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Biomass for Bioenergy: Optimal Collection Mechanisms and Pricing when Feedstock Supply Does Not Equal Availability

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Abstract

The supply chain connecting biofuel processing firms and suppliers of biomass is evolving, and processors face a choice in the collection and pricing strategies they will employ to procure biomass. One option is to pay a single price for biomass collected field-side (processor collection). Another is to pay a single price for biomass at the plant gate (supplier delivery). The literature in this area is relatively young, but there is a sense that the evolution of contracting and pricing structures will dictate the industry's success, and ultimately the costs of producing biofuels from dedicated and non-dedicated energy crops. We examine the collection and pricing choices for a cost-minimizing cellulosic biofuel processor, who initially has monopsony power in feedstock procurement in their collection area. We derive optimal prices, total expenditures on feedstocks, and the collection areas required to meet a processor's fixed input needs. We show that while societal welfare is greatest under supplier delivery; however, the processor will be indifferent between supplier delivery and processor collection unless they are concerned about entry of a competing processor. When this is the case, the processor can use the processorcollection mechanism as an effective deterrent to entry. Numerical simulation based on corn stover for biomass is used to illustrate optimal pricing and the extent of biomass collection areas for different procurement and pricing strategies. We use these findings to calculate the rates at which collection costs increase for a monopsonistic stover processor constrained to a defined procurement area, as might emerge as the industry moves towards commercialization. The derived marginal cost curve for a monopsonistic processor of stover is compared with the marginal cost curve across alternative feedstocks.

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Comments

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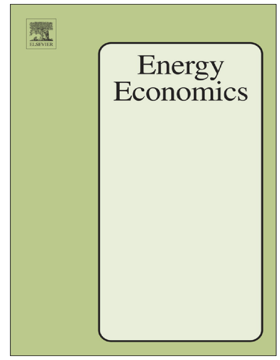

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Biomass for Bioenergy: Optimal Collection Mechanisms and Pricing when Feedstock Supply Does Not Equal Availability [1]

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Abstract

The supply chain connecting biofuel processing firms and suppliers of biomass is evolving, and processors face a choice in the collection and pricing strategies they will employ to procure biomass. One option is to pay a single price for biomass collected field-side (processor collection). Another is to pay a single price for biomass at the plant gate (supplier delivery). The literature in this area is relatively young, but there is a sense that the evolution of contracting and pricing structures will dictate the industry's success, and ultimately the costs of producing biofuels from dedicated and non-dedicated energy crops. We examine the collection and pricing choices for a cost-minimizing cellulosic biofuel processor, who initially has monopsony power in feedstock procurement in their collection area. We derive optimal prices, total expenditures on feedstocks, and the collection areas required to meet a processor's fixed input needs. We show that while societal welfare is greatest under supplier delivery; however, the processor will be indifferent between supplier delivery and processor collection unless they are concerned about entry of a competing processor. When this is the case, the processor can use the processor-collection mechanism as an effective deterrent to entry. Numerical simulation based on corn stover for biomass is used to illustrate optimal pricing and the extent of biomass collection areas for different procurement and pricing strategies. We use these findings to calculate the rates at which collection costs increase for a monopsonistic stover processor constrained to a defined procurement area, as might emerge as the industry moves towards commercialization. The derived marginal cost curve for a monopsonistic processor of stover is compared with the marginal cost curve across alternative feedstocks.

Introduction

Commercial-scale cellulosic ethanol production is a priority under the existing U.S. Renewable Fuel Standard (RFS), calling for nearly 16 billion gallons from cellulosic biomass including grasses, trees, agricultural residues, and municipal waste (Bracmort, 2015). The literature on the availably of cellulosic feedstock, including U.S. Department of Energy (Downing et al. 2011), Ogden and Anderson (2011), Graham et al. (2007), Archer and Johnson (2012), and Dumortier (2015), focuses on whether sufficient cellulosic feedstocks will be physically available to meet the mandate. Common assumptions in this literature are 100% participation in supplying available feedstocks and homogenous producers. However, firms with industry experience in cellulosic biomass markets report that quantity supplied from producers is not equal to physical availability of feedstock (Sesmero et al. 2015, Rosburg et al. 2016), which further suggests the supply curve for cellulosic feedstock will be different than that for corn ethanol and other dedicated feedstocks.[2]

The U.S. Department of Energy "U.S. Billion-Ton Update" study (Downing et al., 2011) suggests that to meet the total advanced biofuels mandate in the RFS, approximately 66 million

