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Contract Theory and Implications for Perennial Energy Crop Contracting

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Abstract

This article provides an overview of modern contract theory and discusses the implications of the theory for contracting for perennial dedicated energy crops. We discuss some of the unique challenges of contracting for dedicated energy crops used for the production of advanced biofuels and survey some of the relevant concepts and research from the contract theory literature to address these challenges. We focus primarily on the “mechanism design” or “complete contracts” approach to contracting, which involves optimizing some objective function (e.g. profits, costs, etc.) with respect to contract terms, subject to important incentive constraints. The solution to these optimization problems typically highlight important tradeoffs that a contract designer needs to consider in order to maximize profits and/or minimize costs.

1. Introduction

Over the last ten years, surges in fuel prices and concerns over carbon emissions have induced increased political and economic support for research and investment in alternative energy in the U.S. Over the last few years in particular, the U.S. biofuels industry has experienced significant growth spurred on in part by renewable fuel mandates that promulgate the use of biofuels. This growth in biofuels production has primarily occurred through corn-based ethanol. Using corn as a feedstock for ethanol production, however, is not without its limitations. First, existing supplies of corn do not have enough potential to meet current domestic energy demand. In 2005, the combined energy potential of the entire U.S. corn crop only accounted for 9% of the embodied energy of U.S. net crude oil imports (Epplin et al. 2007). Second, there might be alternative feedstocks that yield relative reductions in greenhouse gas (GHG) emissions, suggesting that it may be more desirable for future growth in biofuels production to be derived from alternative feedstocks that fall into the category of advanced biofuels (Koonin 2006). U.S. energy policy has already moved in this direction, mandating that production of advanced biofuels grow to 21 billion gallons per year by 2022 through the renewable fuel standard (RFS).

Advanced biofuels are defined as biofuels derived from renewable sources other than corn starch. Cellulosic biofuels are a specific subset of advanced biofuels created from cellulose, hemicellulose, or lignin derived from renewable sources. Sources for advanced and cellulosic biofuels range from wood wastes, to crop residues, to dedicated energy crops such as miscanthus, a perennial grass that shows potential to serve as an energy crop due to its rapid growth and potentially high biomass yield. To meet current mandates for advanced biofuels, production will ultimately need to be derived from a variety of feedstocks including dedicated energy crops. Nonetheless, there are significant barriers to commercial viability of dedicated energy crops today. Firms interested in investing in biorefineries face tremendous uncertainty about the costs of biomass feedstocks over time. A significant determinant of a biorefinery's cost will be how much the refinery has to pay farmers to produce, harvest, store and/or deliver biomass. One way to manage this uncertainty is through contracts between biorefineries and farmers which could enable both parties to undertake the necessary investment for commercial scale production of advanced biofuels.

This article provides an overview of modern contract theory and highlights the most relevant aspects of the theory for designing contracts that are "optimal" in the sense that they can minimize the costs of sourcing an adequate supply of biomass feedstock from perennial dedicated energy crops. Contract theory is an active area of research and the literature is vast, making it impossible to cover the entire field in one survey article. Moreover, there are methodological divides between those who advocate the "complete contracts" versus the "incomplete contracts" approaches to contract theory (Tirole 1999; Hart and Moore 1999; Maskin 2002). Thus, one of our goals for this article is to provide a synthesis of concepts that might be useful to applied and academic economists for conceptualizing contract design issues related to dedicated energy crops. In order to reach a broad audience, we do not rely heavily on mathematics and discuss the theory with constant reference to practical problems that a biorefinery might face. While this article is light on mathematics, we try to remain true to the spirit of the theory by preserving the logic and intuition of the models in our discussion. Our discussion of the theory will also be biased toward the "complete contracts" approach which is based on implementation theory or mechanism design. We chose this bias because mechanism design is primarily concerned with contract or incentive design, which is the focus of this article.[1]

According to the academic literature, contracts are written because there are transactions costs, information barriers or lack of standardization that precludes the existence of well-functioning markets. As such, contracts tend to be highly specialized and transaction specific so

[1] Had we had a different focus for this paper, such as explaining vertical integration issues or the problem of asset allocation, we might have chosen to focus on the incomplete contracts approach.

standardization will be the exception rather than the rule. Given the specific nature of a typical contract, it is very difficult to evaluate the economic virtues of a contract by using empirical studies that are based on cross-section comparisons of different contracts. Consequently, the design of effective contracts cannot rely on surveys or case studies alone, but should also be grounded in good theory, which provides general principles for determining whether insights gathered from one setting can be generalized to new settings.

The mechanism design or the "complete contracts" approach relies on the *Revelation Principle* (Myerson 1981). The Revelation Principle essentially states that, to design an optimal contract, the designer only has to optimize her objective function subject to *incentive compatibility constraints*. An optimal contract is one that maximizes (or minimizes) some objective function, whether it be profits, costs, etc. Alternatively, one can think of an optimal contract as one that allows a biorefinery to achieve productivity goals (e.g. yield or quality targets) at minimum cost. While the Revelation Principle and the concept of incentive compatibility are usually presented rather abstractly in the research literature thereby making these concepts difficult to grasp even for well-trained economists, we try to illustrate these concepts using simple explanations and examples.

