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# Biomass supply contract pricing and environmental policy analysis: A simulation approach

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ABSTRACT

This paper proposes an agent-based simulation model to study the biomass supply contract pricing and policy making in the biofuel industry. In the proposed model, the agents include farmers and a biofuel producer. Farmers' decision-making is assumed to be profit driven, which is formulated as a mixed-integer optimization model, and the biofuel producer's pricing decision is represented with a linear equation with an objective to maximize profits. A case study based on Iowa has been developed to analyze the interactions between the stakeholders and assist determination of the optimal pricing equation for the biofuel producer. Simulation results show that under such a pricing strategy, the biofuel producer can achieve higher profitability than using a fixed price. The impact of government environmental regulations on farmers' decision-making and biomass supply has also been analyzed, and managerial insights have been derived.



## 1. Introduction

Revised Renewable Fuel Standard (RFS2) mandated that 16 billion gallons of cellulosic biofuel should be produced and consumed annually by 2022 [1]. Significant challenges exist to reach this target, such as the design of advanced biofuel supply chains. There are five major components in biofuel supply chain design and optimization: biomass production system, biomass logistics system, biofuel production system, biofuel distribution system and biofuel end-use [2]. Farmers play a significant role in the biomass production process, therefore smooth interaction and coordination between farmers and biofuel producers are essential to the successful deployment of an effective biofuel supply chain.

Biofuel producers are the other major player in the biofuel supply chain. They are generally profit driven and their behaviors are typically described with profit maximization models. In this paper, the decision-making mechanism of the biofuel producers is represented with a profit maximization function, in which the contract prices are the decision variables. It should be noted that as a contribution of this study, we can accommodate variable contract price for individual farmers, which is typically not considered in the literature. The contract pricing equation is motivated by determination of bank loan contract which is a linear function of the bank's quote and the customer's responding price [3]. In this paper, the biomass contract prices are assumed to depend on corresponding farm productivity and contract period length.

For biofuel producers' decision-making, there are several types of biomass supply contracts. For instance, DuPont provides two contract options to farmers for corn stover collection. Farmers can either sell the corn stover at their field or at the gate of biofuel refinery with different prices [4]. The contract type that we consider in this study is as the following: the biofuel producers rent land from farmers and collect biomass by themselves. In other words, the farm owners collect the land rent and the biofuel producers take care of everything else, including planting, harvesting, and transporting the biomass to the production facilities. We adopted a flexible pricing strategy for the scenario of biomass supply contracting, in which the contract pricing equation result in different rent payment for different farmers. This flexibility has proven to be profitability improving.

Farmers' communities have different responses under different formulations of the pricing equation. In other word, different pricing strategies result in different market outcome. Determining the optimal pricing strategy becomes challenging when the number of farmers grows, and simulation tools are introduced into modeling to overcome the difficulty. For instance, Valenzuela,

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Thimmapuram, and Kim [5] analyzed the impacts of dynamic pricing on electricity market performance based on an agent-based simulation model. Similar methodologies are applied to biofuel supply chain analysis and optimization in this paper. The difference between power and biomass market is that for all target customers, the electricity price is the same; however, contract prices for each farmer can be different due to different characteristics of their farms and their willingness of cooperation with the biofuel producers.

Simulation models can offer analysis tools and prediction methods to agricultural decision-making at farm scale [6] and localized farming communities [7]. However, a single farmer's behavior or localized farming communities have limited impact on the biofuel supply chain. Hence analysis on farmers' behavior should be based on a large number of farmers so that farmers' group behaviors and their impacts on the supply chain can be observed. It should be noted that number of stakeholders analyzed in the existing literature was limited and the true group behavior could not be observed. Bai, Ouyang, and Pang [8] designed a biofuel supply chain with 10 farms, 10 candidate refinery locations and 10 local grain markets. Similarly Zhang et al. [9] studied a biofuel supply chain with 3 farmers, 4 biofuel producers and 5 blenders. Limit on number of stakeholders especially the farmers weakened the validity of supply chain analysis, because in reality interactions between a single farmer and a downstream stakeholder do not affect the macroscopic supply chain significantly. Therefore, it is essential to consider a larger number of stakeholders' interactions simultaneously.