[2] The distinction between dedicated and non-dedicated energy crops is important to understanding how markets for biomass function. A dedicated energy crop (such as switchgrass) is grown for purposes of providing an energy feed source. Corn stover, on the other hand, is a non-dedicated crop in that it a by-product of corn production. This is a key distinction for our purposes, because producers who commit to dedicated energy crops must find a buyer for their production. Corn stover and other agricultural residues are not valued as a primary crop, and therefore it is not essential that the byproduct be marketed. Therefore, monopsonistic processors may not be able to exercise pricing power in markets for non-dedicated energy crops as they are likely to for dedicated energy crops.

tons of corn stover will be needed annually. This equates to approximately 50% of the total annual stover produced by Iowa, Illinois, Nebraska, and Minnesota—the four largest corn producing states (Sesmero et al., 2015). However, experience suggests that participation rates are likely closer to 20%–25%, largely due to stover's status as a residual "second crop" and because suppliers are heterogeneous in their willingness to supply stover.[3,4]

This manuscript examines the biofuel processor's feedstock procurement choices and price strategies and characterizes optimal prices, total expenditures, and collection areas required to meet known production quantities. We consider two cases of spatial pricing, each indicating a specific procurement arrangement. In the first, a monopsonistic biofuel processor pays a single price for feedstock delivered to the plant by the supplier. We refer to this as the supplier-delivery model. In the second, the processor collects feedstock from suppliers and pays a single price to all suppliers. This is the processor-collection model. Distinguishing between these

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[3] Based on insights from two stover-based cellulosic ethanol plans in Iowa: POET-DSM in Emmetsburg, Iowa, and DuPont Cellulosic in Nevada, Iowa.

[4] Heterogeneous reservation values are generated by characteristics such as variations in crop rotations, availability of livestock manure, and subjective values of stover based on farmer perceptions. These characteristics influence the opportunity cost of removing the stover from the field because, under some circumstances, stover has fertilizer and carbon value related to the presence of livestock or other enterprises. This value is highest on corn-soybean rotations and lowest under continuous corn, and where livestock manure is applied (Pieper 2015). In our model and analysis, we assume land units are homogeneous and that heterogeneity in reservation prices of stover derive from factors related to production choices and preferences of the producer.

pricing strategies is motivated in two ways: 1) the feedstock price will determine participation rates when producers have heterogeneous reservation values, and 2) pricing strategies that are favorable to the supplier may be used by a firm to deter potential competition for feedstocks.

Our study is motivated by and draws on the experience of two of the only large-scale cellulosic ethanol processors—POET-DSM (20 mga) and DuPont (30 mga)—both of which are located in Iowa and use agricultural residues (i.e., corn stover) as a feedstock.[5,6] The plants are similar in capacity, initial capital investment, and operate in an area with similar production characteristics, yet have chosen different collection and pricing mechanisms. The choice of collection method is a strategic one and depends on the processor's expectations of competition, producer participation, and collection and transportation costs. That two processors operating under similar conditions have chosen different collection strategies suggests the industry has not settled on an optimal procurement strategy. We rely on a basic spatial pricing theory to analyze market outcomes under different procurement models with the goal of providing evidence about how the industry's cost structure may evolve as policies related to the mandated expansion of the industry are implemented. A key result is that while a processor is indifferent between the two procurement models when there is no competition for feedstocks, it will find an advantage in switching to a processor-collection model to deter potential competition as the industry

[5] The institutional details of these plants and their operational dimensions are described in a later section.

[6] Five other operational cellulosic plants exist, but none of these exceed 20 million gallons of ethanol capacity per year according to Ethanol Producer Magazine: http://www.ethanolproducer.com/plants/listplants/US/Operational/Cellulosic/page:1/sort:capacity/direction:asc (accessed Sept 21, 2017).

approaches capacity utilization of a feedstocks. This has implications for overall system welfare and costs.

Following a review of the relevant literature, our study proceeds as follows. First, we use a cost-minimization framework within a simple line model for each of the collection strategies and compare optimal prices, collection distances, and procurement costs given a known feedstock requirement. Three propositions related to the procurement system are presented, which show that in the absence of competition, the processor is indifferent between processor collection and supplier delivery, but that welfare is higher under supplier delivery. In a situation where the potential for competition for feedstocks exists, we use a sequential game with backward induction to characterize the optimal procurement strategy of each firm. Second, we use numerical simulation to trace a marginal cost curve for a monopsonistic processor under each collection mechanism to highlight that input and collection costs increase as additional feedstock supplies are needed. Finally, we discuss the policy implications of our findings in the context of the current RFS and other research that estimates the marginal cost of biofuels. The slope of the marginal cost curve for the monopsonistic processor is compared with the slope of the cost curve across other feedstocks. The results suggest that substantial quantities of these non-stover feedstocks may be required to meet the mandate.

