This paper analyzes the effect of landowner risk preferences and land quality on the optimal mix of vertically integrated production and contracted production of an energy crop in a region characterized by heterogeneity in landowners' risk preferences and land quality and with riskiness of returns from both energy crop and conventional crop production. We examine the determinants of the decision of landowners to grow an energy crop for biofuel production under one of three types of contracts, a land leasing contract, a fixed price contract and a revenue sharing contract and the impact of risk and time preferences, land quality and riskiness of energy crop production and prices on the optimal contract terms and effective cost of biomass. We find that as the degree of risk aversion and rate of time preference increases and as the riskiness of producing both the conventional crop and the energy crop increases, the share of vertically integrated production of energy crops increases. While low quality land is more likely to be converted to energy crop production, an increase in the degree of risk aversion results in an increase in the threshold level of land quality converted to energy crops under a land leasing contract but a decrease in the threshold level of land quality converted under a fixed price contract and a revenue sharing contract. We also find that the refinery can potentially earn a higher profit by offering a menu of different types of contracts rather than a single type of contract only; by allowing self-selection of contract type based on their risk preferences, the risk premium needed to induce production of energy crops is reduced.

Keywords: Contract Farming, Energy Crops, Risk Preferences, Vertical Integration

JEL Classification: D86, Q42

The emphasis on cellulosic biofuels mandated by the Renewable Fuel Standard under the Energy Independence and Security Act, 2007 is anticipated to lead to a demand for biomass from dedicated energy crops as a feedstock for biofuels (Perlack and Stokes 2011). This has led to interest in high yielding perennial energy crops, like miscanthus and switchgrass, which can be grown productively on low quality land (Khanna et al. 2011). However, these crops are new and unfamiliar and are yet to be grown commercially. Markets for their sale and information about biomass prices are largely non-existent. Uncertainty about feedstock availability and feedstock cost, which is anticipated to be a substantial share of a biorefinery's cost, can be a significant barrier to investment in cellulosic biofuels which also face a risky output price that is linked to the price of oil.

Landowners that grow perennial energy crops need to make a significant upfront investment in establishment and equipment and a long term commitment of land to these crops to recover the returns on their investment. Energy crop production also exposes farmers to price and yield risks that may differ from those for conventional crops, to the extent that weather variations affect yields of these crops differentially and output prices are affected by demand conditions in different markets that may not be perfectly correlated. Energy crops are costly to transport long distances and may face thin spot markets with few buyers because they may have no alternative uses; thus they expose farmers to demand side risks as well and make them dependent on the capacity of local biorefineries.

Contracts have emerged as a management strategy to control risks associated with the production and marketing of agricultural commodities, such as livestock, fruits and vegetables and crops and ensure coordination between growers and processors. Formal contractual arrangements (instead of spot market transactions) accounted for 40% of the value of US agricultural production in 2008 as compared to 11% in 1969 (McDonald and Korb 2011). Contracts for biomass, could similarly be used as a coordination and risk management tool, by shifting the price and yield risks to market participants who are better positioned to bear them as well as ensuring that the investment in large scale, capital intensive biorefineries is accompanied by an adequate and timely supply of biomass instead of relying on spot market transactions. They would also facilitate the development of a supply chain when there is asymmetric information about productivity, land quality, costs of production and risk preferences between a processor and heterogeneous farmers.

Contracts in the agricultural sector have taken the form of either production or marketing contracts. Marketing contracts are agreements between a contractor and a grower that set a price or pricing mechanism before harvest with the grower bearing all risks of production and either sharing the price risk with the contractor or passing on all the price risk to the contractor under a forward sale at a fixed price. Under a production contract, on the other hand, the contractor supplies the inputs and financing and controls the production practices used and the amount produced. The production and price risks are jointly shared by the grower and the contractor. Production contracts have primarily been used in the livestock sector, possibly because of the multi-stage supply chain that requires coordinated movement of a uniform quality product from growers to downstream processors. Marketing contracts are more common in the fruits, vegetable and row crop sectors to address price and demand risks (USDA 1996).

Contracts for biomass could take the form of either production or marketing contracts. The need for financing for upfront investment in establishing perennial grasses, crop-specific genetic material for planting and equipment and quality of biomass could lead to the emergence of production contracts with the refinery supplying inputs and sharing production risks.

However, potential moral hazard problems and high transactions costs of monitoring production activities could lead the refinery to lease land and undertake fully vertically integrated production itself (see review in Du et al. forthcoming). Full vertical integration can, however also involve high administrative costs and result in all risks being borne by the refinery alone. Contracting with farmers to supply a portion of the feedstock requirements can shift a portion of the biomass yield risks to farmers.

The purpose of this paper is to analyze the effect of risk preferences and land quality on the optimal mix of vertically integrated production and contracted energy crop production in a region characterized by heterogeneity in landowners' risk preferences and land quality and with riskiness of returns from both energy crop and conventional crop production. We develop a principal-agent framework where the principal seeks to offer a menu of contracts, each with take-it-or-leave-it contract terms, to agents that are heterogeneous in their risk preferences and land quality. The principal is assumed to know only the distributions of risk preferences and land quality in the region and to consider three types of contractual arrangements that differ in their allocation of yield and price risks among landowners and the refinery. This framework is used to analyze the factors that influence the extent to which biomass production in a region is likely to be vertically integrated with the refinery offering a land leasing contract to landowners and undertaking the production of the energy crop itself or independently produced under one of two types of contracts: a fixed price contract or a revenue-sharing contract with the price indexed to the revenue of biofuel production. We examine the determinants of the terms of these three types of contracts, the attributes of the risk and land quality attributes committed to alternative contracts and their implications for landowner utility and refinery profits. Lastly, we examine the benefits to landowners (and the refinery) of having (offering) a menu of contracts to choose from instead of any one of the three contracts by itself.

The three types of contracts differ in their riskiness and their allocation of risk between landowners and the refinery and in the timing of the returns they provide. A land leasing contract with the refinery shifts the yield and price risk to the refinery and offers immediate returns to the landowner. A fixed price contract for a given quantity of biomass delivery exposes the landowner to energy crop yield risk while an indexed price contract exposes the landowner to both yield and price risk; both of these contracts also require the landowner incurring the upfront cost of investment in a perennial energy crop and obtaining returns over the life-span of the crop. Alternatives to these contracts for the landowners/refinery are to sell/purchase biomass at a distant spot market at an uncertain market price. The terms of these contracts are determined to ensure participation by landowners to meet the biomass requirements of the refinery while maximizing utility for the landowners and refinery. For each type of contract, the terms are the same for all landowners that enroll in that contract type.[1] The choice of contract will depend on the risk and time preferences of the landowner and the risk-return trade-off these crops offer relative to existing uses of that land.

Our results show that as the degree of risk aversion increases, as the riskiness of producing both the conventional crop and the energy crop increases and as the landowner's rate of time preference increases, the degree of vertically integrated production of energy crops increases. While low quality land is more likely to be converted to energy crop production, the threshold level of land quality converted will depend on the risk preferences of landowners. Landowners with a relatively high degree of risk aversion will prefer to lease their land to the refinery while those with relatively low (medium) risk aversion will choose a revenue sharing (fixed price) contract. Moreover, an increase in the degree of risk aversion results in an increase in the threshold level of land quality converted to energy crops under a land leasing contract but a decrease in the threshold level of land quality converted under a fixed price contract and a revenue sharing contract. We also find that the refinery's feedstock costs are lower when farmers are offered a choice of contract types rather than a single type of contract only; by allowing self-selection of contract type based on their risk preferences, the risk premium needed to induce production of energy crops is reduced. The rest of the paper is organized as follows. Section 2 discusses the previous literature and the contribution of this paper. Section 3 presents the conceptual framework and is followed by a description of the data. Section 4 presents the results of the numerical simulation and sensitivity analysis. The results are presented in Section 5 followed by the conclusions and discussion of implications.

2. Previous Literature

Previous studies have analyzed the impact of heterogeneity in land quality on technology adoption decisions under certainty and show that land augmenting technologies are more likely to be adopted on land qualities below a threshold level (Caswell and Zilberman 1986; Khanna, Isik, and Zilberman 2002). Early studies also apply the expected utility framework to show that risk aversion and the riskiness of returns with the new crop relative to the conventional crop influence crop adoption decisions (Just and Zilberman 1983); they find empirical evidence of the validity of the expected utility hypotheses (Bar-Shira, Just, and Zilberman 1997) and of the significance of risk in explaining crop choice (Just 1974) and technology adoption decisions (Marra and Calson 1987).

There is a large literature examining the impact of risk aversion, transactions costs, asymmetric information and moral hazard on the type and design of contracts selected in the agricultural and livestock sectors (see review by Du et al. (forthcoming)). This paper extends that research by analyzing the effects of heterogeneous risk preferences and land quality on the choice between an annual conventional crop and a perennial energy crop and the mix and terms of a menu of contracts that jointly maximize the utility of the principal (refinery) and the agents (landowners) in the context of an emerging cellulosic biofuel industry.

Earlier studies have analyzed the effects of risk aversion on the choice between two types of contracts for a representative landowner. Buccola (1981) shows that the share of output a farmer (processing firm) would sell (buy) under a fixed price or cost-plus pricing contract and on the spot market depends on the degree of risk aversion of the farmer and the firm and the covariances between the market price of the raw product, final product, and production costs. Anderson et al. (2004) show that preferences for a contract may differ between a principal and an agent due to differences in the risks faced and in risk aversion; while a pasture owner prefers a grazing contract to owning cattle as risk aversion increases, a cattle owner prefers leasing land to contract grazing if the risk reducing benefits of contract grazing are insufficient to compensate for its costs. Other studies use survey data to provide empirical evidence of the importance of risk aversion as a determinant of contract choice. Katchova and Miranda (2004) find that highly leveraged (more risk) crop producers were more likely to adopt marketing contracts and that marketing contracts were used not only to reduce price risk but also to have an outlet for the harvested crop. Reliance on fixed contracts instead of the spot market has been found to be significantly related to the level or price risk, risk aversion and risk perception among hog producers (Franken, Pennings, and Garcia 2009; Pennings and Smidts 2000; Pennings and Wansink 2004).

Much of this research has focused on a producer’s choice between a contract and selling on the spot market. An exception is Zheng and Vukina (2008) that analyze the choice among alternative types of contracts by hog producers and find that the most risk averse hog producers prefer production contracts because they are less risky than marketing contracts. They also show that forcing risk-averse farmers to choose the more risky marketing arrangements could lead to significant welfare losses. A few studies have used simulation models to examine the trade-offs between the risk-reducing benefits of contracts and the expected returns from contracting with exogenously specified contract terms and under alternative levels of risk aversion. Johnson and Foster (1994) rank alternative contracts for hog production based on stochastic dominance while Parcell and Langemeier (1997) do so for feeder-pig production and feeder-pig finishing.