Incentive compatibility typically refers to the idea that well-designed contracts will contain good incentives. For example, to motivate farmers to meet certain quality or yield objectives, a contract might contain performance bonuses for meeting these objectives. However, if the incentives are weak so that the bonuses fail to cover the increased costs of meeting objectives, then it may not make economic sense for a farmer to produce the extra quality or yield. Thus, the contract fails to be incentive compatible. Incentive compatibility constraints are set up specifically to ensure that a farmer operating under the contract has more to gain by meeting the contract objectives and thus producing at the biorefiner's target specifications.

The Revelation Principle states that the contract designer can obtain an optimal contract simply by choosing contract terms that maximize the biorefinery's profit (or minimizing the biorefiner's cost) subject to incentive compatibility constraints. A contract that satisfies this simple criterion is optimal. Even if one were to devise excessively fancy and complex schemes, it would not be possible to find a contract that can outperform the incentive compatible optimal contract. Thus, the Revelation Principle has tremendous practical usefulness because it reduces the set of contracts that need to be considered when one is searching for optimal contracts. We will highlight the important economic insights and principles that emerge from solutions based on the Revelation Principle.

While incentive compatibility constraints ensure that the contract will contain adequate pay-for-performance provisions, the biorefinery also has to design a contract that farmers will accept, meaning that the contract must also satisfy a *participation constraint*. The participation constraint requires that the contract compensate the farmer in such a way that his/her payoff from producing the energy crop will be at least as high as the payoff from the next best use of the land. Participation is a critical issue for dedicated energy crops as farmers have expressed concerns about signing contracts for crops that have little commercial history and face significant market, technological and logistical uncertainties (Alexander, et. al. 2010).

Because a biorefinery plant is expensive to build, it is critical that a steady supply of feedstock can be guaranteed for a sufficiently long period of time (e.g. ten or more years). This means that biomass feedstock contracts will have to be long term contracts. Over a long enough time horizon, market conditions and technological uncertainties could change how the parties value the contract. These changes increase the likelihood that either the refinery or farmers will attempt to renegotiate or default on the agreement. To reduce the likelihood of default, contracts must also contain incentives for both parties to stick to their agreements in the face of adverse market conditions and discourage them from renegotiating the contract. If parties expect that the contract will be renegotiated, then it erodes the credibility of the initial contract. Therefore, an optimal contract should be credibly enforceable and *renegotiation proof*.

Enforceability of a contract over a long period can also be problematic. Contract law and arbitration work imperfectly. As a consequence it is rare in practice to have all the important aspects of performance be governed by a legalistic contract. Real world contracts typically involve a mixture of legalistic components along with tacit expectations, verbal agreements and implicit understandings. These types of contracts are called *relational contracts* in the economics literature.

Participation constraints, incentive compatibility constraints, renegotiation proof constraints, and relational contracting form the bedrock of modern contract theory. They also have substantial practical implications for the design of cost-minimizing supply contracts. In this overview paper, we will discuss each of these concepts in detail and provide a rationale for why they are important for structuring biomass contracts. However, we will begin with an overview of some unique challenges that biorefineries are likely to face when sourcing biomass feedstock from perennial dedicated energy crops.

2. An Overview of Issues Related to Contracting for Perennial Energy Crops

This section discusses some of the unique contracting issues that are specific to many perennial dedicated energy crops.   We will build our discussion around Miscanthus, a warm season perennial grass that has the potential to serve as a dedicated energy crop. Miscanthus provides a good case study as it has not been widely adopted and therefore faces the challenges of commercialization.

Commercial-scale production of miscanthus, and that of all dedicated energy crops, has significant obstacles to overcome. In particular, an efficient supply chain that can procure biomass in an economically cost effective manner is crucial for producing advanced biofuels (Yoder 2010). One 50 million gallon biofuel plant is estimated to require more than 700,000 DM tons of biomass annually to operate at capacity (Tiffany 2007). Besides obvious issues such as creating an efficient transportation system and adapting equipment to suit the characteristics of miscanthus, farmers will require incentives to produce large volumes of the crop. Consequently, finding ways to incentivize farmer investment in miscanthus will be crucial to the development of the industry.

At the same time, the lifecycle of miscanthus is unique in comparison to alternative commercial row crops. In particular, miscanthus is a perennial grass with a ten year lifecycle of which the first two years are spent establishing the crop. This creates significant risk for the farmer who faces a decision to invest in a crop that will not generate significant revenue until the third year. Considering the risk and uncertainty that farmers face, it's clear that inducing farmers to invest will require a contractual arrangement between the farmer and plant that adequately addresses risk (Yoder 2010). Finally, in some cases, farmers may use third-parties to do some of their planting and harvesting work (also known as "custom work") due to high opportunity costs and/or the lack of economies of scale from having the wrong equipment set. In this case, farmers must pay the going "custom rates" for specific tasks and services that they custom hire. Contractual payments must be sufficient to cover either specialized equipment purchases or custom rate expenditures. These considerations typically tighten farmers' participation constraints as they raise the costs of inducing farmers to accept contracts for dedicated energy crops.