Spatial pricing in the literature

In the market for cellulosic biomass, the ability of processors to engage in spatial price discrimination, coupled with supplier heterogeneity, will drive a processor's choice of procurement and pricing strategy. The question of procurement and price strategies—where in the market space product ownership is transferred and who bears transportation responsibility—

has been examined for a number of products and market situations, from perfect competition to monopoly/monopsony, and premised on varying degrees of information exchange (Hoover, 1937; Greenhut and Greenhut, 1975; Beckman, 1976; Greenhut et al., 1980; Balcer, 1983; Aguirre et al., 1998, Sesmero 2015, 2016).

The spatial pricing literature can be thought of in two broad strands. In one, where the market is characterized by sellers pricing an output, there are potentially many sellers, and each contemplates competitive and spatial factors in determining its optimal pricing and delivery mechanism. The second, and the one on which our investigation focuses, focuses on procurement markets, particularly like those in agriculture, which are fundamentally different than other output markets. In procurement markets, many sellers exist but pricing is largely determined by one or few buyers (processors) with market power.

Common pricing nomenclature for spatially differentiated products are free on board (FOB), uniform delivered (UD) and optimal discriminatory pricing or partial freight absorption (OD). In procurement markets, FOB pricing (also known as mill pricing) involves a single bid at the processor's plant (plant gate) and suppliers (farmers) are responsible for the cost of transporting their output to the processor. This is analogous to our supplier-delivery procurement method and is the convention in the procurement of agricultural commodities including corn, soybeans, and wheat. UD pricing in procurement markets—analogous to our processor-collection method—reverses FOB pricing: all suppliers receive the same price for their output and the processor bears the transportation cost from farm gate to plant gate.[7] In this case, all

[7] Our model does not correspondence easily with the existing literature in two ways. First, by assumption, our single-price, monopsonistic firms do not have the ability to price discriminate or engage in markdown pricing below the marginal value of the stover to the processor. Our firms

suppliers are equally as well off given a homogeneous production cost structure. Finally, OD pricing in procurement is an intermediate condition in which an FOB price is used along with partial freight absorption by the processor.[8] Buyers are able to segment supply markets to remain competitive and extract optimal rents.

Graubner et al. (2011) provide a thorough discussion of the studies in the spatial pricing literature, and note that most studies focus on FOB pricing, while UD pricing studies of agricultural procurement markets are relatively few, likely owing to a lack of evidence of UD-priced products. Their work made significant headway in understanding OD and UD price strategies using simulations of a general spatial competition model in the context of processors competing for inputs. Among their findings are that UD pricing is an equilibrium strategy for

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do not have any realistic opportunity to price discriminate across suppliers, and this is consistent with the experiences of the processors. A reviewer noted that one way to generalize this model is to allow the processor to absorb partial transportation costs, and in that case the single-price assumption can be relaxed. Second, we solve a cost minimization problem subject to a capacity constraint whereas the literature has focused on profit maximization.

[8] A reviewer notes that OD pricing in mature monopsonistic procurement markets is the likely outcome, and Sesmero (2016) documents the efficiency of partial freight absorption. The market for stover is not established and the firms we model have not evolved beyond the simpler pricing schemes we present. Further, there is reason to doubt that partial freight absorption is possible in the market for stover given how producers currently evaluate its value and its status as residual crop. We limit our study to the FOB (supplier delivery) and UD (processor collection) cases. Pricing with partial freight absorption in the procurement for non-dedicated biomass is a topic for future research.

firms that compete spatially for inputs. As competition becomes less intensive, firms will move toward partial freight absorption, where the amount of freight absorbed is decreasing as space becomes more important. In local monopsony, pricing converges to OD.

Until recently, the bulk of theoretical and applied work in procurement markets has focused on commoditized agricultural outputs, including grain and milk. By comparison, the literature considering procurement of agricultural residues and other feedstocks for cellulosic biofuel is relatively young. Examples of stover-based investigations include Petrolia (2008), Perrin et al. (2012), Altman et al. (2015), Sesmero et al. (2015), Rosburg et al. (2016), and Sesmero (2016). Because the industry lacks commercial scale and is also without significant competition for feedstocks, these and other studies focus on price and supply in a monopsonistic context and ignore producer supply responses and processor pricing behavior.