Farmers and processors can also choose to hold a portfolio of contracts. Buccola and French (1979) simulate the expected utility maximizing portfolios of three different pricing contracts that a tomato processing cooperative, tomato growers and a tomato paste distributor would hold under price and output uncertainty and shows that a risk averse firm would prefer to hold two or three price contracts simultaneously given price and output uncertainty. Using survey data for the pork packing industry, Vukina et al. (2009) find that firms that used a mix of procurement arrangements paid lower prices to procure hogs than firms that used the spot market alone. This suggests that producers and downstream processing firms may benefit from offering a menu of alternative contractual arrangements.

More specifically in the context of energy crops, several studies have examined the incentives to produce them under perfect certainty. Studies analyzing the breakeven price needed to make energy crop production viable show that key determinants include the yield of the crop, the opportunity cost of converting land to energy crops and time preferences of the landowner that is foregoing returns from a conventional annual crop (Jain et al. 2010; James, Swinton, and Thelen 2010; Khanna, Dhungana, and Clifton-Brown 2008). Other studies have examined the amount of biomass that would be supplied assuming perfectly elastic demand for biomass (Perlack and Stokes 2011; Khanna et al. 2011). These studies assume that landowners have complete foresight about crop yields and the opportunity cost of converting land and that the market would be willing to pay a constant price for any amount of biomass over the life of the crop.

There has been relatively little analysis of the effects of risk on the incentives to produce these crops. Griffith et al. (2012) analyze the first-order and second order stochastic dominance ordering of alternative types of contracts for switchgrass production in Tennessee relative to corn and cow-calf production systems under various assumptions about the degree of risk aversion and land quality of a farmer while considering yield and input and output price risks. Similarly, Yoder (2010) compare the stochastic dominance of various types of contracts for miscanthus production in Indiana. These studies analyze the choice of a representative landowner with a given level of risk aversion among contracts with exogenously given contract terms.

This study makes several contributions to the existing literature. It presents a framework to examine how a biorefinery can use a menu of contracts that differ in their pricing and quantity requirements as a screening mechanism to induce heterogeneous landowners with private information about their risk preferences and land quality to self-select the contract type that maximizes net benefits for the refinery and landowners (Alexander et al. 2012). We endogenously determine the optimal contract terms and contract choices and analyze the mix of vertically integrated and independently contracted production of a perennial energy crop under various assumptions about the distributions of land quality, landowner risk and time preferences, and riskiness of production and prices.

[Insert Table 1 here]

3. Model Setup

Consider a refinery with a fixed production capacity of $\overline{K}$ gallons of ethanol (*e*) per year located in an agricultural region. We assume that a commercial technology for producing ethanol from a dedicated perennial energy crop exists and that G gallons of ethanol can be produced per ton of biomass. The fixed cost of the refinery is F_e and its variable cost per gallon of ethanol is V_e. The refinery faces an uncertain price per gallon of ethanol at time t, P_{et} which is distributed with mean $\overline{P_e}$ and variance σ_e^2 and could be linked to the price of oil. The refinery can lease land to produce the energy crop itself or it can induce landowners in the vicinity of the refinery to produce it under one of two types of contracts described below. Another alternative is to purchase biomass from a spot market located Z miles away from the refinery.

The region in the vicinity of the refinery consists of $i=1,..N$ parcels that are heterogeneous in their land quality q_i which determines the productivity of the conventional crop (*c*). Assuming a constant returns to scale production system, the per acre profit of the i^{th} parcel growing crop *c* at time *t* is $\pi_{ct}(q_i)$; it is an increasing function of land quality of the parcel, q_i and is distributed with mean $\overline{\pi_c} q_i$ and variance σ_c^2.

Current research suggests that energy crops can be grown productively even on low quality land and their yield is determined primarily by temperature and precipitation and the yield penalty due to lower land quality is likely to be small (Valentine et al. 2012; Varvel et al. 2008).[2] For simplicity we assume that the yield of the energy crop is uniform across the region. The production of an energy crop typically involves a crop establishment phase that could be one or two years long during which no yield is generated. We assume this yield is zero in year $t=1$ and following that the annual yield is represented by Y_{bt} where $t \in \{2,...,T\}$ and $T>1$ is the life span of the energy crop. This yield varies stochastically with an average value $\overline{Y_b}$ tons per acre and a random disturbance component ε_{yt} assumed to be independently and identically distributed over time following a distribution with mean 0 and variance $\sigma_y^{\ 2}$. Thus,

$$Y_{bt} = \begin{cases} 0 & if \ \ t = 1 \\ \overline{Y_b} + \varepsilon_{yt} & if \ \ t = 2, ..., T \end{cases} \tag{1}$$

We consider four options for a landowner that seeks to convert his land from conventional crop production to an energy crop. Under option 1, landowners are offered a fixed rental rate ω_t per acre per year for the contract period $t = 1, ..., T$ to lease their land to the refinery to produce bioenergy crops. Land leasing represents the highest level of vertical integration with the biorefinery bearing all the risks associated with biofuel production. Under option 2, the landowner produces energy crop on his land and agrees to deliver a guaranteed amount of biomass $\overline{Y_b}$ to the biorefinery from year 2 onwards at a fixed price $\overline{P_y}$ per ton of biomass. If the harvest of biomass exceeds/falls short of the committed amount, the landowner sells the surplus/buys the deficit from the spot market at a price of $P_{bt} \mp W$ per ton, where W represents a fixed per ton transportation cost.[3] Under option 3 with a revenue sharing contract, the biorefinery pays a price indexed to its revenue for a guaranteed amount of biomass $\overline{Y_b}$. The price is a pre-specified α percent of its revenue $P_{et}G$ generated per ton of biomass supplied by the landowner and converted to G gallons of ethanol that is sold at the price P_{et} per gallon. A fourth option is for the landowner to produce the energy crop without a contract and sell the biomass on the spot market at an exogenously given price per ton, P_{bt}. The price per ton of biomass on the spot market in year *t* is a stochastic variable, P_{bt}; we assume it is distributed with mean $\overline{P_b}$ and variance $\sigma_b{}^2$. We assume that the spot market price P_{bt} is negatively correlated with the yield of the energy crop Y_{bt} with a correlation coefficient denoted by $\rho < 0$.

Under the fixed price and the revenue sharing contracts, the landowner pays the one-time establishment cost F_b per acre and the annual production cost V_b per acre and agrees to deliver a committed amount $\overline{Y_b}$ tons of biomass to the biorefinery with excess and deficit made up through the spot market. We now specify the landowner's profits under each of the three types of contracts and then examine the determinants of his utility maximizing choice among crops and contract types. Since the yield and price distributions are assumed to be the same over time, the terms of the contracts will also be the same over time. Under option 1, the per- acre profit from the land leasing contract is:

$$\pi_{1t} = \omega \quad for\ t = 1,...,T \tag{2}$$

Under option 2 with a fixed price contract with price $\overline{P_y}$ the per-acre profit is:

$$\pi_{2t} = \begin{cases} -F_b & if\ t = 1 \\ \overline{P_y}\,\overline{Y_b} - (P_{bt} + I \bullet W)(\overline{Y_b} - Y_{bt}) - V_b & if\ t = 2,...,T \end{cases} \tag{3}$$

where $I = 1$ if $Y_{bt} \leq \overline{Y_b}$ and $I = -1$ otherwise and W is the cost of transporting biomass from the spot market to the refinery. Under option 3 the landowner's per-acre profit from the revenue sharing contract is: $$\pi_{3t} = \begin{cases} -F_b & if\ t = 1 \\ \alpha P_{et} G \overline{Y_b} - (P_{bt} + I \bullet W)(\overline{Y_b} - Y_{bt}) - V_b & if\ t = 2,...,T \end{cases} \tag{4}$$

where $I = 1$ if $Y_{bt} \leq \overline{Y_b}$ and $I = -1$ otherwise. Under option 4, a landowner plants a conventional crop and earns a profit:

$$\pi_{ct} = \pi_{ct}(q_i) \quad for\ \ t = 1,...,T\ . \tag{5}$$

[Insert Table 2 here]

3.1 Landowner's Problem

We now analyze a utility maximizing landowner's decision about whether to plant a conventional annual crop or a perennial energy crop on land parcel *i* under one of the four alternative options described above. Each land parcel is assumed to have homogeneous land quality. The four discrete choices for each land parcel are denoted by $l_1, l_2, l_3, and\ l_4$ each of which is equal to 1 if that option is chosen and zero otherwise and $l_1 + l_2 + l_3 + l_4 = 1$. Landowners are assumed to be risk averse with utility represented by a second-moment utility function: $U(E(\pi_{it}),Var(\pi_{it})) = E(\pi_{it}) - \frac{\lambda_i}{2}Var(\pi_{it})$ where λ_i is the Arrow-Pratt measure of absolute risk aversion for the landowner of parcel *i* and π_{it} is the per acre profit with an expected value and variance defined below. [4]

The utility function is increasing in expected profit and decreasing in variance of profits for a risk averse landowner ($U_1 > 0$, $U_2 < 0$, $U(0,0) = 0$, $U_{11} < 0$, and $U_{12} = 0$). The mean variance utility function has been shown to lead to an ordering of investment portfolios that is almost identical to the order obtained by directly maximizing expected utility specified by various utility functions and an infinite number of alternative distributions of returns (Kroll, Levy, and Markowitz 1984). It has been widely used by previous studies to model landowners' allocation of land among crops, time between leisure and labor and technology adoption decisions (Bar-Shira, Just, and Zilberman 1997; Isik and Khanna 2003; Serra, Goodwin, and Featherstone 2011).

A landowner of parcel *i*, with discount rate *r* ($0 \le r \le 1$), chooses the crop and contract to maximize his net present value of utility over T years as follows:

$$Max_{\{l_1,l_2,l_3,l_4\}} \sum_t \left(\frac{1}{1+r}\right)^{t-1} U(E(\pi_{it}),Var(\pi_{it})) \quad \text{where}$$

$$E(\pi_{it}) = l_1 E\pi_{1it} + l_2 E\pi_{2it} + l_3 E\pi_{3it} + l_4 E\pi_{cit}$$

$$Var(\pi_{it}) = l_1^2 Var(\pi_{1it}) + l_2^2 Var(\pi_{2it}) + l_3^2 Var(\pi_{3it}) + l_4^2 Var(\pi_{cit}) \quad (6)$$

$$l_1 + l_2 + l_3 + l_4 = 1$$

We use the condition that a landowner will choose the crop/contract choice that leads to the highest level of utility and obtain the following results based on the comparative static analysis shown in Table 2 and derived in Appendix A.1.

Result 1. The rental payment needed to induce a risk-averse landowner to choose a land leasing contract decreases with an increase in variability of energy crop yield and biomass price and an increase in the variability of biofuel price. It will increase with an increase in land quality and a decrease in the variability of conventional crop profits. It decreases with an increase in the degree of risk aversion and an increase in the rate of time preference.

A land leasing contract offers a risk free option for the landowner and the rental rate needed to induce a landowner with a high degree of risk aversion and low land quality to accept it will decrease as the riskiness of the other alternatives increases. For a given level of riskiness of the various options, an increase in the degree of risk aversion and in the rate of time preference will lead a land owner to offer a risk discount on the rental rate at which he is willing to lease his land, particularly if land quality is low.