Alexander et al. (2010) conducted focus groups which indentified additional barriers to farmer adoption of miscanthus. Several groups of farmers were asked whether they are willing to produce miscanthus under contract. The major points that were raised included:

a) Producer unfamiliarity with a new crop such as Miscanthus, including lack of information about cultural practices, logistics, initial investment and new equipment purchases, costs of variable inputs, expected yields and variability of yields, and crop quality expectations.
b) Ensuring profitability and return on investment both long term and year-to-year.
c) Complementaries in cultural practices and harvest timing between the new energy crop and existing high valued crops.
d) Quality maintenance under storage. For example, if stored bales pick up moisture, how is the grower penalized (if at all)?
e) Commitment issues under a long term contract. The miscanthus life-cycle is ten years. This raises serious concerns about counter-party risk or renegotiation issues as conditions under which the contracts were formed may become obsolete. Growers expressed concern that contracts have built in flexibility to accommodate changes in input, output and competing crops markets. Additionally, there is concern that ethanol plants might go out of business during the course of a ten year contract.
f) Concern about returns during the initial establishment period where yields are low or non-existent.
g) Concern about the cost of initial establishment via investment in new equipment and/or rhizomes. Here credit constraints matter.
h) Preference for payment indexing to output and input prices. At the same time, the index prices should be transparent and easy to understand.

Many of the points raised above translate directly to terms within the participation/incentive compatibility constraints framework. For instance, points (a), (b), (c), (f), and (g) are all related to farmers' willingness to engage in miscanthus contracting which can be captured by the participation constraint. At the same time, quality considerations such as (d) or biorefineries' preference for biomass with low moisture content are issues related to incentive compatibility. Creating strong incentives typically increases uncertainty and risk for farmers which raises production costs and makes it more difficult to satisfy the participation constraints. Weaker incentives imply a less demanding contract but farmers are more willing to participate. Thus, conceptualizing these issues within the participation/incentive compatibility constraints framework allows us to quickly recognize the key tradeoff: relaxing the participation constraint typically implies a tightening of incentive compatibility and vice versa. Optimal contracts balance this tradeoff in such a way that the marginal benefit of relaxing one constraint is balanced against the marginal cost of tightening the other constraint.

3. Important Terms and Concepts in Modern Contract Theory

In the introduction, we mentioned that participation constraints, incentive compatibility, renegotiation proof constraints, and relational contracting form the bedrock of modern contract theory. To put these concepts into the proper context, we begin with a brief overview of how economists think about contracting problems. Economists model contracting problems using what is called a "principal-agent" framework. A principal is the party who designs and proposes the contract; an agent is the contractee, who either accepts or rejects the contract proposed by the principal. In some cases, there is mutual bargaining, but for many agricultural problems, processors or biorefineries typically make take-it-or-leave-it offers to growers. The principal-agent model is the appropriate model for conceptualizing take-it-or-leave-it offers, although the existence of collective bargaining would require us to model the bargaining process as well.

An important function of a contract is to overcome what economists call an *agency problem* where there is a conflict of interest between the principal and the agent. For example, the principal may want the agent to grow and harvest large quantities of high quality feedstock but this generally raises production costs to the agent. The agent would prefer to minimize on costs, all else being equal. A contract can be designed to include adequate incentives to align the agent's goals with the principal's goals.

Agency problems are exacerbated if both parties to a contract have different or incomplete information. Economists use the term asymmetric information when one party to a contract knows more information than the other party.   If the agent possesses more information than the principal, the principal will often design a contract that induces the agent to reveal this information. Revealing the otherwise private information allows the contractor to better match payments to quality and yield, which strengthens incentives for both participation and the production of high quality.

There are two types of private information problems: *moral hazard* and *adverse selection*. Moral hazard refers to a situation where the contractee (agent) knows more about his own actions than the contractor (principal). For example, under moral hazard, the principal cannot observe many of the agent's actions and must rely on the agent's "word" that he has undertaken practices that assure high yield and quality (efficient production). When yield and quality are affected by other random factors (e.g. weather), it is virtually impossible to know whether performance shortfalls are caused by poor weather or lack of good practices. A contract must therefore contain adequate incentives to induce the agent to use good practices but at the same time, not punish the agent excessively for poor performance caused by random factors beyond the agent's control.

Adverse selection, on the other hand, refers to the situation where the agent knows more about certain characteristics of the crop, production conditions, and/or innate characteristics of the agent himself. For example, growers might differ in their willingness to tolerate risk. Risk tolerant growers might be willing to accept more fluctuation in contract price in exchange for a higher average contract price. These risk tolerant agents would be willing to accept a contract with more powerful performance incentives. Conversely, risk averse growers will want more stable contract prices and are more willing to accept lower average returns in return for price stability. They would be reluctant to accept contracts that involve strong performance incentive.

Under adverse selection, it is difficult for the principal to calibrate the correct level of incentives, indexing, and risk premium for each grower. For example, if the principal under-calculates the risk premium, then the agent may reject the contract and no trade will occur. Over-calculating the risk premium, however, means that the principal is paying a higher price than necessary to contract, which unnecessarily increases the principal's costs. The challenge is then for the principal to design a contract that provides just the right incentives for growers with different risk profiles to select a contract that is best suited for them.