Agent-based simulation has been employed to study the group behavior in agricultural systems in the literature because of its advantages argued by Berger [10] on the capability of capturing interactions between stakeholders. Former researchers usually adopted agent-based model to observe the one-way effect of outer entities or situation on the researched objects, rather than emphasizing the interactions between origins of the effect and researched objects [11–14]. Such interactions are the major motivation of this paper. In this paper, an agent-based simulation model is formulated, in which farmers make individual decisions based on their own decision-making criteria and mechanism. The farmers' decisions are collected, aggregated, and transitioned to the biofuel producer. With this information, the biofuel producer can adjust biomass contract pricing strategy. In turn, farmers can change the farming decisions in the next year. This dynamic process will continue until equilibrium has been reached between the stakeholders. Generally, these agent-based models could all be classified into Bio-economic farm models since they were developed to enable assessment of policy changes and technological innovations (in our case it is bioenergy crop adoption) [15].

Decision-making mechanism of farmers is complicated to model since there are multiple impacting factors involved. Reimer et al. [16] pointed out that farmers' decisions are difficult to model since a variety of factors can contribute to a farmer's decisions and often with uncertainties. In practice, factors included in a farming decision-making model are limited. Typically, researchers assume that all farmers are rational and analyze their behaviors with economic models with a profit maximization objective. For example, Willock et al. [17] conducted a qualitative study on farmers' attitudes and behaviors in farming and claimed that profit or production maximization is the main objective of most farming practices. Similarly, in this paper, farmers are assumed to be profit driven in the basic scenario. On the other hand, farmers in reality may not always be purely profit-driven. In addition, conservation and environmental concerns contribute to the farmers' decision-making. Lynne and Rola [18] argued that income alone was not a significant predictor of conservation behavior, but a positive attitude about the environment was also required. Growing concerns on environmental impact in farmers' community affects farmers' behavior, and one evidence is that from 1982 to 2007 soil erosion rate dropped from 4.0 tons to 2.7 tons per acre in US [19]. Therefore, soil erosion has been selected as a representative environmental concern for farmers in this study. With additional environmental regulation from government, the decision-making of farmers could be impacted significantly. In this paper, it is shown that mild regulations can motivate the adoption of bioenergy crops and an aggressive policy regulation can significantly impact/alter the current farming practice.

There have been increasing interests in incorporating complicated decision-making models into simulation platforms. Almeder, Preusser, and Hartl [20] incorporated discrete-event simulation with mixed-integer linear programming for supply chain design and planning. Data were transmitted between the simulation platform and the optimization model solver via a database. Frequent data transmission between different platforms consumes significant computing time and resources, and thus creates challenges when the model is applied to real world scale. One alternative is to incorporate optimization solvers into the simulation platforms to accommodate larger scale model. In this paper, we chose a Java-based simulation platform, which can call the CPLEX solver within the simulation platform.

The remainder of this paper is organized as follows: the mathematical decision-making model of farmers is formulated in Section 2 and biofuel producers' decision-making is modeled in Section 3. The agent-based simulation model of their interaction is introduced in Section 4. The case study and analysis of the results are presented in Section 5, and the scenario with environmental policy regulation is discussed in Section 6. The paper concludes with a summary of research findings in Section 7.

## 2. Farmers' decision-making model

Optimization models are appropriate tools to simulate decision-making processes if the decisions can be represented explicitly with analytical relationships [21]. A farmer's decision-making is represented with an optimization model with an objective of farming profit maximization. By applying such a model to each farmer, farmers' macroscopic response on biomass contracts provided by the biofuel producers can be analyzed.

There are several bioenergy crops that produce biomass, and several business types exist on biomass supply. The model we describe here is for a special case, that farmers rent out land to the biofuel producer, and the biofuel producer plant switchgrass (*Panicum virgatum*) on this land. To simplify the model, we choose corn (*Zea mays*) as the representative row crop that farmers conventionally plant. Therefore, the farmers make decisions on planting area and time period for corn and switchgrass.

### 2.1. Notations

Notations for modeling of the farmers' decision-making are included in Table 1.

### 2.2. Model formulation

Farmers are assumed to be profit-driven. Profit maximization serves as the objective function as illustrated in Equation (1).

$$\max_{x_k^W, x^C} \sum_k k p_k^W x_k^W + \left(P^C R^C - c\right) \sum_k (n-k) x_k^W + n\left(P^C R^C - c\right) x^C \tag{1}$$