Result 2. The fixed biomass price needed to induce a risk-averse landowner to choose a fixed price contract increases with an increase in the variability of energy crop yield and biomass price and an increase in the degree of risk aversion, land quality and rate of time preference. It decreases with an increase in the volatility of conventional crop profits or biofuel price.

A fixed price contract exposes a landowner to a biomass yield risk and to spot market price volatility because of the need to purchase (sell) shortfalls (excess) on the spot market. The greater the volatility in these, particularly relative to conventional crop profits, the larger the risk premium that will be needed to induce a landowner to convert land to energy crop production. A landowner with a higher rate of time preference will require a higher biomass price to induce choice of this contract which requires waiting till the energy crop is established to earn a return.

Result 3. The revenue sharing rate needed to induce a risk-averse landowner to choose a revenue sharing contract increases with an increase in energy crop yield and price variability, increase in biofuel price volatility, degree of risk aversion, land quality and rate of time preference and with a decrease in conventional crop profit volatility.

A revenue-sharing contract exposes a landowner to both biomass price and yield risk and the risk premium needed to induce a risk averse landowner to choose this contract will increase with an increase in the variability of biomass yield or the spot market price. However, this premium will decrease as the variability of the profits of the conventional crop increases or the degree of risk aversion decreases.

We obtain the threshold level of risk aversion and land quality that would induce a landowner to choose each of the three types of contracts and as illustrated in Figure 1 find:

Result 4. A landowner with a relatively high degree of risk aversion will prefer a land leasing contract while a landowner with a relatively low degree of risk aversion will prefer a revenue sharing contract and the rest will chose a fixed price contract.

Energy crops are more likely to be planted on lower quality land parcels because of the lower opportunity cost of converting this land from conventional crop production; as the degree of risk aversion increases, the threshold level of land quality converted to energy crops under a land leasing contract will increase while the threshold levels of land quality in a fixed price contract and a revenue sharing contract will decrease. The landowner will choose fixed price contract if his land quality is low and risk aversion coefficient is medium, he will choose revenue sharing contract if land quality is low and risk aversion coefficient is low, otherwise he will choose to grow the conventional crop.

We also demonstrate in the Appendix A.2 that producing an energy crop for sale on the spot market is a dominated option as long as the fixed price contract offers a price greater than the average price on the spot market net of transportation cost. The spot market, therefore, serves as the last resort for landowners and the refinery to purchase (sell) any shortfall (excess).

[Insert Figure 1 here]

Figure 1 shows that the choice of contracts depends on the interaction between land quality and risk aversion coefficient. With any given level of risk aversion, landowners with lower land quality are more likely to switch to energy crop production while with any given level of land quality, landowners with a higher risk aversion coefficient are more likely to choose a land leasing contract to avoid both yield risk and price risk. Landowners with a smaller risk aversion coefficient (that are more risk loving) are more likely to choose a revenue-sharing contract while those with an intermediate level of risk aversion are likely to choose the fixed price contract because they only need to bear the yield risk and not the price risk. As shown in the Appendix A.1 and illustrated in Figure 1, the threshold level of land quality under land leasing contract is increasing in risk aversion while the threshold levels of land quality in fixed price contract, revenue sharing contract and conventional crops respectively are decreasing in risk aversion.

The results above also imply that a lower discount rate will lead a landowner to choose contract farming while a higher discount rate will lead to a preference for conventional crops if land quality is high and to leasing land for energy crops if land quality is relatively low to avoid paying the upfront establishment cost and waiting for returns till the crop is established under contract farming (Table 2).

3.2. Biorefinery's Problem

We assume a risk neutral biorefinery[5] that chooses the contract terms $\omega, \overline{P_y}, and\ \alpha$ to maximize its expected profits taking into account the joint distribution of risk preferences and land quality in the region, as well as their impact on the landowners' incentives to produce energy crops under three different contracts and the cost of purchasing/selling biomass from the spot market in the event of a shortfall/surplus (S_t) on the leased land. Aggregate acres enrolled in the land leasing contract are denoted by A_1, and the contract payment to these landowners by the biorefinery is the per acre payment ω times A_1. The acres enrolled in the fixed price contract are denoted by A_2 and receive $\overline{P_y}\overline{Y_b}$ as the payment per acre from the biorefinery. The acres enrolled in the revenue sharing contract are denoted by A_3 and receive a per acre payment of α percent of the per acre profit $P_{et}G\overline{Y_b}$. The biorefinery's problem is expressed as follows.

$$Max_{\{\omega,\overline{P_y},\alpha\}} E\{\sum_t (\frac{1}{1+r})^{t-1} P_{et}\overline{K} - F_e - \sum_t (\frac{1}{1+r})^{t-1} V_e - (F_b + \sum_t (\frac{1}{1+r})^{t-1} V_b + \sum_t (\frac{1}{1+r})^{t-1} \omega) A_1$$

$$-\sum_t (\frac{1}{1+r})^{t-1} \overline{P_y}\,\overline{Y_b} A_2 - \sum_t (\frac{1}{1+r})^{t-1} \alpha P_{et} G \overline{Y_b} A_3 + \sum_t (\frac{1}{1+r})^{t-1} (P_{bt} + J \bullet W) S_t\}$$

$$\text{s.t. } [A_1 Y_{bt} + (A_2 + A_3)\overline{Y_b} + S_t]G = \overline{K}$$

$$\overline{P_b} - W \le \overline{P_y} \le \overline{P_b} + W \tag{7}$$

$$\text{where } J = 1 \text{ if } S_t > 0 \text{ and } J = -1 \text{ otherwise}$$

We solve the biorefinery's problem numerically and examine the terms of the contracts and the allocation of land among crop-contract choices under parametric assumptions about crop markets, land quality and landowner preferences shown in Table 1 and described below.

4. Numerical Simulation

We consider the case of a 35 million gallon a year cellulosic biorefinery located in a Southern Illinois region with 100,000 acres of agricultural land within a radius of 7 miles. The smallest decision making unit is a 1 acre land parcel. The refinery has the option of leasing land or contracting for biomass within this region or of purchasing biomass from a spot market located 30 miles away. Two perennial crops, miscanthus and switchgrass, have been considered promising sources of biomass for cellulosic biofuels, due to their relatively high yields and ability to adapt to growing conditions in the Midwest. The relatively higher temperatures and longer growing season in southern Midwest and the lower yields of corn in this region make it a more likely place for growing energy crops than the northern Midwest (Jain et al. 2010; Khanna, Dhungana, and Clifton-Brown 2008).

We model the distribution of land quality q of each land parcel that ranges between 0 and $\bar{q}$ as a beta distribution represented by $\int_0^{\bar{q}} g(q;\alpha_1,\beta_1)dq$ where g is the distribution function with parameters α_1 and β_1. A beta distribution provides the flexibility to represent a wide variety of uniform, asymmetric, unimodal and linear distributions (Martinet 2010; Eugene, Lee, and Famoye 2002) and has been used by previous studies to model agricultural crop yields and land quality (Hennessy 2009; Khanna, Isik, and Zilberman 2002). We scale land quality to lie between 0 and 2 with an average value of 1. Using maximum likelihood methods, a 2-parameter beta distribution was fit to generate a negatively skewed distribution with parameters α_1 and β_1 equal to 5 and 3.5, respectively.

We model expected farm-level returns of each parcel as proportional to its land quality, *q*, and as ranging between 0 and $200 per acre with an average value of $100 per acre. We assume that realized conventional crop returns on each land parcel are normally distributed with the mean return level of $100 per acre scaled by the land quality for each unit of land and a standard deviation of $80 per acre based on crop return data from the Illinois Farm Business Farm Management Association (FBFM) for southern Illinois farms from 2005 to 2011. These returns are estimated as the difference between crop revenues and the cost of variable inputs, machinery and land costs. We test sensitivity to alternative assumptions about the distribution of land quality and crop returns.

We consider a generic energy crop that has stylized attributes similar to those of miscanthus and switchgrass as the feedstock for the refinery. Using a crop growth simulation model, Jain et al. (2010) estimated the yield of miscanthus and switchgrass in Illinois to be about 14 tons of dry matter (zero moisture) per acre and 5 tons of dry matter per acre for miscanthus and switchgrass, respectively. Dwivedi et al. (2013) report average yield estimates of 9 and 6 tons of dry matter for miscanthus and switchgrass, respectively, in Marion County in southern Illinois. In our analysis, we assume that the yield of biomass is 8 dry tons per acre with a standard deviation of 1.5 tons per acre.

We assume that the energy crop takes one year to be established and provides no harvestable yield in the first year and has a life span of 10 years. Based on Khanna et al. (2008) and Jain et al. (2010), we assume that the establishment cost is $1000 per acre in the first year. The operating costs are assumed to be $300 per acre per year from year 2 to year 10 and include the costs of fertilizers, harvesting and storage. For simplicity, we assume these costs are fixed per acre; relating these costs to yield will not affect the results qualitatively.

Since cellulosic biofuels are yet to be produced commercially, there is considerable uncertainty about the technology. Chen and Khanna (2012) review the existing techno-economic literature on the costs of a cellulosic biorefinery and the efficiency of converting biomass to fuel. Using estimates from the National Renewable Energy Laboratory (Humbird et al. 2011) we assume that 80 gallons of cellulosic ethanol can be produced per ton of feedstock using dilute acid pretreatment with enzymatic hydrolysis and co-fermentation technology. The cost of biorefinery can be divided into two components: operating cost and capital cost. Capital costs include equipment installation cost, land cost, site development cost, and indirect costs. Operating costs include natural gas, catalysts, raw materials, waste disposal, electricity, capital depreciation and income tax. We assume the capital cost for a 35 million gallon per year biorefinery is $303 Million and operating cost is $0.35 per gallon.

A 35 million gallon a year refinery requires 437,500 tons of biomass a year. With a yield of 8 tons per acre this would imply that 55% of the land in the region should produce the energy crop. Given our assumptions about the distribution of land quality and returns to corn production in this region and assuming the lowest quality land converts to energy crops, marginal opportunity cost of land that would need to convert is $105 per acre. This is close to the estimated opportunity cost of land of $121 per acre for Marion county, IL (Dwivedi et al. 2013). This implies that the marginal cost of supplying the above quantity of biomass, including the cost of establishing, maintaining, harvesting and storing the biomass described above, the break-even discounted cost of biomass at the farm gate with an opportunity cost of land of $105 per acre is $66 per ton with a 2% discount rate. Other studies have estimated a breakeven farm-gate price of miscanthus in Illinois (using a discount rate of 4%) and found that it ranges between $54 and $70 per ton in Southern Illinois (Khanna, Dhungana, and Clifton-Brown 2008). Dwivedi et al.