In general, biorefineries and farms that are large and well diversified will tend to be better positioned to accept more risk; they might be considered "risk-tolerant" with respect to any one enterprise, such as producing a dedicated energy crop. On the other hand, smaller operations or individuals will tend to be more risk averse as there is not much diversification potential. For example, the major source of income for most workers is their labor income, and it is difficult to diversify this. Hence, employees tend to be more risk averse than large businesses that are well diversified. Beyond the ability to diversify, certain individuals and companies simply have low risk tolerance in which case a high risk premium would have to be paid to get them to accept an incentive contract.

Finally, it is important to note that there are separate forms of incentive compatibility constraints for dealing with moral hazard and adverse selection problems. Subsequent sections will detail these differences.

4. Moral Hazard and Pay for Performance Contracts

The literature on contract theory emerged to propose solutions to moral hazard problems. Classic articles on contract theory discussed the usefulness of pay-for-performance incentive contracts for mitigating moral hazard problems (Holmstrom 1979; Holmstrom 1982; Grossman and Hart 1983). In technical terms, pay-for-performance provides "incentive compatibility" by giving agents the proper incentives to do what the principal wants the agent to do. For instance, the farmer's goals of minimizing her costs often conflict with the refinery's goal of generating the highest yield with the least amount of moisture. Hence, to align the goals of the refinery and the grower, pay-for-performance incentives must be provided to achieve "incentive compatibility" between the refinery and the grower. In general, more powerful incentives (e.g. strong pay-for-performance incentives) induce greater incentive compatibility. Pay-for-performance contracts offer high payments for high performance and low payments for low performance so that the agent has an incentive to work hard to realize the high performance outcome. However, pay-for-performance contracts are risky for the agent because her payment can be tied to factors outside of her control. A fundamental lesson from this literature is that there is always a tradeoff between risk and incentives. Productivity gains for the principal from offering pay-for-performance incentives must be weighed against the cost of having to pay the agent a "risk premium" to entice her to accept a risky incentive contract. An optimal pay-for-performance contract maximizes performance while minimizing costs. This occurs when the incremental gain from introducing the pay-for-performance plan equals or exceeds the incremental increase in the risk premium.

As mentioned earlier, the participation constraint works against incentive compatibility. When the principal strengthens pay-for-performance incentives, this increases the agent's risk exposure and makes her participation constraint more difficult to satisfy. That is, an agent is more likely to reject a contract that contains excessive pay-for-performance payments. As a consequence, a well-designed contract must account for both incentive compatibility and participation constraints.

To illustrate, consider an example of a refinery that contracts with a farmer to produce biomass. The refinery may want to offer the grower a pricing schedule dependent on yields so that the grower is rewarded for "high" yield and punished for "low" yield. This enhances incentive compatibility of the contract. Yield, however, is also subject to factors beyond the grower's control (e.g. poor weather). If the payments are too dependent on yield, then the grower may be reluctant to accept the contract unless the processor offers a "risk premium" to raise the average payoff from the contract. That is, the cost of "stronger" incentives is a higher risk premium and the contractor should find the right balance to maximize his own profits. The "right balance" usually implies that the incremental gain from strengthening incentives a little bit is just offset by the incremental increase in risk premium from strengthening incentives. If a contractor does not bear this tradeoff in mind, then naively implementing pay-for-performance schemes will induce the grower to reject the contract.

These insights have implications for the design of contracts that tie payments to acres versus yields. Acreage contracts protect the farmer's revenue from random fluctuations in yield (relaxing the participation constraint) but provide weak incentives for farmers to engage in yield maximizing activities (weaken incentive compatibility). On the other hand, yield contracts provide stronger incentives to maintain high yield, but are more risky to farmers. Thus, when deciding between an acreage versus a yield contract, it is important for the contractor to assess whether the marginal incentive gains from a yield contract will offset the margin risk premium savings from an acreage contract.

It is important to note that a more random production environment may also imply that it is more costly to provide pay-for-performance incentives. This is because risk premiums are also a function of the volatility of the production environment. Thus, in regions where farmers face greater yield uncertainty, it may simply be too costly to provide performance incentives. In this case, pay-for-performance contracts might be replaced with production contracts which incorporate more hands-on management and control of the production process by the refinery.

The general lessons of this section are:

1. There is a tradeoff between strong pay-for-performance incentives and risk premiums. Implementing strong incentives means that higher average payments must be promised to the grower or the grower will reject the contract. This has implications for acreage versus yield contracts.
2. In highly volatile environments, it may not be cost effective to use pay-for-performance incentives. Farmers will reject contracts unless a very large risk premium is provided. It may be more effective to use production contracting with input control, monitoring, and joint management of production and harvesting.

5. Multiple Tasks, Pay-for-Performance, and Incentive Conflicts

Incentive conflicts can occur when the principal cares about more than one performance factor. For example, a biorefinery may want high yield but at the same time, want to control the carbon footprint due to uncertainty about potential future regulations. Maximizing yield would increase farming intensity, incentivize increased emission of greenhouse gases, and lead to potentially higher future costs.