Sesmero et al. (2015) argue that while for now the spatial monopsony context for biomass feedstock may be appropriate, relying on estimates of market extent, supply, and participation from studies that do not consider competition may lead to false inferences about the true availability and cost of stover-based biofuels in competition. Their work uses data from Indiana to compare stover pricing and biofuel production and costs with participation (supply) feedback across markets structures, including duopsony, monopsony, and three-firm oligopsony. Their results suggest that competition for feedstocks by profit-maximizing firms increases feedstock prices and surpluses to producers, thereby increasing feedstock and biofuel production costs. They note that their study ignores strategic behavior when entry by other firms is possible, presumes profit maximizing behavior of firms, and focuses only on FOB pricing. Other works that allow for a participation response from feedstock suppliers include Altman et al. (2015) and Rosburg et al. (2016). Both find that producers' participation in supplying biomass is not particularly sensitive to price increases, which further suggests an importance of understanding the trade-off in collection distances versus paying a higher price for feedstock. Our work is positioned in this growing literature and fills a gap identified by Sesmero et al. (2015) in the need to investigate alternative delivery regimes as a form of strategic behavior while at the same time incorporating supplier heterogeneity.

Methods

A model of biomass procurement for biofuel processing

We model the procurement strategies of a cost-minimizing corn stover processor following the spatial price theories developed by French (1960) and refined by Greenhut et al. (1987). We assume a fixed and exogenous plant capacity. Processors minimize the cost of procuring the necessary feedstock to meet operating targets by choosing a price to pay for feedstock, either purchased field side (processor collection) or delivered to the plant (supplier delivery).

Feedstock supply and procurement are analyzed using a simple line model, where land units that supply feedstock are uniformly located on a line segment, with the processor at one end.[9] Land units are homogeneous in their production of feedstock (i.e., each land unit has equal

[9] We present the line model in our theoretical section because it is tractable with closed-form solutions that can be compared across collection strategies. Later in the paper we present a simulation model that uses a circular market. The goal of simulation is to model supply distances and prices using parameters based on the real world experiences of each of these plants, this corresponds most closely to a circular market.

feedstock yield), and we normalize this to a total quantity available of one.[10] Within a land unit are suppliers who, because they have varying reservation values for feedstock, are heterogeneous in their willingness to supply. These suppliers are uniformly distributed within the land unit.

A processor with fixed and known production quantity, Q, buys feedstock R land units from the plant such that production is satisfied. Here, R is both the distance to the last land unit and a total number of land units supplying stover, where each land unit is located r distance from the plant, and $r \leq R$. Transportation costs per unit per mile, t, are assumed equivalent for processors and suppliers. The net price any supplier receives for feedstock is denoted generically as NP, and is either a single field-side price, p, paid to all suppliers in the case of processor collection or is a delivered plant-gate net price, $p - tr$, where p is the announced price and suppliers differ in their net price by distance from the plant and transportation costs. When the net price of feedstock a supplier receives, p or $p - tr$, exceeds a supplier's reservation value, s/he is willing to sell all of the feedstock produced on that unit. In this way, the proportion of a land unit that supplies feedstock, denoted $b(NP)$, is a function of net price and this is also a quantity supplied per land unit for a given price.[11] For simplicity, we assume supply is linear in price, and therefore, $b(NP) = b * NP$ is the proportion (quantity) of the available feedstock

[10] Assuming the processor is located at one end of a line segment reflects the radius of a circular collection region. If instead the processor is located in the middle of the line segment, our line model presentation and results hold. This is true because land units are homogenous, and distance, R, is an aggregate distance; the processor can collect from units in one direction, opposing directions, or any direction in the case of a circular model.

[11] The equivalence between proportion and quantity holds because each land unit is assumed to produce one unit of feedstock.

supplied per land unit. The processor has collection costs of $p + tr$ for processor collection and p under supplier delivery.

Optimal feedstock prices and collection distances are presented for three no-competition scenarios: (a) the processor is able to perfectly price discriminate, paying each supplier his reservation value and uses processor collection; (b) the processor is a single-price monopsonist that collects feedstock field-side and transports it to the plant (processor collection); and, (c) the processor is a single-price monopsonist that buys delivered feedstock at the plant (supplier delivery). We then extend the model to consider processors' procurement choices in a game-theoretic framework when there exists a potential for competition for feedstock. Feedstock prices, collection distances, and total collection costs are compared in a case where an existing processor faces the threat of a potential entrant whose collection method is chosen under competitive conditions.

Perfect price discrimination using processor collection, no competition

Perfect price discrimination, though an unrealistic market outcome, serves the purpose of identifying the competitive price and collection distance with no deadweight loss in the system (Varian, 2009). It also provides a benchmark against which two of the more likely scenarios—a single-price monopsonist using either supplier-delivered or processor-collection methods—are measured.

A feedstock processor would ideally wish to price discriminate, paying each supplier their unique reservation value for feedstock. The payment to each land unit under this form of price discrimination is given as $bp^2 - \int_0^p bx dx = 0.5\, bp^2$. When the processor is unable to price discriminate, it must pay each land unit bp^2; therefore, the cost difference, $0.5bp^2$, is the advantage to a processor of this form of price discrimination. Total feedstock expenditures are found by integrating the feedstock cost and transportation over the total collection distance, R: $\int_0^R (0.5bp^2 + bptr)dr$.