(2013) estimate the cost of growing miscanthus and switchgrass on low quality land in Marion county in southern Illinois to be $47 per ton and $62 per ton, respectively

We set the average price of biomass in the spot market at $60 per dry ton and assume the price is normally distributed with a standard deviation of $10 per ton. For simplicity we assume that there is no transportation cost from the farm-gate to the refinery gate within the region. However, there is a transportation cost of obtaining or selling biomass on the spot market. Following Searcy et al. (2007), we assume that the biomass bales are transported using a 20 ton capacity flatbed truck. The transportation cost of shipping biomass is a function of distance (4.39+0.19Z), where Z is the distance between the farm and the biorefinery in miles. This implies a transportation cost of about $10 per ton for a distance of 30 miles. Based on the observed national average price of gasoline and its standard deviation in 2012 we assume that the ethanol price distribution has an average price of $2.4 per gallon and a standard deviation of $0.3 per gallon (DOE 2012).

Following assumptions about average risk aversion in Babcock et al. (1993), Love and Buccola (1991) and Zacharias and Grube (1984) we calibrate an average risk aversion level of 0.0045 to reflect 15% of risk premium for landowners. We assume that individual risk preference are normally distributed and that 80% of landowners are risk averse and 20% are risk loving as in Schurle and Tierney (1990) and Wilson and Eidman (1985). This implies that risk preferences follow a continuous normal distribution $N(0.0045, 0.0054^2)$.

5. Simulation Results

We simulate the model using baseline parameters discussed in the previous section. First, we solve endogenously for the optimal contract terms that maximize the expected profits for the biorefinery subject to the expected utility maximizing contract decisions of the landowner of each parcel. Following that, we perform Monte-Carlo simulation by drawing 10,000 random realizations from the biomass price, biomass yield, biofuel price and conventional crop profit distributions. Then the landowners' ex-post net returns and utility are calculated for each realization given the terms of the contracts and their land allocation decision. Selected outcomes from various model scenarios are discussed and reported in the tables below.

[Insert Table 3 here]

4.1 Baseline Case

The simulation results from the benchmark case are summarized in Table 3. The optimal contract terms are $86 per acre for the land leasing contract, $66 per ton for the fixed price contract and a 34% sharing rate for the revenue-sharing contract. Under the optimal contract terms, 41.5% of the 100,000 land parcels in the contract region choose the land leasing contract, 8.3% of the land parcels select the fixed-price contract and 4.5% of the land parcels choose the revenue-sharing contract. The remaining 45.7% of the landparcels continue to plant conventional crops. The average quality of land used to produce conventional crops is substantially higher than the quality of the land converted to bioenergy crop production. Only risk-loving producers select the revenue-sharing contract option, while those choosing the fixed-price contract are on average close to risk neutral. The land parcels who choose land leasing contracts tend to be owned by more risk averse landowners who are willing to convert relatively higher quality land to energy crop production as compared to those that choose the other two contracts. Less than 0.1% of the biomass is obtained from the spot market. All landowners are at least as well off as they were without biomass contracts since conventional crop production remains an option. The average gain in utility by converting to an energy crop under one of the three contracts ranges from 20% to 33% relative to the utility level with the conventional crop under each contract, some landowners earn significant rents while the marginal landowner is at least as well off as with conventional crop production. The equivalent price of biomass acquisition, averaged across all contract types, is $65 per ton.

4.2 Effect of Landowners' Risk Preferences, Time Preferences and Land Quality

We investigate the impact of changes in the assumptions related to distributions of the landowners' risk preferences and land quality in the contract region. We consider three alternative distributions of risk preferences that represent (i) a mean-preserving contraction, (ii) a mean preserving spread and (iii) a mean-shift with the same variance. We refer to (i) as a Concentrated Risk distribution in which 10% of the landowners are classified as risk loving (instead of the baseline of 20%) and to (ii) as the Diversified Risk distribution in which 30% of the landowners are risk loving. The average risk aversion level remains the same as in the baseline. In case (iii) referred to as the Low Mean Risk Aversion, the mean of the distribution is shifted so that 50% of the landowners are risk loving. We also consider two alternative land quality distributions with an average return to land that is 25% lower in the Low Land Quality Case and 25% higher than the benchmark case in the High Land Quality Case, respectively. We analyze the sensitivity to two alternative discount rates of 5% and 10% for both landowners and the biorefinery. Panel A of Table 4 summarizes the optimal contract terms and Figure 2 shows the enrollment rates under different contracts across these scenarios.

[Insert Figure 2 here]

[Insert Figure 3 here]

We find that across these wide ranging scenarios, 40-50% of the land parcels that convert land for energy crop production prefer to lease their land, except in the case with the Lower Mean Risk Aversion where the corresponding percentage is 20% and the largest percentage (30%) of land parcels enroll in the fixed price contract. The percentage of land parcels in the revenue sharing contract ranges from negligible in the Concentrated Risk and Low Land Quality scenarios to nearly 30% of those switching from conventional crops in the Diversified Risk case.

Figure 3 shows the impact of changes in the distribution of risk preferences on the crop-contract choice in the region. It shows that the optimal mix of contracts offered will depend on risk preferences with negligible demand for the fixed price contract in the Diversified Risk preferences case and no demand for revenue-sharing contract and reduced demand for the land leasing contract with Concentrated Risk preferences. In the latter case this is due to a larger number of landowners with risk preferences closer to risk-neutrality and fewer extremely risk-averse or risk-loving land owners who tend to prefer the land lease and revenue sharing contract, respectively.

[Insert Table 4 here]

Table 4 shows that Diversified Risk preferences will lower the land leasing rate and fixed price rate needed to induce energy crop production while a Lower Mean Risk Aversion will raise the land leasing rate and fixed price needed to induce landowners to choose these contracts. As indicated by the comparative static analysis above, a decrease in the average level of risk aversion reduces the risk discount on the land leasing contract that landowners are willing to accept and increases the fixed price that needs to be offered to induce them to switch to energy crop production. An increase in the average land quality in the region and in the discount rate will also increase the terms of all three contracts needed to induce energy crop production. The terms of the revenue sharing contract are fairly insensitive to risk preferences but the percentage enrolled in this contract varies significantly with the risk preference distribution as shown in Figure 2. The terms of the revenue sharing contract increase as the discount rate increases and as average land quality increases.

[Insert Table 5 here]

Changing risk preference and land quality also impacts the aggregate expected profits earned by the biorefinery, and the expected profits and utility levels realized by the contracted landowners. Table 5 summarizes these effects under the various scenarios which are reported as percentage changes relative to the baseline.

The concentrated risk preference scenario results in a 3.2% increase in expected profit for the landowners but reduce the expected profit for the biorefinery by 0.7% due to higher overall feedstock costs as compared to the level under the benchmark case. The aggregate utility of all landowners is 1.6% lower while their net gain in utility (relative to that with the conventional crop) is 7% lower than in the benchmark scenario; this is because of the absence of the extremely risk averse or risk loving landowners whose gains in utility from choosing the land leasing and revenue sharing contracts, respectively, in the benchmark case were the highest. More of the risk averse and the risk loving landowners now choose the fixed price contract instead of a land leasing and revenue sharing contract, respectively (as shown in Figure 2) and the gain in utility experienced by these landowners is much smaller than in the baseline case. On the other hand, the Diversified Risk case results in a 6% reduction in expected profits for the landowners, but increases aggregate utility gains for landowners because the risk averse and the risk loving landowners can now choose the contract (land leasing and risky revenue-sharing, respectively) with their preferred level of risk while increasing expected profits for the biorefinery relative to the benchmark due to lower overall feedstock costs. These results illustrate the benefit of risk preference heterogeneity for the biorefinery in terms of lowering overall procurement costs with the menu of contracts through more effective price discrimination.

A lower average land quality in the contract region significantly reduces both expected profits and aggregate expected utility gains for the landowners, but increases expected profits for the biorefinery by approximately 4.5%. Increasing the average land quality in the region has the opposite effect, resulting in profit and utility gains of more than 30% relative to the baseline for the landowners, but a 5% reduction in expected profits for the biorefinery. These results are as expected given the assumed relationship between land quality and conventional crop production, which results in larger opportunity costs of accepting a biomass production contract for landowners with more productive land.

An increase in the discount rate to 5% and 10% increases preference for the land leasing contract as shown in Figure 2 and increases the terms of the contracts which increases feedstock costs and lowers the profits of the refinery. The discounted value of landowner profits and utility gains decrease due to a lower value being attached to future returns relative to the upfront costs of establishing energy crops.

4.3 Effect of Changes in Production Risk and Price Uncertainty

We also consider the impact of alternative scenarios where the relative price and production riskiness of biomass, biofuel, and conventional crop production are varied. Specifically, four alternative combinations of riskiness of conventional and energy crops are considered: where the standard deviation of conventional crop returns is increased or decreased by 50% relative to the baseline and the standard deviations of biomass yields, the biomass spot price, and ethanol prices are all increased or decreased by 50%.

The impact of changes in relative risk levels on the optimal contract terms are summarized in panel B of Table 4. Increasing the standard deviation of conventional crop returns lowers the opportunity cost of biomass production in utility terms for risk-averse landowners, which leads to a reduction in the land-leasing rate to between \$70 and \$73 per acre and the revenue share to 0.32 and 0.33, respectively. Lowering the standard deviation of conventional crop returns by 50% increases the opportunity cost for biomass production, leading to increases in the optimal rates for the lease and fixed price contracts. Similar to the risk preference and land quality scenarios, the larger impacts are seen in the sign-up rates across contracts illustrated in Figure 2. When the risk associated with conventional crop production increases, enrollment rates in the land-leasing contract increase, enrollment in the fixed price contract goes to zero, and revenue sharing contract enrollment declines slightly. This result holds even when biomass production and biofuel price risks are increased since the terms offered in the various contracts address those sources of uncertainty.

When conventional crop returns, biomass production, and biofuel price risks are all lowered by 50%, enrollment in the land leasing and revenue sharing contracts decline relative to the baseline and more landowners select the fixed price contract. When the riskiness of conventional crop returns is lowered, but biomass production and biofuel price risks are increased, enrollment in the land-leasing contract declines and a larger share of risk-loving landowners enroll in the revenue-sharing contract as the biorefinery is forced to improve contract terms.

Total profits and utility of landowners is higher (and for the refinery are lower) when conventional crops are less risky because the refinery has to offer better contract terms (particularly for the land leasing contract held by over 60% of the landowners that convert to the energy crop as shown in Figure 2). As compared to the benchmark case, the net gain in utility for landowners is higher when either the conventional crop or the energy crop is riskier because that increases their benefits of selecting their preferred contract.

[Insert Table 6 here]

4.4 Offering Single Contract Types vs. a Menu of Contract Types

The results in the previous subsections show that, across the scenarios considered, the biggest impact of changing distributional assumptions or relative risk levels is seen in the enrollment rates across contract types (Figure 2). In Table 6, we compare aggregate expected utility, profits, and feedstock costs for the landowners and the biorefinery when just a single contract type is offered rather than the full menu of three contract types.