Incentive conflicts fall under the category of *multi-task principal-agent* models (Holmstrom and Milgrom 1991). Holmstrom and Milgrom made the following important points:

- If tasks are independent of each other (no substitution or complementary effects), then there no need to worry about incentive conflicts.
- If tasks are complements, then rewarding one task will indirectly incentivize other complementary tasks. For example, yield incentives will also induce growers to use efficient harvest methods.
- If tasks are substitutes, then there are incentive conflicts. Then the contract must,
  a) Balance incentives so that one task is not rewarded significantly more than another task.
  b) Weaken incentives for both tasks or eschew pay-for-performance altogether and use production contracting where the contractor is more involved in the production process.

With regard to (b), one way to weaken pay-for-performance incentives without eschewing them altogether is to have a bonus or penalty be triggered only in unusual circumstances. For example, if there is a conflict between yield and carbon credits, one can provide a penalty that is triggered only if a minimum yield threshold is breached. Alternatively, if the contract price is tied to a price index, the contract could provide for a yield bonus that becomes active only when the price index becomes unusually low.   This would incentivize the grower not to divert resources away from the energy crop due to low prices.

6. Adverse Selection and Screening contracts

Recall that adverse selection refers to the situation where the agent has more information about specific characteristics of the production process, crop, or the agent's own attributes than the principal. This problem was first studied by George Akerlof, who was awarded the Nobel Prize in economics for his analysis of adverse selection problems (Akerlof 1970). Akerlof's basic insight was that with adverse selection, the quantity and quality of trade can be severely impaired possibly leading to market collapse. Trade can breakdown because buyers do not have sufficient information to properly value the good or to offer a price that adequately captures the seller's cost of production. In this case, buyers might over- or underpay for a product. The fear of over-paying causes buyers to withdraw offers from the marketplace.

Economists have since devoted considerable attention to the study of pricing or contractual mechanisms that can be used to address adverse selection problems. One such mechanism is a *screening contract,* where the principal creates a menu of contracts that differ in their pricing and quantity requirements. A well-designed menu can induce heterogeneous agents to voluntarily choose the contract that is best suited for them, thereby mitigating the adverse selection problem. In other words, screening contracts can create good matches between buyer and seller or buyer and product even when the buyer does not have full information. Screening contracts have been studied by a number of economists since the seventies (Rothschild and Stiglitz 1976; Wilson 1977; Mussa and Rosen 1978; Maskin and Riley 1984; Maskin and Tirole 1992; Gonzalez

2004; Liu and Browne 2007; Dai 2008; Araujo, Gottlieb, and Moreira 2009). Rothschild and Stiglitz received the Nobel Prize in economics for their work in this area.

To illustrate how screening works, consider the case where growers are heterogeneous in their degree of risk tolerance. To keep things simple, suppose there are two types of growers (agents): a risk tolerant type and a risk averse type. Also suppose that the manager of the biorefinery is risk averse and would like to mitigate risk as much as possible for planning purposes. Now consider the problem of whether the refinery should tie the contract price to an index. For simplicity, let's assume that the chosen index is the price of an alternative crop produced by the farmer, say corn. Since corn is might be the next best alternative to producing the energy crop, returns from corn represent an opportunity cost for the farmer. Thus, an index on corn operates like an input cost index. In other words, when corn prices go up, the farmer's opportunity cost increases but if contract payments are indexed to corn prices, the farmer is hedged. Thus an input index reduces the variability of economic profits.

Note that the most natural tendency is for a refinery to either offer a fixed payment contract that is not indexed or a perfect index contract which provides a contract payment that moves 1-to-1 with the corn price. That is, a 1% change in the corn price will result in a 1% change in the contract payment to the grower. If the biorefinery had perfect knowledge of the grower's level of risk aversion, then the solution is simple. Offer a fixed price contract to the risk tolerant grower and an *imperfect* index payment to the risk averse grower. To understand the logic, note that a risk tolerant grower does not require a risk premium to bear risk as he is indifferent to risk. On the other hand, the manager of the biorefinery is risk averse and therefore has a positive risk premium. Then the optimal contract should be a contract that minimizes the biorefinery's risk exposure. This is because any contract that exposes the biorefinery to risk will provide strong incentives for the manager to divert resources toward managing that risk. For example, the manager might be willing to purchase insurance up to the level of her risk premium to insure its risk. This ultimately reduces profitability. The contract that minimizes the biorefinery's risk exposure is a fixed payment contract that is not indexed to any random variables. On the other hand, the risk averse grower does care about risk and is willing to pay a risk premium to avoid risk. Therefore, the optimal contract should involve risk sharing between the grower and the biorefinery plant to minimize their combined risk premia. Note that the optimal contract cannot be the perfect 1-to-1 corn price index as this would eliminate only the risk averse grower's risk premium, leaving the risk averse biorefinery to absorb all the risk. Instead the strength of the index should be proportional to the relative risk aversion of the grower and the biorefinery. For example, if the two parties are equally risk averse, then for a 1% movement in corn price, the contract payment should only move by 0.5%. This minimizes the combined risk premiums of both parties by having each party bear half of the total risk.[2]

Things become more complicated when each grower's degrees of risk aversion is private information. The biorefinery cannot target a contract at a specific grower. Offering a fixed price contract may mean that, if the grower is risk averse, the grower will reject the contract. Offering the imperfect index contract may mean that the refinery is bearing more risk than necessary when contracting with the risk tolerant grower. Either scenario leads to sub-optimal outcomes which potentially reduces profits for the biorefinery. The optimal strategy then is to offer a screening contract.