Single-price monopsonist using processor collection, no competition

In the processor collection scenario, the processor is responsible for transporting feedstock to the plant and pays every supplier the same price; thus, the proportion of feedstock collected from a land unit is constant. Given a single price, p, and linear supply per land unit, $b(P) = bp$ and the processor collects from distance $R = \frac{Q}{bp}$ to meet production needs. Total feedstock expenditures are again found by integrating procurement costs over distance: $\int_0^R bp(p + tr)dr$.

Single-price monopsonist using supplier delivery, no competition

In a supplier-delivered collection model, the processor announces a price of p per unit of feedstock delivered to the plant, such that the price results in participation sufficient to meet the production requirement, Q. A supplier r distance from the processor incurs transportation costs and thus receives a net feedstock price, $p - tr$. Suppliers nearer to the processor have a transportation cost advantage and receive higher net prices than those further away. The feedstock supply is $b(p - tr)$ and is not constant across suppliers in the collection area. The proportion of stover supplied will be greatest near the processor and declines to zero at the margin of the collection distance. The processor's total feedstock expenditures are $\int_0^R pb(p - tr)pdr$.

We are interested in comparing optimal prices, p^*, collection distances, R^*, and total expenditures to meet a known production, Q, for the three pricing and collection scenarios. These are explored with the following propositions.

Proposition 1: *When transportation costs are identical for a monopsonistic feedstock processor and suppliers, total collection expenditures and collection distances, are identical under processor-collection and supplier-delivery models, and the processor is therefore indifferent between the two.*

Under processor collection, the expenditure minimization problem to collect Q feedstock quantity is expressed as $min_{\{p\}}\, pQ + 0.5\,\frac{tQ^2}{bp}$. The first-order condition (FOC) for this problem is $Q - \frac{tQ^2}{2bp^2} = 0$, which implies solutions $p^* = \left(\frac{tQ}{2b}\right)^{0.5}$ and $R^* = \left(\frac{2Q}{bt}\right)^{0.5}$. Substituting the equilibrium price and distance into a processor's expenditure function, total expenditures are: $p^*Q = \sqrt{2}\left(\frac{t}{b}\right)^{0.5} Q^{1.5}$. Under supplier delivery the expenditure minimization problem to collect Q feedstock is $min_{\{R\}}\left(\frac{Q}{bR} + 0.5tR\right)Q$. The FOC is $\frac{1}{2}tQ - \frac{Q^2}{bR^2} = 0,$ which implies solutions $p^* = \left(\frac{2tQ}{b}\right)^{0.5}$ and $R^* = \left(\frac{2Q}{bt}\right)^{0.5}$. Note that the optimal collection distance for both processor collection and supplier delivery are identical. Total expenditures are $p^*Q = \sqrt{2}\left(\frac{t}{b}\right)^{0.5} Q^{1.5}$, the same as expenditures under the processor collection mechanism. The processor's indifference between the two models is intuitive: because it cannot price discriminate, it cannot capture the supply efficiencies generated by participation rate effects.[12]

Proposition 2: *Supplier welfare is higher and total transportation costs are lower under the supplier-delivery model than the processor-collection mechanism.*

In either collection mechanism, the payment to the supplier is the difference between the total expenditure of the processor and the cost of transportation. In the processor collection mechanism, the payment to suppliers is $\int_0^{R^*} bp^2 dr = bp^2 dR = \frac{\sqrt{2}}{2}\left(\frac{t}{b}\right)^{0.5} Q^{1.5},$ and this represents half of the total expenditure. Under supplier delivery, total expenditures to collect Q feedstock is $\left(\frac{Q}{bR} + 0.5tR\right)Q = \sqrt{2}\left(\frac{t}{b}\right)^{0.5} Q^{1.5}$, and the transportation costs are $\int_0^{R^*} b(p - tr)trdr = \frac{\sqrt{2}}{3}\left(\frac{t}{b}\right)^{0.5} Q^{1.5}$. Thus, the payment to suppliers is the difference, $\frac{2\sqrt{2}}{3}\left(\frac{t}{b}\right)^{0.5} Q^{1.5}$.