When single contracts are offered, contract rates increase as the biorefinery is no longer able to price discriminate based on the heterogeneity of landowner risk preferences and land quality. Thus, expected profits for the landowners increase, while expected profits and feedstock costs for the biorefinery decline. However, the aggregate net benefits of the landowners decline due to the risk impacts on utility in the shift from a contract menu to a single contract type being offered. Under the benchmark scenario, moving to lease contracts only increases expected landowner profits by less than 2% relative to the baseline with a menu of contracts, while the biorefinery's expected profits decline by 0.5% The effects are much larger if a revenue sharing contract is used, with expected profits for the landowners increasing by more than 25% and expected profits for the biorefinery declining by more than 5%. We also observe that the total utility of landowners is increased under several single contract cases while their net benefits fall. This is due to the improved contract terms (i.e. a higher sharing rate) required to contract with a sufficient number of land parcels to supply the biorefinery while risk averse landowners' net utilities was decreased because they take more risks under single contracts cases.

Two other scenarios are also considered in Table 6 – the case where there is a left shift in the mean of the risk preference distribution (Low Mean Risk Aversion), and the case where conventional crop return risk is reduced by 50% and biomass production and biofuel price risks are increased by 50%. These two cases were selected because they were characterized by relatively large diversity in the mix of contracts selected in the benchmark case as shown in Figure 2. For both scenarios, the results are similar to those reported for the benchmark case. The profits of refinery are highest when a menu of contracts is offered. As the mean risk aversion level decreases, landowners are better off with land leasing or fixed price contracts only relative to the case when all three contracts are offered because of the higher contract terms the refinery is forced to offer to induce sufficient biomass production. However, the net gain for landowners under a revenue sharing contract is lower because 85% of the contracted land parcels that would have otherwise chosen a fixed price or land leasing contract are now forced to choose a riskier contract. Single contracts of any of the three types leave the landowners and the refinery worse off when the risks of producing energy crops are high and those of conventional crops are low because of the high contract terms ($101 per acre of land leased, $70 per ton of biomass and a revenue share of 0.36) that need to be offered to induce landowners to choose a single contract. By offering a menu of contract types, the biorefinery is able to earn a higher level of expected profits but may have to also incur the higher transaction costs associated with designing and enforcing multiple types of contracts. Whether the gains in expected profitability exceed those additional costs will depend on the characteristics of the area where the biorefinery is located, as well as market conditions and characteristics of the landowners in the region.

6. Conclusions

This paper undertakes an integrated analysis of the decision of landowners to grow an energy crop and their choice among a land leasing contract, a fixed price contract and a revenue sharing contract simultaneously with a biorefinery's decision about the contract terms they are willing to offer. The joint optimization by landowners and the refinery determines the optimal contract terms and the extent to which a refinery will prefer to be vertically integrated instead of contracting for independently produced energy crops. We show the impact of risk preferences, land quality and riskiness of energy crop production and prices on the optimal contract terms and effective cost of biomass. Our findings suggest that landowners' land allocation decisions depend jointly on their individual land quality and risk preferences. Landowners with a lower land quality and a higher degree of risk aversion are willing to lease their land for biomass production while those with low land quality but low (moderate) degree of risk aversion are more willing to grow the energy crop themselves under a revenue sharing (fixed price) contract. We also investigated the relationship between the variation in landowners' risk aversion coefficient and regional distribution of land quality and profitability of the biorefinery. We find that the biorefinery earns a higher profit if there is a big variation in risk aversion coefficients keeping everything else constant and if the average land quality is lower. This suggests that a biorefinery should choose a location where landowners have diverse risk preferences and lower land quality.

We find that offering a menu of contracts results in greater expected profits for the refinery but not necessarily for landowners as compared to cases where the refinery offers only one contract type. If a refinery is able to offer only one type of contract then the refinery's loss of profits is lowest under a land leasing contract even when landowners have lower average risk aversion and bioenergy crop production is risky. In contrast, offering only a revenue sharing contract will lead to the largest relative losses in the profits of the refinery compared to offering a menu consisting of the three contract types. Note that we do not consider the transaction costs associated with offering multiple types of contracts to growers within the region. In practice, a biorefinery will have to weigh the benefits of offering multiple contracts illustrated in our model against those transaction costs.

A robust and important result for biomass contracts in practice is that land leasing contracts are likely to be predominant in terms of total contracted acreage for energy crop production. Specifically, we find that a biorefinery will prefer to be more vertically integrated and grow its own energy crop when biomass yield and price risks are high to avoid paying a high risk premium to risk-averse landowners. It will also prefer to be more vertically integrated when the variability in returns to crop production is high and risk-averse landowners are more willing to choose land leasing contracts as a safer option. Since our model assumes that biomass yield risk is systemic, below average yield realizations for individual landowners result in below average yield realizations for all contracted production. In practice, at least a portion of the biomass yield risk will be idiosyncratic and therefore poolable at the refiner's level. This would result in the potential for even greater gains to a risk-neutral processor when contracting with risk-averse landowners, and suggests that if transactions costs are large enough to encourage single contract types the land leasing contract and a higher level of vertical integration would be expected for cellulosic biorefineries. Finally, although we did not explicitly consider the availability of idle/fallow land that could be converted for energy crop production, our findings can used to infer the implications of including a zero return, zero-risk alternative instead of a conventional crop for contract terms and refinery profits. While the availability of marginal land would lower the land leasing costs, it will raise the fixed price and revenue share required to induce landowners to choose independently contracted production and is likely to further increase incentives for vertically integrated production.

Table 1. Variable Definitions and Parameter Values in the Benchmark Scenario

Parameter	Unit	Definition	Value
N	-	Number of land parcels in an agricultural region	100,000
r	-	Discount rate	2%
q_i	-	Land quality of parcel i	
$\overline{K}$	M gallons	The capacity of the biorefinery	35
T	Years	Life-span of bioenergy crops	10
Y_{bt}	tons/acre	Biomass yield in year t	
$\overline{Y}_b$	tons/acre	Average biomass yield	8
σ_y	tons/acre	Standard deviation of biomass yield disturbance	1.5
π_{ct}	\$/acre	Profit of conventional crop in year t	
$\overline{\pi}_c$	\$/acre	Average conventional crop profit	100
σ_c	\$/acre	Standard deviation of conventional crop profit	80
P_{bt}	\$/ton	Biomass price in year t	
$\overline{P}_b$	\$/ton	Average biomass price	60
σ_b	\$/ton	Standard deviation of biomass price	10
P_{et}	\$/gallon	Biofuel price in year t	
$\overline{P}_e$	\$/gallon	Average biofuel price	2.4
σ_e	\$/gallon	Standard deviation of biofuel price	0.3
ρ	-	Correlation coefficient between biomass price and yield shock	-0.1
G	gallon/ton	Biomass conversion rate	80
F_b	\$/acre	Establishment cost of bioenergy crops	1000
V_b	\$/acre	Production cost of bioenergy crops	300
F_e	\$M	Capital cost of the biorefinery	303
V_e	\$/gallon	Operating cost of the biorefinery	0.35
W	\$/ton	Average biomass transportation cost	10

Table 2. Determinants of the Terms of Alternative Contracts

$\Psi =$	ω	$\overline{P_y}$	α
$\partial\Psi / \partial\sigma_y$	$\frac{D_1}{D_1+1}\rho\sigma_b - \frac{\lambda_i D_1}{D_1+1}(\overline{P_b}^2+\sigma_b^2+W^2)\sigma_y$ <0	$\frac{1}{\overline{Y_b}}[-\rho\sigma_b+\lambda_i(\overline{P_b}^2+\sigma_b^2+W^2)\sigma_y]$ >0	$\frac{-\rho\sigma_b+\lambda_i(\overline{P_b}^2+\sigma_b^2+W^2)\sigma_y}{\overline{P_e}G\overline{Y_b}-\lambda_i\alpha\overline{Y_b}^2G^2\sigma_e^2}>0$
$\partial\Psi / \partial\sigma_b$	$\frac{D_1}{D_1+1}\rho\sigma_y - \frac{\lambda_i D_1\sigma_y^2\sigma_b}{D_1+1}<0$	$\frac{1}{\overline{Y_b}}[-\rho\sigma_y+\lambda_i\sigma_y^2\sigma_b]>0$	$\frac{-\rho\sigma_y+\lambda_i\sigma_y^2\sigma_b}{\overline{P_e}G\overline{Y_b}-\lambda_i\alpha\overline{Y_b}^2G^2\sigma_e^2}>0$
$\partial\Psi / \partial\sigma_c$	$-\lambda_i\sigma_c<0$	$-\frac{(D_1+1)\lambda_i\sigma_c}{D_1\overline{Y_b}}<0$	$-\frac{(D_1+1)\lambda_i\sigma_c}{D_1(\overline{P_e}G\overline{Y_b}-\lambda_i\alpha\overline{Y_b}^2G^2\sigma_e^2)}<0$
$\partial\Psi / \partial\sigma_e$	$-\frac{\lambda_i D_1}{(D_1+1)}\alpha^2\overline{Y_b}^2G^2\sigma_e<0$	$-\lambda_i\alpha^2\overline{Y_b}G^2\sigma_e<0$	$\frac{\lambda_i\alpha^2\overline{Y_b}^2G^2\sigma_e}{\overline{P_e}G\overline{Y_b}-\lambda_i\alpha\overline{Y_b}^2G^2\sigma_e^2}>0$
$\partial\Psi / \partial q_i$	$\overline{\pi_c}>0$	$\frac{D_1+1}{D_1\overline{Y_b}}\overline{\pi_c}>0$	$\frac{(D_1+1)\overline{\pi_c}}{D_1(\overline{P_e}G\overline{Y_b}-\lambda_i\alpha\overline{Y_b}^2G^2\sigma_e^2)}>0$
$\partial\Psi / \partial\lambda_i$	$-\frac{D_1}{2(D_1+1)}(\overline{P_b}^2\sigma_y^2+\sigma_b^2\sigma_y^2+W^2\sigma_y^2)<0$	$\frac{1}{2\overline{Y_b}}(\overline{P_b}^2\sigma_y^2+\sigma_b^2\sigma_y^2+W^2\sigma_y^2)>0$	$\frac{\alpha^2\overline{Y_b}^2G^2\sigma_e^2+\overline{P_b}^2\sigma_y^2+\sigma_b^2\sigma_y^2+W^2\sigma_y^2}{2(\overline{P_e}G\overline{Y_b}-\lambda_i\alpha\overline{Y_b}^2G^2\sigma_e^2)}>0$
$\partial\Psi / \partial r$	$\frac{\alpha\overline{P_e}G\overline{Y_b}+\rho\sigma_b\sigma_y-V_b-\frac{\lambda_i}{2}\sigma_2^2-\omega}{D_1+1}D_2<0$	$-\frac{\overline{P_y}\overline{Y_b}+\rho\sigma_b\sigma_y-V_b-\frac{\lambda_i}{2}\sigma_1^2-\omega}{D_1\overline{Y_b}}D_2$ >0	$-\frac{\alpha\overline{P_e}G\overline{Y_b}+\rho\sigma_b\sigma_y-V_b-\frac{\lambda_i}{2}\sigma_2^2-\omega}{D_1(\overline{P_e}G\overline{Y_b}-\lambda_i\alpha\overline{Y_b}^2G^2\sigma_e^2)}D_2>0$

where $\sigma_1^2 \equiv (\overline{P_b}^2\sigma_y^2+\sigma_b^2\sigma_y^2+W^2\sigma_y^2)$, $\sigma_2^2 \equiv (\alpha^2\overline{Y_b}^2G^2\sigma_e^2+\overline{P_b}^2\sigma_y^2+\sigma_b^2\sigma_y^2+W^2\sigma_y^2)$, $D_1 \equiv \sum_{t=2}^{T}(\frac{1}{1+r})^{t-1}$

and it can be shown that $D_2 \equiv \{-\frac{1}{r^2}[1+r-(\frac{1}{1+r})^{T-1}]+\frac{1}{r}[1+(T-1)(\frac{1}{1+r})^{T}]\}<0$ for $0<r<1$ *and* $T>1$