Under a screening contract, the biorefinery would offer a menu of two different contracts to every grower. Contract A should contain no indexing and contract B should include an index on corn price. Note that the risk averse grower has a natural incentive to accept the index

[2] The perfect 1-to-1 index would be optimal however, if the biorefinery is risk neutral and the grower is risk averse.

contract as it prefers to hedge its input cost risk. Thus, the risk averse grower will likely be matched to the right contract. To ensure that the risk neutral grower accepts the fixed payment contract, recall that risk neutral growers only care about expected profits and not risk. Hence, the biorefinery must design the contract in such a way that the risk neutral grower's expected profit from choosing the fixed payment contract just exceeds the expected profit from the index contract. The requirement that the risk neutral grower's expected profit is higher under the contract meant for him is the "incentive compatibility" constraint for adverse selection, screening contracts. The refiner sees two major gains from trade by offering the screening contract:

1) The screening contract induces growers to "choose" the right contract and therefore induces more contract acceptance by growers. This makes it possible to contract with more growers.
2) The average amount of risk borne by the biorefinery is much smaller which means that a risk averse refinery has to divert fewer resources toward risk management. This saves the biorefinery money.

While our two-type grower example is relatively simple, the screening principle can generalize to a large number of heterogeneous growers. If there are N-types of growers with N-levels of risk aversion, then the refinery might offer N-different contracts to try to match each grower to the right contract. Unfortunately, as the size of the menu expands, the problem becomes far more complicated. Therefore, at some point, there might be an optimal menu size that segregates growers by risk preference classes rather than to try to match each individual grower to exactly the right contract. Currently, the economics literature does not offer insights into the optimal tradeoff between optimality and complexity of contract, which represents an opportunity for new research.

It is important to emphasize that, regardless of the size of the menu, the entire menu needs to satisfy "incentive compatibility" constraints for adverse selection. In simple terms, this means that each type of grower should choose the contract targeted toward the grower rather than to prefer a contract meant for another grower. Revisiting our two-type grower example, the two contracts must be constructed in such a way that the risk tolerant grower should not prefer the contract meant for the risk averse grower. That is, the risk tolerant grower should not choose the index contract over the fixed price contract. To insure this, the contract designer might start by specify the minimum payment required to induce the risk averse grower to accept the index contract. This minimal payment would represent the minimum cost of inducing the risk averse growers to participate. And then the payment on the fixed payment contract can be raised to induce the risk tolerant grower to accept the fixed payment contract. This typically means that the risk tolerant grower will earn excess profits, which is called *information rents* in the contract theory literature. These information rents are necessary to induce the risk tolerant type to "reveal" the fact that he is risk tolerant by choosing the fixed payment contract. But the difference in expected pay across the two contracts should not exceed the risk premium demanded by the risk averse grower or there will be a reverse problem where the risk averse grower will prefer the fixed payment contract. The refinery can conduct break-even analysis or enterprise budgeting across the two contracts to ensure incentive compatibility. Note that we can again see a tradeoff between incentive compatibility and participation. Ensuring incentive compatibility requires that the profit to the risk tolerant grower be raised or the risk tolerant grower will reject the contract.

In addition to adjusting the strength of index, a screening contract can also adjust the quantity under contract, whether it's based on acres or yield. The risk premium is a function of both the index strength and the quantity produced under contract. Thus, adjusting quantity gives the contractor another variable for raising or lowering the risk premium and insuring incentive compatibility. The price index and quantity can be jointly chosen to ensure participation and incentive compatibility.

Note that the previous example applied to an input index. However, Alexander et al. report that some growers have expressed interest in output indexes based on the price of the biofuels that are produced with the feedstock. It is straightforward to derive the optimal output price index contracts using the Revelation Principle. The optimal output price index contracts specify that risk tolerant growers should receive strong indexing whereas risk averse growers should be matched to fixed payment or weakly indexed contracts. Thus, the results are reversed from the case of input indexes. Moreover, if instead of a pure output price index, one chooses an index that is both an output price and at the same time affects growers' input costs, then the optimal contract turns out to be a perfect index contract where the contract payment moves 1-to-1 with the index price. Moreover, this perfect index contract is optimal for all growers regardless of risk preferences. Biodiesel prices are one example of a hybrid output/input index.

Finally, while we have used heterogeneity in risk preferences to illustrate the concept of screening, one can screen across other variables besides risk tolerance. For example, farmers can be heterogeneous with respect to production costs, access to credit (so the contract can be designed to share both upfront investments and operating expenses), preference for autonomy, etc.

The key points of this section can be summarized as follows:

- Screening contracts are used to enhance cost efficiency by matching growers to the right contract.

- Screening avoids the problem of the principal having to "measure" the risk preferences of each grower. Instead, the principal only needs to have a general understanding of the range of risk tolerance levels in the population and then construct a menu around the population distribution.
- Screening contracts need to be incentive compatible. That is, each grower should choose the contract that is meant for him. To achieve this, the contracts must be designed in such a way that each grower type has the highest expected profit under the contract designed for that grower type.
- Contracts within a menu can be differentiated by the strength of indexing, the quantity under contract, and the average payments under contract. These variables can all be used to achieve screening and incentive compatibility.