Table 1 compares optimal prices, collections distances, and expenditures for each of the three cases. These highlight the tradeoff between the processor collection and supplier-delivery

[12] Sesmero (2016) develops a model with a monopsonistic market for an agricultural commodity where the firm has the market power that allows it to offer a plant price that is below the marginal value product and the ability to partially absorb the freight advantage enjoyed by suppliers that are close to the plant. The latter type of power is called spatial price discrimination and involves processor collection. He shows that the socially optimal solution is FOB pricing, and this agrees with our results. However, the privately optimal solution always involves spatial price discrimination. Our results suggest that in the absence of the ability to absorb freight costs, the firm will be indifferent between UD and FOB pricing.

models. In a single-price monopsony, total expenditures on feedstock collection and R^* are equivalent, but the share of costs attributable to transport and feedstock varies depending on whether processors collect feedstock or suppliers deliver. This is because participation is driven by net price, and these are not uniform in the supplier-delivery model as they are in processor collection model. Instead, participation is greatest near the plant where transportation costs are lowest. The supplier-delivery model has higher average feedstock payments to suppliers and lower total transportation costs relative to processor collection.

<insert Table 1 here>

By proposition 1, the processor is indifferent between the two collection options because the costs to the processor are equal. However, supplier participation increases closer to the plant under supplier delivery, thereby reducing overall transportation costs. The single price is a limitation that precludes the plant from capturing the efficiencies associated with supplier delivery. Instead, these benefits are captured by suppliers located near the plant—a location rent. Costs for processors are the same under both mechanisms but societal welfare will be higher with the supplier delivery mechanism. These propositions explain, in part, why supplier delivery pricing (FOB) dominates in the commodity grain market, generating lower transportation costs and higher overall welfare.

Collection strategy as a barrier to entry

The simple analysis above is useful to understand how collection areas and feedstock pricing, and therefore transportation costs and total expenditures, are affected by procurement strategy choice. In this section we extend the framework to show optimal pricing and collection distance outcomes for the procurement strategies when there is a potential threat of competition for feedstock in the processor's feedstock area. The optimal solutions are influenced by the distance between processors, which is intuitive. The motivation for considering this case is the need to understand implications of policies that mandate the use of large quantities of cellulosic feedstocks. As the industry expands under the mandate, and as processors move to occupy current gaps or unused feedstock production areas, collection mechanisms will be chosen strategically to deter competition and minimize feedstock procurement costs.

We continue with the line segment model to characterize the nature of the interaction between an existing processor of feedstock (an incumbent) and a new processor (the entrant) who will potentially compete for a portion of the incumbent's feedstock in an overlapping area.[13] We assume processors are homogenous with equivalent production technologies, per-unit cost structures, and capacities. Both minimize total collection costs and therefore have identical optimization problems. The firms choose either processor collection or supplier delivery to procure feedstocks.

Processors' pricing and collection choices depend on the distance between them. Let d be the distance between two processors: an existing processor and potential entrant. In the single-price monopsonist case, the optimal collection distance is $R^* = \left(\frac{2Q}{bt}\right)^{0.5}$. Intuitively, when $d \geq 2R^*$ there is no competition and we have shown that the collection distances and total

[13] This can arise either due to a new firm with the same technology, and a new firm using the same input for a differentiated technology, or an existing firm that contemplates encroachment on the procurement region of an existing firm.

expenditures are equivalent regardless of the collection strategy. However, in cases where $d \leq 2R^{*}$, there will be competition for feedstocks, and we characterize that competition in what follows.

Let $C_i^{jk}(d)$ be the total cost in equilibrium for processor i using strategy j when the other processor uses strategy k. The incumbent (I) and entrant (E) are indexed $i = (I, E)$ and $j, k = (P, S)$ indexes the collection strategies processor collection (P) and supplier delivery (S). The following matrix denotes the potential equilibria:

Entrant

		Processor Collection	Supplier Delivery
Incumbent	Processor Collection	$\left(C_I^{PP}(d), C_E^{PP}(d)\right)$	$\left(C_I^{PS}(d), C_E^{SP}(d)\right)$
	Supplier Delivery	$\left(C_I^{SP}(d), C_E^{PS}(d)\right)$	$\left(C_I^{SS}(d), C_E^{SS}(d)\right)$

The interaction between the two processing firms to arrive at optimal prices and collection mechanisms represents a sequential price-leadership framework solved by backward induction. The entrant observes the collection and price strategy of the incumbent and chooses its optimal decision set. Knowing this is how the entrant will respond, the incumbent optimally sets its collection and price strategy to protect feedstocks and deter competition. The four potential equilibria reduce to three strategic combinations shown in the matrix above: (a) both firms use processor collection; (b) both use supplier delivery; and, (c) the incumbent and entrant choose different collection mechanisms.

We first consider how collection costs change as the distance between two plants shrinks. Greater details of the firms' interactions and collection strategies are provided in the appendix for each of the three strategic combinations.