Table 3. Contract Choice and Terms of Contract in Benchmark Scenario

	Land Leasing Contract	Fixed Price Contract	Revenue Sharing Contract	Conventional Crops
Contract Terms	$86/acre	$66/ton	0.34	
Profit ($/Acre)	86	94	89	122
Percentage of Landowners (%)	41.5	8.3	4.5	45.7
Average Land quality	0.84	0.72	0.78	1.22
Range of Land quality	0.1-1.57	0.06-0.94	0.16-1.22	0.92-1.67
Average Risk aversion	0.004	-0.0001	-0.003	0.001
Range of Risk aversion	0.0009 to 0.02	-0.001 to 0.0009	-0.01 to -0.001	-0.008 to 0.01
Average gain in utility (%)[1]	32.7	21.9	19.7	
Range of gain in utility (%)[2]	0 to 146.9	0 to 93.5	0 to 84.6	

[1] Average percentage gain in utility for landowners choosing a specific contract instead of growing the conventional crop.

[2]Range of the percentage gain in utility across all landowners choosing a specific contract instead of growing the conventional crop

Table 4. Optimal Contract Terms Under Alternative Scenarios

	Land Leasing Contract	Fixed Price Contract	Revenue Sharing Contract
Panel A	$/acre	$/ton	Sharing Rate
Benchmark	86	66	0.34
Concentrated Risk	86	67	0.34
Diversified Risk	79	65	0.34
Low Mean Risk Aversion	91	67	0.34
Low Land Quality	62	62	0.31
High Land Quality	111	70	0.36
5% discount rate	88	NA	0.35
10% discount rate	90	NA	0.36
Panel B	$/acre	$/ton	Sharing Rate
High C, High B	70	62	0.32
High C, Low B	73	NA	0.33
Low C, Low B	100	67	NA
Low C, High B	94	68	0.35

Note: High and Low C refer to scenarios where the standard deviation of conventional crop returns is increased or decreased by 50%, respectively. High and Low B refer to scenarios where the standard deviations of biomass yield, the biomass spot price, and ethanol prices are increased or decreased by 50%, respectively. NA indicates contracts that were not offered/selected in a particular scenario.

Table 5. Aggregate Expected Profits, Landowner Utility, and Feedstock Costs Under Alternative Scenarios

Scenarios	Total Profits of Landowners	Total Utility of Landowners	Total Net Benefits of Landowners	Profits of Refinery	Feedstock Costs
Effect of Landowners' Risk Preference					
Concentrated Risk	3.22%	-1.56%	-6.77%	-0.65%	0.65%
Diversified Risk	-6.13%	2.44%	7.52%	0.97%	-0.98%
Low Mean Risk	9.82%	17.56%	-4.51%	-1.29%	1.74%
Effect of Land Quality					
Low Land Quality	-28.74%	-27.78%	-16.54%	4.53%	-4.55%
High Land Quality	32.55%	35.56%	27.07%	-5.18%	5.20%
Effect of Time Preference					
5% discount rate	-11.34%	-11.11%	-9.77%	-0.49%	0.49%
10% discount rate	-24.35%	-25.56%	-21.80%	-0.65%	0.81%
Effect of Crop Riskiness					
High C High B	-20.24%	-17.56%	42.11%	1.78%	-1.79%
High C Low B	-16.55%	-18.67%	48.87%	3.72%	-3.58%
Low C Low B	13.56%	11.11%	-8.27%	-1.29%	1.30%
Low C High B	12.23%	23.11%	17.29%	-2.75%	2.93%

Note: Percentage changes are estimated relative to the benchmark case.

Table 6. Effect of a Single Contract Offer Relative to a Menu of Contracts

Scenarios	Total Profits of Landowners	Total Utility of Landowners	Total Net Benefits of Landowners	Profits of Refinery	Feedstock Costs
Benchmark					
Land Leasing Contracts Only	1.60%	-1.11%	4.51%	-0.49%	0.49%
Fixed Price Contracts Only	22.15%	0.67%	-8.27%	-3.72%	3.90%
Revenue Sharing Contracts Only	26.94%	5.78%	-5.26%	-5.34%	5.37%
Low Mean Risk Aversion					
Land Leasing Contracts Only	9.77%	-0.19%	11.81%	-1.97%	1.95%
Fixed Price Contracts Only	18.92%	8.70%	6.30%	-3.93%	2.64%
Revenue Sharing Contracts Only	-2.08%	-2.27%	-6.30%	-1.64%	1.43%
Low C High B					
Land Leasing Contracts Only	2.73%	-8.84%	-20.51%	-1.16%	0.95%
Fixed Price Contracts Only	-15.17%	-25.81%	-22.44%	-3.83%	3.63%
Revenue Sharing Contracts Only	-33.99%	-38.27%	-25.64%	-3.16%	3.00%

Note: Percentage change is calculated relative to case with all three contracts offered in each scenario, that is keeping all else the same.