7. Enforcement and Renegotiation-proof Contracts

As mentioned earlier, when the length of the contract extends to multiple years, this can raise serious concerns about counter-park risk as farmers might fear that biorefineries can go bankrupt before the contract ends. At the same time, biorefineries may be concerned that growers may be tempted to opt out of the contract if there are severe shocks to the prices of alternative crops. When contracts are extended to cover multiple harvest periods, then contracts have to be designed such that neither party wants to back out of the deal once it's signed. Suppose that a firm contracts with a group of farmers to grow Miscanthus for ten years. Two years later, the price of corn spikes and the farmers would like to replant their fields with corn to earn a higher profit per acre. Unless the contract has provisions to convince the farmers to stick with

Miscanthus, the firm will face losses from that harvest and future harvests until new farmer suppliers can be contracted.

At the time the contract is offered, neither party knows what the actual price of miscanthus will be, what the actual harvested quantities will be, or what their actual profits will be. So both parties make their decision to contract based upon their expectations for future prices, quantities, and profits. Over the course of a multi-period contract, however, both the principal and the agents learn more information. Both parties can use their common history of prices, harvests, and payments to update their individual expectations about future prices, harvests, and payments. Once they learn the new information, they may have strong incentives to renegotiate the original deal with a new contract that is more "efficient" given the new information. Over time, the parties will have a strong incentive to either breach or renegotiate the initial contract. While the problem of breach is obvious, the consequences of renegotiation are more subtle. If both parties know that a contract might be renegotiated, then it erodes the credibility of the initial contract. Hence, contractual credibility is an important aspect of designing long term contracts. Without credibility, the parties might be less willing to sign contracts in the first place. Thus, the lack of credibility can put pressure on participation constraints and erode ex ante incentives for parties to engage in trade.

To achieve this credibility, the principal must incorporate *renegotiation proofness* constraints (Dewatripont 1988; Dewatripont 1989; Laffont and Martimort 2002; Battaglini 2007; Bester and Strausz 2007). These constraints essentially force the principal to incorporate foreseeable renegotiation into the initial contract. For example, both parties can anticipate that extreme price movements will likely cause the parties to renegotiate the contract payments and/or to even breach the contract. Index contracts are a way of preempting renegotiation caused by adverse price movements and achieving a level of commitment about the rules that will determine how contract payments will respond to market prices. As such, the contract purposely builds in flexibility to preempt renegotiation. However, indexing to create flexibility with respect to market price movements does not necessarily remove the danger of counter-party risk. In fact, it may increase counter-party risk. For instance, if the contract is indexed to corn and corn prices spike, the biorefinery's total contractual payouts to farmers will increase reducing its profitability. If corn prices remain high for a sustained period of time, it could result in bankruptcy for the biorefinery. Thus, one way to mitigate counter-party risk is to place a collar or cap on contract price if corn prices move above a specified threshold. These collars reduce the flexibility of the contract to respond to market conditions, but decrease counter-party risk. Note that these collars may reduce the efficiency of the price index to adjust to market conditions, but they do mitigate anticipated counter-party risk which provides growers with stronger incentives to participate in the contract. Thus, the contract designer must balance these tradeoffs in an optimal way. As an alternative to price indexing, the parties can specify rules that allow a fixed contractual payment to adjust in response to new information. The fundamental insight from the literature on renegotiation and commitment is that there is always a tradeoff between ex ante efficient (incentives to participate in contracting or make efficient pre-contractual investments) and ex post efficiency (improving contract terms and decisions after the arrival of new information or the resolution of uncertainty).

While these are simple examples, more complex forms of renegotiation-proof incentives can be built into contracts at the beginning of a relationship. In summary:

- The fundamental issue with long term contracts is credibility.

- Contracts that cover multiple periods provide more common information to both principals and agents over time. Both parties can update their expectations about future choices and payoff based on actions taken in earlier periods. A contract can specify upfront provisions for how this information should be used to update payment terms.
- A renegotiation-proof contract provides incentives to the parties so that common information revealed during the course of the contract will not induce either party to break or renegotiate the contract.
- Contracts that do not build into the initial contract anticipated renegotiation under certain conditions (e.g. price spikes or extremely unusual weather) are not fully credible and may be less effective as parties anticipate that the contract will be revised if certain events occur. Thus, anticipated renegotiation-proofs incentives should be built into the initial contract to enhance credibility.
- There is a tradeoff between ex ante incentives and ex post efficiency.

8. Contract Enforceability and Informal Incentives

In practice, it is impossible to govern every aspect of performance using legalistic contracts. This is partly due to the complexity and subtlety of certain transactions and partly due to the fact that contract law functions imperfectly. For example, to protect against breach, parties can specify *liquidated damages* in the initial contract which designate the amount of money that the injured party is to be compensated by the party who breaches the contract. However, in practice, courts will enforce liquidated damages only if specific conditions are met (Edlin and Schwartz 2003). In other cases, it is simply impossible to specify every possible contingency that may arise over a long term contract. The contract designer might choose only to specify the most foreseeable events that have the largest impact on the efficiency of the transaction. Hence, real world contracts typically involve a mixture of legalistic components along with informal incentives motivated by relational contracting.