Proposition 3: *The processor collection strategy adds to the feedstock procurement costs of a potential competitor when their optimal collection areas absent competition overlap. Given competition for feedstocks, both processors will optimally choose processor collection to lower total expenditures.*

We begin by demonstrating that the incumbent and entrant will choose processor collection when competition for feedstock exists. Let R^P be the collection distance for a processor using processor collection and R^S be the collection distance under supplier delivery; similarly, $p^S$and p^P are the feedstock prices under supplier deliver and processor collection, respectively. As shown following proposition 2, the total cost for a firm using supplier delivery is a function of collection distance, R^S, and is given by: $f(R^S) = p^S Q = \frac{Q^2}{bR^S} + \frac{tR^S Q}{2}$, where p^S is the price offered by the processor using supplier delivery. The first order condition of this equation is $f'(R^S) = -\frac{Q^2}{b(R^S)^2} + \frac{tQ}{2} = 0$, which implies $R^S = \pm\left(\frac{2Q}{bt}\right)^{0.5} = \pm R^*$. When $0 < R^S < R^*$, $f'^{(R^S)} < 0$, and we find that the shorter collection distance results in greater collection expenditures.

In the appendix we show that when the incumbent chooses processor collection, the total cost for the entrant if it also chooses processor collection is $\frac{2Q^2}{bd} + \frac{tdQ}{4}$. This cost is the same as $f\left(\frac{d}{2}\right)$. If instead the entrant chooses supplier delivery, its total expenditure is as given above, $f(R^S) = \frac{Q^2}{bR^S} + \frac{tR^SQ}{2}$. Notice that the collection distance for the firm using processor collection is always larger than the collection distance for the firm using supplier delivery, which implies $R^S < \frac{d}{2}$. Therefore, it must be true that $f(R^S) > f\left(\frac{d}{2}\right)$. Thus, an entrant's best strategy is to choose processor collection to lower its collection expenditure when the incumbent uses processor collection.

When the incumbent uses supplier delivery, we showed that the entrant's total collection expenditure is $\frac{2Q^2}{bd} + \frac{tdQ}{4}$ if it also uses supplier delivery. If the entrant instead chooses processor collection, its expenditures are $g(R^P) = p^P Q + 0.5\frac{tQ^2}{bp} = \frac{Q^2}{bR^P} + \frac{tR^PQ}{2}$. As with $f(R^S)$, $g(R^P)$ is decreasing over $(0, R^*)$. Since the collection distance for processor collection is always larger than that for supplier delivery, $R^* \geq R^P > \frac{d}{2}$, and therefore, $g(R^P) < g\left(\frac{d}{2}\right)$. The entrant will optimally choose processor collection to lower its total collection expenditure when it observes the incumbent choosing supplier delivery.

In general, the dominant strategy for a potential entrant that creates competition for feedstock is processor collection, and given the entrant's known best response, the incumbent firm will choose processor collection. This is true because it is more difficult for a firm to poach existing suppliers located at some distance from the plant if the existing processor is using processor collection. An incumbent processor can therefore use processor collection of feedstock as a way to deter an entrant who is considering siting a plant that results in some overlap of required feedstocks. The additional cost of competition compared to the single-price monopsonist occurs because both firms receive only one-half of the feedstock supplied in the area where they compete. They both therefore increase participation nearer to their plants by increasing the price and offering a premium over some suppliers' reservation values to the point at which there is no overlapping area. This increase in collection costs can be treated as the penalty for moving into the collection area of an existing processor, and the penalty increases as the distances between the two decreases.

Simulation of collection models using corn stover feedstock

The theoretical analysis of processor collection and pricing regimes with and without competition for feedstock give useful insight into the tradeoffs that exist between feedstock price and distance (transportation costs) when suppliers are heterogeneous in their reservation values of feedstock. From these simple models and the propositions put forth, we can draw some general conclusions to explain processors' procurement strategy and the associated costs: (a) a processor not facing competition for feedstocks is indifferent between processor collection and supplier delivery because expenditures are equal between the two; (b) similarly, when two firms compete for feedstocks and choose the same collection mechanism, feedstock procurement costs are the same under supplier-delivery and processor-collection; however, supplier-delivery results in higher weighted-average prices in the collection area; and, (c) an incumbent firm can impose a penalty on a potential entrant who will compete for feedstocks by choosing processor collection, thereby adding to the entrant's costs relative to the baseline no-competition scenario.

These insights derive from a simple line model, where feedstocks are located along a segment between the two processors. In reality, the collection region for a processor will better resemble a circle whose radius we approximate with a line model. The line model generalizes to a circle model by thinking of the line as one of many, each of which connects the center of the circle—the processor's plant—with a point on the circumference of ever-larger circles. In the presented scenarios, collection quantities are obtained by integrating the line from 0 to 2π. Just as expenditures and collection distances are the same for processor collection and supplier delivery in the line model, the optimal collection regions (size) and expenditures are also equivalent for the two collection mechanisms when modeled as a circle.