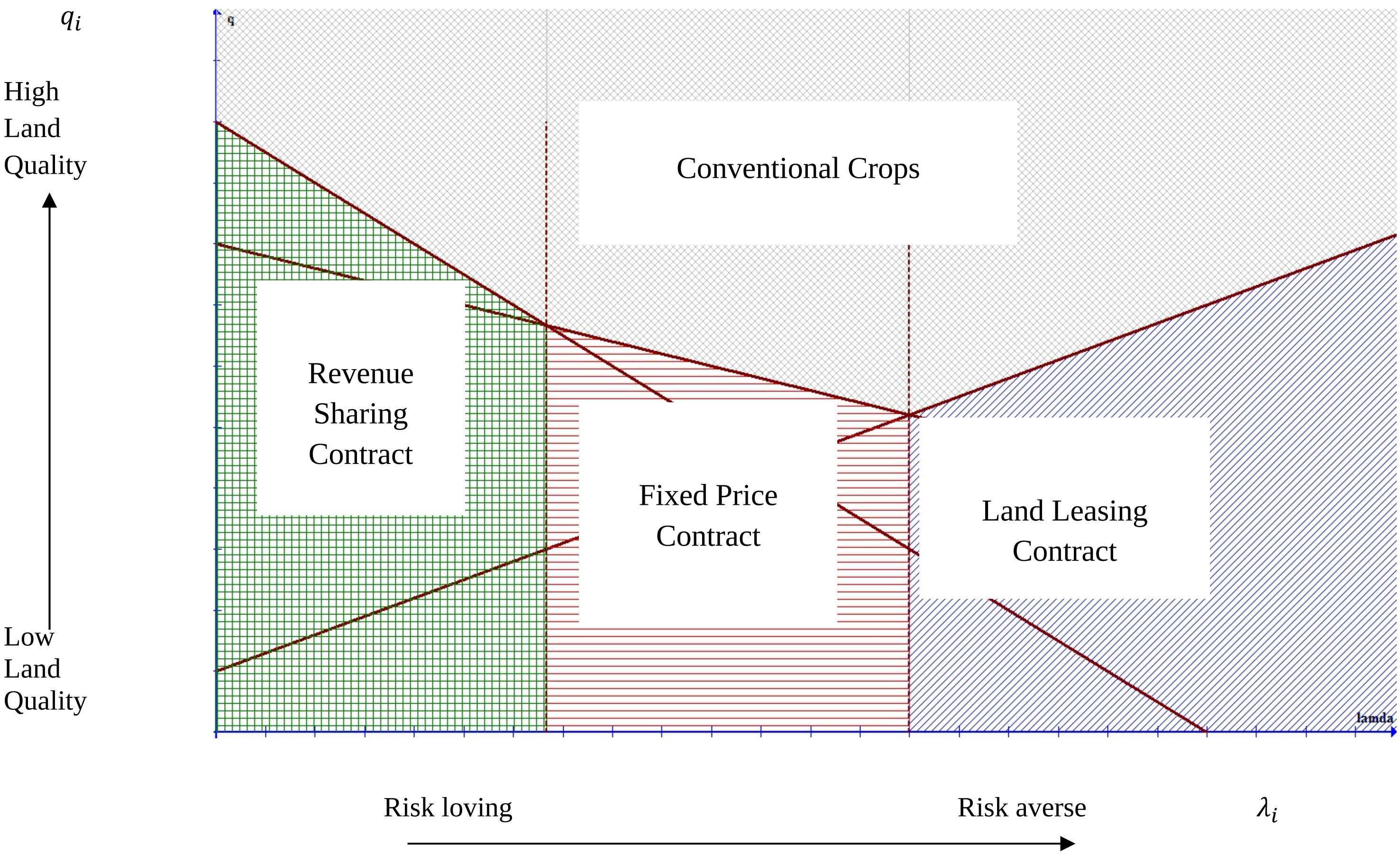


Figure 1. Effect of Risk Preference and Land Quality on Contract Choice

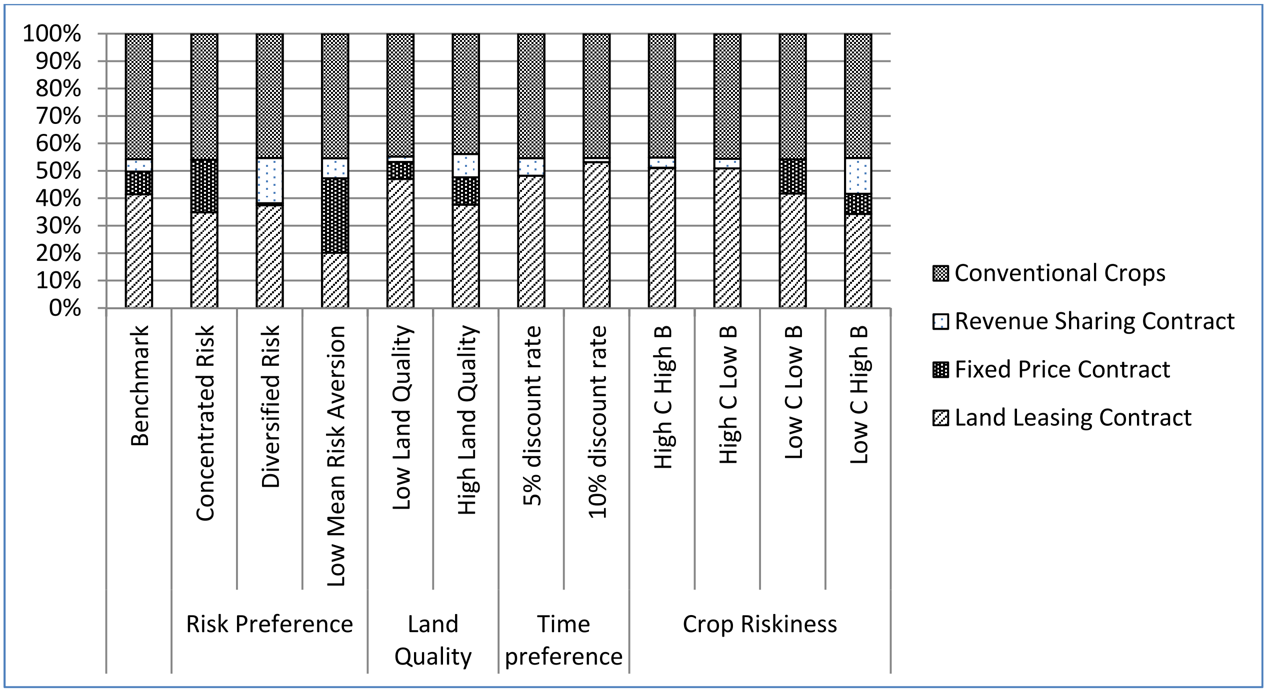
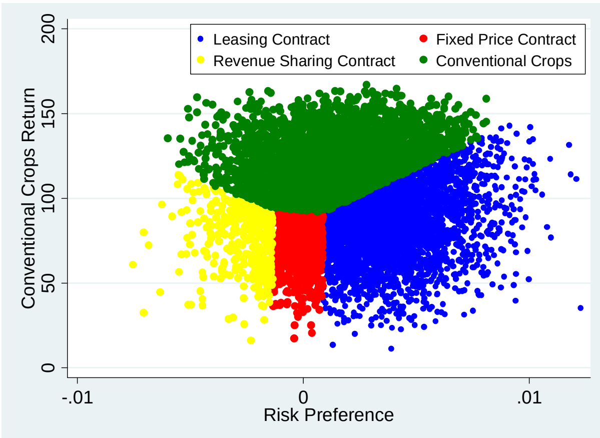
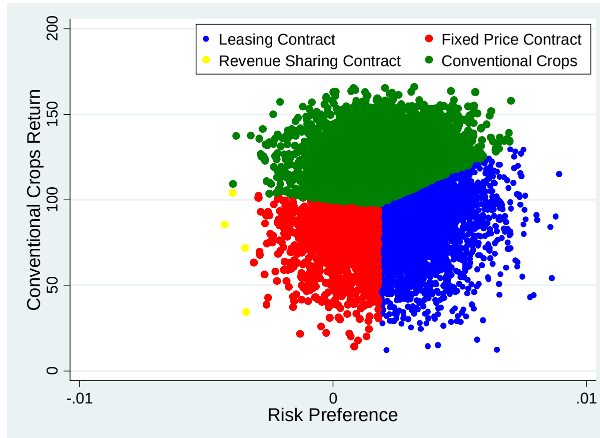


Figure 2. Percentage of Acreage Enrolled in Alternative Contracts under Various Scenarios

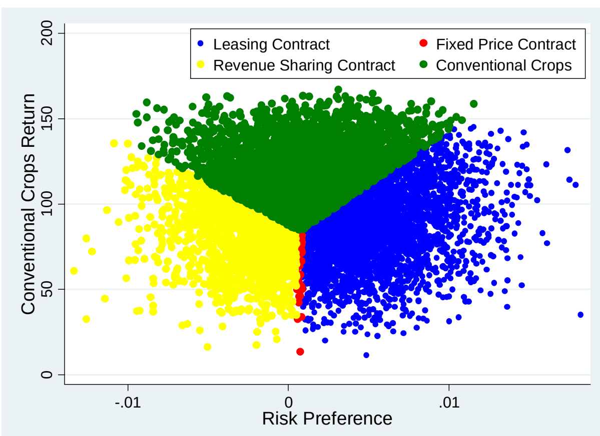
(Note: In general, reliance on the spot market for biomass is low in all scenarios, the maximum share of biomass bought/sold on the spot market was 1% in the Concentrated Risk scenario**)**



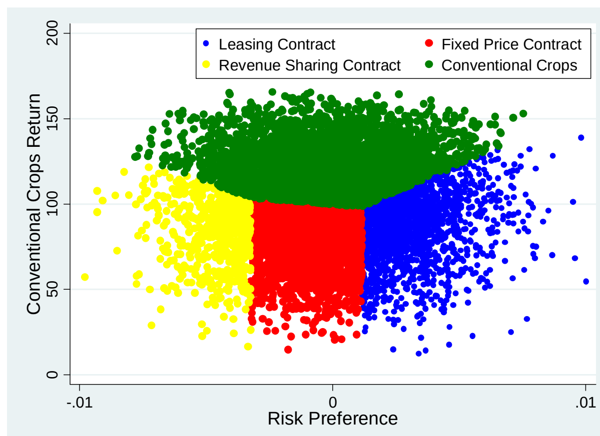
3.1Benchmark



3.2 Concentrated Risk



3.3 Diversified Risk



3.4 Low Mean Risk Aversion

Figure 3 Effect of Risk Preferences and Land Quality on Contract Choices

Appendix

A.1 We derive the mathematical expressions for results 1-4 by representing a landowner's utility from each choice as follows:

A landowner's utility from a land leasing contract is: $\sum_{t=1}^{T}(\frac{1}{1+r})^{t-1}\omega$

and from a fixed price contract is:

$$\sum_{t=2}^{T}(\frac{1}{1+r})^{t-1}(\overline{P_y}\,\overline{Y_b}+\rho\sigma_b\sigma_y-V_b)-F_b-\sum_{t=2}^{T}(\frac{1}{1+r})^{t-1}(\frac{\lambda_i}{2})(\overline{P_b}^2\sigma_y{}^2+\sigma_b{}^2\sigma_y{}^2+W^2\sigma_y{}^2)$$

A landowners's utility from a revenue sharing contract is:

$$\sum_{t=2}^{T}(\frac{1}{1+r})^{t-1}(\alpha\overline{P_e}G\overline{Y_b}+\rho\sigma_b\sigma_y-V_b)-F_b-\sum_{t=2}^{T}(\frac{1}{1+r})^{t-1}(\frac{\lambda_i}{2})(\alpha^2\overline{Y_b}^2G^2\sigma_e{}^2+\overline{P_b}^2\sigma_y{}^2+\sigma_b{}^2\sigma_y{}^2+W^2\sigma_y{}^2)$$

and from conventional crop production is:

$$\sum_{t=1}^{T}(\frac{1}{1+r})^{t-1}(\overline{\pi_c}q_i)-\sum_{t=1}^{T}(\frac{1}{1+r})^{t-1}(\frac{\lambda_i}{2})\sigma_c{}^2$$

We compare the utility level from each of these choices and find the following conditions:

Land leasing contact is chosen (i.e. $l_1=1$ and $l_2=l_3=l_4=0$) if:

$$\lambda_i \geq \frac{2D_1(\overline{P_y}\,\overline{Y_b}+\rho\sigma_b\sigma_y-V_b)-2F_b-2(D_1+1)\omega}{D_1(\overline{P_b}^2\sigma_y{}^2+\sigma_b{}^2\sigma_y{}^2+W^2\sigma_y{}^2)} \equiv \lambda_1 \qquad \text{(A.1)}$$

$$\lambda_i \geq \frac{2D_1(\alpha\overline{P_e}G\overline{Y_b}+\rho\sigma_b\sigma_y-V_b)-2F_b-2(D_1+1)\omega}{D_1(\alpha^2\overline{Y_b}^2G^2\sigma_e{}^2+\overline{P_b}^2\sigma_y{}^2+\sigma_b{}^2\sigma_y{}^2+W^2\sigma_y{}^2)} \equiv \lambda_2 \qquad \text{(A.2)}$$

$$\lambda_i \geq \frac{2(\overline{\pi_c}q_i-\omega)}{\sigma_c{}^2} \equiv \lambda_3 \qquad \text{(A.3)}$$

where $D_1 \equiv \sum_{t=2}^{T}(\frac{1}{1+r})^{t-1}$ is the summation of discount factors from year 2 to year T .

Fixed price contract is chosen (i.e. $l_2=1$ and $l_1=l_3=l_4=0$) if the following conditions are satisfied:

$$\lambda_i \le \frac{2D_1(\overline{P_y}\,\overline{Y_b} + \rho\sigma_b\sigma_y - V_b) - 2F_b - 2(D_1+1)\omega}{D_1(\overline{P_b}^2\sigma_y{}^2 + \sigma_b{}^2\sigma_y{}^2 + W^2\sigma_y{}^2)} \equiv \lambda_1 \tag{A.4}$$

$$\lambda_i \ge \frac{2\alpha\overline{P_e}G\overline{Y_b} - 2\overline{P_y}\,\overline{Y_b}}{\alpha^2\overline{Y_b}^2G^2\sigma_e{}^2} \equiv \lambda_4 \tag{A.5}$$

$$\lambda_i \le \frac{2D_1(\overline{P_y}\,\overline{Y_b} + \rho\sigma_b\sigma_y - V_b) - 2F_b - 2(D_1+1)\overline{\pi_c}q_i}{D_1(\overline{P_b}^2\sigma_y{}^2 + \sigma_b{}^2\sigma_y{}^2 + W^2\sigma_y{}^2) - (D_1+1)\sigma_c{}^2} \equiv \lambda_5 \tag{A.6}$$

assuming that $D_1(\overline{P_b}^2\sigma_y{}^2 + \sigma_b{}^2\sigma_y{}^2 + W^2\sigma_y{}^2) > (D_1+1)\sigma_c{}^2$ which means that the risk from energy crop production is larger than from conventional crop production.