Relational contracts are based on informal promises and obligations. In a relational contract, two parties can make a "handshake" agreement where the principal asks the agent to produce a certain level of output in exchange for some promised payment. What distinguishes relational contracts from legalistic contracts is that at least one party's obligation or promise is not third-party enforceable. As such, relational contracts must be "self-enforcing". Self-enforcement primarily comes from repeat contracting where the principal and agent trade repeatedly overly many periods. Repeat trading creates inter-temporal incentives so that threat of future punishments or the promise of future rewards can discipline current behavior. For example, a grower may deliver biomass with low moisture content if the grower anticipates that the refinery will share future costs or make discretionary payment adjustments in the future for good performance. Alternatively, the refinery can terminate a grower who has breached his obligations too many times. When the future matters enough to the contracting parties to discipline their current behavior, then an informal contract is said to be self-enforcing.

Nonetheless, relational contracts are self-enforcing only in very specific circumstances. Several recent papers clarify the conditions under which relational contracts can enhance the value of a transaction (MacLeod and Malcomson 1989; Levin 2003; Wu and Roe 2007). First, parties must have a reputation to protect and care about the future. Relational contracts therefore function very well in environments where the contracting parties interact repeatedly and the industry is relatively small so that people are more familiar with each other. Second, relational contracts require a relatively stable environment. In rapidly changing environments with substantial technological changes or market uncertainty, relational contracts tend to be less effective as the conditions under which the relationship is formed might become obsolete quickly. For example, during the recent financial crises, many financial institutions were willing to breach long term informal relationships due to the severity of the recession. In addition, the VeraSun bankruptcy resulted in the shutdown of many ethanol plants and breach of their contracts to purchase corn from farmers. Similarly, many relational contracts in the fertilizer industry unraveled due to extreme price volatility.

With regard to biomass contracting, contracts will have to be long-term and there is substantial regulatory and technological uncertainty. Hence, it is important that contracts between refineries and growers not rely solely on relational contracts. While some less important aspects of performance can be governed by relational incentives, we anticipate that securing a supply commitment of ten years will have to be legally enforceable. Relying on self-enforcement alone will likely be insufficient as the contracting environment will likely change over time.

9. Conclusion

This overview article highlights general principles that can inform the design of multi-year contracts for perennial energy crops. Four important principles include balancing risk against incentives, balancing incentives to reduce incentive conflicts, using screening to induce efficient matching between growers and contract type, and incorporating renegotiation-proof incentives in the initial contract (to increase contractual credibility), when possible. These principles emerge from solutions to contract design optimization problems based on the Revelation Principle. While these principles have substantial practical implications for the design of optimal contracts that can contribute to supply chain efficiency, additional research is needed to address some issues that are not covered in the literature.

One important and cutting edge area of research that has tremendous practical significance is to study the tradeoff between optimality and complexity of the contract. Contracts that are theoretically optimal may not guarantee sensible real world outcomes, partly because theoretical contracts might be overly complex. For instance, an optimal menu might contain as many contract choices as there are grower types. Clearly including a large number of choices is not practical and may confuse farmers. The current economics literature is silent on the optimal number of contracts within a menu. One hypothesis is that increasing the number of choices within a menu can, in principle, increase efficiency. In reality, too many choices may reduce farmer participation as people tend to be more reluctant to participate in enterprises that they are not familiar with. Increasing the number of choices will increase complexity and reduce familiarity. Thus, it would be important to understand the optimal number of choices that balance complexity against efficiency.

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Marc A. Johnson Conference Room
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"Contract Theory and Implications for Advanced Biofuels Contracting"

Dr. Steven Wu, Associate Professor, Agricultural Economics Purdue University

Steve Wu is currently an Associate Professor in the Department of Agricultural Economics at Purdue University; a Research Fellow with the Institute for the Study of Labor (IZA) in Bonn, Germany; and a member of the Economic Design Network through the Department of Economics at the University of Melbourne. His research and teaching interests are in the areas of Applied Contract Theory and Incentive Systems, Applied Microeconomics, Experimental Economics,

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Regulation and Public Policy related to Agricultural Contracting. He is currently studying the optimal design of informal incentives used by individuals and organizations to manage performance and regulate economic activity. He is also examining potential risk sharing and incentive problems that may arise when contracting for dedicated energy crops. He earned his Ph.D. from the University of California-Berkeley in Agricultural and Resource Economics in December 2001.

Sponsored in part by the K-State Center for Sustainable Energy.

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Dr. Konstantinos Giannakas, University of Nebraska-Lincoln, presented "Economic Effects of Purity Standards in Food Labeling

Laws."

Dr. Susan Capalbo, Department Head & Professor, Department of Agricultural and Resource Economics from Oregon State University entitled "Leadership and Other Challenges Facing Agricultural & Resource Economics Departments."

Dr. Amalie (Emie) Yiannaka, University of Nebraska-Lincoln, "Getting Away with Robbery? Patenting Behavior with the Threat of Infringement." Link to paper

Dr. Greg Perry, Oregon State University, "What is the Future of the Agricultural Economics Profession?" See the archived presentation here

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