Landowners will choose the revenue sharing contract (i.e. $l_3 = 1$ and $l_1 = l_2 = l_4 = 0$) if the following conditions are satisfied:

$$\lambda_i \le \frac{2D_1(\alpha\overline{P_e}G\overline{Y_b} + \rho\sigma_b\sigma_y - V_b) - 2F_b - 2(D_1+1)\omega}{D_1(\alpha^2\overline{Y_b}^2G^2\sigma_e{}^2 + \overline{P_b}^2\sigma_y{}^2 + \sigma_b{}^2\sigma_y{}^2 + W^2\sigma_y{}^2)} \equiv \lambda_2 \tag{A.7}$$

$$\lambda_i \le \frac{2\alpha\overline{P_e}G\overline{Y_b} - 2\overline{P_y}\,\overline{Y_b}}{\alpha^2\overline{Y_b}^2G^2\sigma_e{}^2} \equiv \lambda_4 \tag{A.8}$$

$$\lambda_i \le \frac{2D_1(\alpha\overline{P_e}G\overline{Y_b} + \rho\sigma_b\sigma_y - V_b) - 2F_b - 2(D_1+1)\overline{\pi_c}q_i}{D_1(\alpha^2\overline{Y_b}^2G^2\sigma_e{}^2 + \overline{P_b}^2\sigma_y{}^2 + \sigma_b{}^2\sigma_y{}^2 + W^2\sigma_y{}^2) - (D_1+1)\sigma_c{}^2} \equiv \lambda_6 \tag{A.9}$$

From (A.1), (A.2) and (A.3), we can see that a land leasing contract is chosen when the following condition is satisfied:

$$\lambda_i \ge Max\{\lambda_1, \lambda_2, \lambda_3\} \tag{A.10}$$

From (A.4), (A.5) and (A.6), we find that a fixed price contract is chosen when the following condition holds:

$$\lambda_4 \le \lambda_i \le Min\{\lambda_1, \lambda_5\} \tag{A.11}$$

From (A.7), (A.8) and (A.9), we see that a revenue sharing contract is chosen when the following condition is true:

$$\lambda_i \le Min\{\lambda_2, \lambda_4, \lambda_6\} \qquad \text{(A.12)}$$

These three contract selection conditions (A.10-A.12) underlie Result 4. They are also graphically illustrated in Figure 1.

We equalize the utility from each contract and conventional crops and derive the boundary conditions for the leasing rate (ω), fixed price rate ($\overline{P_y}$) and revenue sharing rate (α), then we calculate the derivatives with respect to the risk parameters and landowner risk and time preferences analyzed in Table 2. The derivations in Columns 1, 2 and 3 in Table 2 underlie Results 1, 2 and 3 in the paper. With the exception of the signs of the expressions in the last row of Table 2, the other expressions in columns 1 and 2 can be readily signed as shown for a risk averse landowner with $\lambda_i > 0$ and $\rho < 0$.

To obtain the signs for the expressions in column 3 in Table 2, we need to show that the denominator is positive. We derive that from the expression in (A.8) as follows:

From A.8, it follows that $\lambda_i \le \dfrac{2\alpha \overline{P_e} G \overline{Y_b} - 2\overline{P_y}\,\overline{Y_b}}{\alpha^2 \overline{Y_b}^2 G^2 \sigma_e^{\,2}} \equiv \lambda_4$

$$\lambda_i < \frac{2\alpha \overline{P_e} G \overline{Y_b}}{\alpha^2 \overline{Y_b}^2 G^2 \sigma_e^{\,2}} < \frac{\alpha \overline{P_e} G \overline{Y_b}}{\alpha^2 \overline{Y_b}^2 G^2 \sigma_e^{\,2}} = \frac{\overline{P_e} G \overline{Y_b}}{\alpha \overline{Y_b}^2 G^2 \sigma_e^{\,2}} \qquad \text{(A.13)}$$

After re-arranging terms, we derive that $\overline{P}_e G \overline{Y}_b - \lambda_i \alpha \overline{Y}_b^{\,2} G^2 \sigma_e^{\,2} > 0$, which implies the denominator in column 3 is positive.

To show the sign of $\partial \Psi / \partial r$ in the last row, we need to show below that the numerators of the three expressions in the last row of Table 2 are positive.

From (A.2) $\lambda_i \ge \dfrac{2D_1(\alpha \overline{P_e} G \overline{Y_b} + \rho \sigma_b \sigma_y - V_b) - 2F_b - 2(D_1+1)\omega}{D_1(\alpha^2 \overline{Y_b}^2 G^2 \sigma_e^{\,2} + \overline{P_b}^2 \sigma_y^{\,2} + \sigma_b^{\,2}\sigma_y^{\,2} + W^2 \sigma_y^{\,2})} \equiv \lambda_2$

Using the definition of σ_2^2 from above, we can write this expression at the boundary as:

$$D_1\lambda_i\sigma_2{}^2 = 2D_1(\alpha\overline{P_e}G\overline{Y_b} + \rho\sigma_b\sigma_y - V_b) - 2F_b - 2(D_1+1)\omega \qquad \text{(A.14)}$$

We then arrange terms to obtain the following condition:

$$(\alpha\overline{P_e}G\overline{Y_b} + \rho\sigma_b\sigma_y - V_b) - \frac{\lambda_i}{2}\sigma_2{}^2 - \omega = \frac{F_b+\omega}{D_1} \qquad \text{(A.15)}$$

This implies that for $0 < r < 1$, $T > 1$ and $D_2 < 0$, we obtain the following:

$$\frac{\partial\omega}{\partial r} = \frac{\alpha\overline{P_e}G\overline{Y_b} + \rho\sigma_b\sigma_y - V_b - \frac{\lambda_i}{2}\sigma_2{}^2 - \omega}{D_1+1}D_2 < 0 \qquad \text{(A.16)}$$

Similarly, from (A.4) we have:

$$\lambda_i \le \frac{2D_1(\overline{P_y}\overline{Y_b} + \rho\sigma_b\sigma_y - V_b) - 2F_b - 2(D_1+1)\omega}{D_1(\overline{P_b}^2\sigma_y{}^2 + \sigma_b{}^2\sigma_y{}^2 + W^2\sigma_y{}^2)} \equiv \lambda_1$$

At the boundary, this condition can be written as

$$D_1\lambda_i\sigma_1{}^2 = 2D_1(\overline{P_y}\overline{Y_b} + \rho\sigma_b\sigma_y - V_b) - 2F_b - 2(D_1+1)\omega \qquad \text{(A.17)}$$

We then re-arrange terms to obtain the following:

$$(\overline{P_y}\overline{Y_b} + \rho\sigma_b\sigma_y - V_b) - \frac{\lambda_i}{2}\sigma_1{}^2 - \omega = \frac{F_b+\omega}{D_1} > 0 \qquad \text{(A.18)}$$

With $0 < r < 1$, $T > 1$ and $D_2 < 0$, we obtain the following:

$$\frac{\partial\overline{P_y}}{\partial r} = -\frac{\overline{P_y}\overline{Y_b} + \rho\sigma_b\sigma_y - V_b - \frac{\lambda_i}{2}\sigma_1{}^2 - \omega}{D_1\overline{Y_b}}D_2 > 0 \qquad \text{(A.19)}$$

Lastly, from (A.7): $\lambda_i \le \dfrac{2D_1(\alpha\overline{P_e}G\overline{Y_b} + \rho\sigma_b\sigma_y - V_b) - 2F_b - 2(D_1+1)\omega}{D_1(\alpha^2\overline{Y_b}^2G^2\sigma_e{}^2 + \overline{P_b}^2\sigma_y{}^2 + \sigma_b{}^2\sigma_y{}^2 + W^2\sigma_y{}^2)} \equiv \lambda_2$

At the boundary, the condition is:

$$D_1\lambda_i\sigma_2^{\ 2} = 2D_1(\alpha\overline{P_e}G\overline{Y_b} + \rho\sigma_b\sigma_y - V_b) - 2F_b - 2(D_1+1)\omega \qquad \text{(A.20)}$$

We then arrange terms to obtain:

$$(\alpha\overline{P_e}G\overline{Y_b} + \rho\sigma_b\sigma_y - V_b) - \frac{\lambda_i}{2}\sigma_2^{\ 2} - \omega = \frac{F_b + \omega}{D_1} > 0 \qquad \text{(A.21)}$$

With $0 < r < 1$, $T > 1$ and $D_2 < 0$, we can prove that

$$\frac{\partial\alpha}{\partial r} = -\frac{\alpha\overline{P_e}G\overline{Y_b} + \rho\sigma_b\sigma_y - V_b - \frac{\lambda_i}{2}\sigma_2^{\ 2} - \omega}{D_1(\overline{P_e}G\overline{Y_b} - \lambda_i\alpha\overline{Y_b}^2G^2\sigma_e^{\ 2})}D_2 > 0 \qquad \text{(A.22)}$$

A.2 Condition that the spot market is a dominated choice

The profit from the spot market can be represented by

$$\pi_{st} = \begin{cases} -F_b & if\ \ t=1 \\ (P_{bt} - W)(\overline{Y_b} + \varepsilon_{yt}) - V_b & if\ \ t = 2,...,T \end{cases} \qquad \text{(A.23)}$$

The utility derived from spot market choice is:

$$\sum\nolimits_{t=2}^{T}\left(\frac{1}{1+r}\right)^{t-1}(\overline{P_b}\overline{Y_b} + \rho\sigma_b\sigma_y - \overline{Y_b}W - V_b) - F_b - \sum\nolimits_{t=2}^{T}\left(\frac{1}{1+r}\right)^{t-1}\left(\frac{\lambda_i}{2}\right)(\overline{P_b}^2\sigma_y^{\ 2} + \sigma_b^{\ 2}\sigma_y^{\ 2} + W^2\sigma_y^{\ 2} + \overline{Y_b}^2\sigma_b^{\ 2})$$

We compare this utility with the utility level a landower can derive from a fixed price contract and find that the volatility of spot market is larger than for a fixed price contract. If the biorefinery can provide a fixed price which is higher than $\overline{P_b} - W$, risk averse landowners will choose a fixed price contract instead of spot market. This condition is incorporated in the biorefiney's profit maximization problem. Similarly, we can prove that the revenue sharing contract is also superior to the spot market contract if the following conditions are met:

$$\frac{\overline{P_b}}{\overline{P_e}G} < \alpha < \frac{\sigma_b}{G\sigma_e} \qquad \text{(A.24)}$$

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Endnotes:

[1] Our analysis differs from the studies analyzing optimal contracts or policies under asymmetric information that use mechanism design to determine individual specific contracts/policies that give farmers the incentive to truthfully reveal their private information (Peterson and Boisvert 2004).

[2] This has led studies to suggest that energy crops should be grown on low quality idle/fallow land to avoid diverting cropland from food/feed production (Gelfand et al. 2013). The analysis here could be readily extended to include idle land with a net return and variance of return of zero. The general framework presented below allows us to derive implications for this special case which are discussed in the concluding section.

[3] For simplicity, we assume that size of the region is small enough such that the transportation cost of delivering biomass to the refinery within the region is negligible. But there is a cost w per ton of transporting biomass to and from the spot market, which consists of a centralized biomass storage unit.

[4] A farmer with a given level of risk aversion may own one or more parcels with different land qualities. For simplicity we assume that the level of risk aversion is not related to farm size and that a farmer makes a decision about each land parcel independently.

[5] This assumption is for simplicity; the framework above could be easily extended to consider a risk-averse refinery and to determine an efficient contract that will share risks between the landowners and the refinery based on their risk preferences. All implications of the above model will hold as long as the risk aversion of the refinery is less than that of the landowners. This may be reasonable because the refinery may have a more diversified portfolio as compared to the landowner.