Closed-form solutions for prices, distances, and expenditures do not exist in all cases if the circular model is used, this is due to the irregular shape of any overlapping areas between processors. To illustrate how collection distances and costs are impacted by the choice of collection strategies when firms compete, we employ simulation techniques using realistic parameters from the experiences of two commercial scale feedstock processors of cellulosic feedstock, both using corn stover for inputs.

DuPont's facility, located in Nevada, Iowa, was completed in 2015 with a capital investment of approximately $225M and stated capacity of 30 million gallons per year, requiring approximately 375,000 tons of dry stover per year. POET's plant characteristics are similar. Located in Emmetsburg, Iowa, the plant was finished in 2014 with a capital investment of approximately $275M, stated capacity of 20 million gallons per year, and is expected to need approximately 250,000 tons of dry stover per year. The plants are approximately 138 miles apart by road distance, and approximately 96 miles apart by straight line. Both have acquired and stocked significant quantities of feedstock for production. In the last five years, Story County's and Palo Alto County's producers planted on average 167,600 and 183,100 acres of corn, respectively.

Each farmer has a unique production situation, and this will determine their participation in stover removal. The experiences of DuPont and POET have been that less than 20% of farmers are willing to participate in stover supply at current prices (Pieper, 2015). Both processors have collection areas that are larger than originally anticipated that can reach as far as 50 miles from the plant in one direction (Pieper, 2015; Swoboda, 2014). DuPont utilizes processor-collection contracts in which it collects feedstock field-side and transports it to the plant or storage facilities. It originally expected to collect in a 30-mile radius around the plant. POET's collection strategy was supplier-delivery, with some utilization of processor collection for those at some distance from the plant.

Simulation of Costs and Distance Based on Experience Parameters

We simulate the collection distances and net prices to suppliers for the three collection strategies absent competition and when competition for feedstocks exists. The simulations rely on a circular feedstock collection area with a processor at the center and distance measured as a straight-line from the processor; the price and participation variables are the same as in the line model presented earlier. To operationalize the model, we use parameters values based on Darr et al. (2013).[14] Specifically, we assume transportation costs of $0.65 per ton of stover per mile, processor feedstock requirements of 300,000 metric tons per year, a stover removal rate of two

[14] Darr et al. (2013) used assumptions based on the DuPont plant in central Iowa.

metric tons per acre per year, and corn planted on approximately one-third of the total area.[15] Simulation results of the optimal collection costs per ton for each of the three collection strategies without competition over a plausible range for b are provided in table 3. As an example, for a given supplier response to price changes, $b = 0.015$, the collection radii required is 38 straight-line miles under both the processor collection and supplier delivery model. This participation rate and collection radius is very close to that experienced by the plants; therefore, we base our discussion on the simulation results using $b = 0.015$.[16]

<insert table 3 approximately here>

The simulation results corroborate our theoretical analysis and findings that optimal collection distances (radii) are equivalent for the processor collection and supplier delivery mechanisms, and in all cases are higher than what we would observe if the processor was able to perfectly price discriminate. Also, as suppliers become increasingly price-responsive, optimal feedstock prices and collection radii decrease.

Competition for Stover

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[15] In 2015, Story County producers had corn planted on approximately 43% of the total acres and Palo Alto producers planted corn on approximately 47% of the total acres.

[16] This suggests participation increases by 1.5 percentage points for each $1/ton increase in the stover price. By means of comparison, the simulation results in Sesmero (2015), figure 1, suggest an increase in stover supply of approximately 80% - 250% for an increase in stover price from $50 to $100 per ton, depending on agronomic parameters.

Given the same parameters used in the simulation above, figure 1 illustrates how the collection costs change as the distance between two processors decreases. Processors can expect costs to reflect that of a single-price monopsonistic processor until the point at which the processors must pay a higher price to suppliers near the plant to compensate for suppliers further away that are lost to the competing firm. Potential entrants will optimally select processing locations such that their required feedstock areas do not overlap. However, as least-cost locations are used and firms are incentivized to use existing stover, some overlap is likely, particularly in light of lower than expected producer participation. Based on our simulation assumptions and the participation rates of suppliers that may happen at approximately 72 miles distance between processors. The important take-away is that competition for feedstock, which may occur as firms are incentivized to utilize existing stover as feedstock, represents a significant cost increase for the industry under processor collection.

<insert figure 1>

In the market we considered, significant increases in cellulosic ethanol from stover will arise only if existing processors increase supply from within their existing collection regions. This is because expansion creating an overlapping area is more costly than procuring stover more intensively within a smaller area closer to the plant due to the significant role of transportation costs associated with stover biomass. The case of competition, modeled using a line market, suggests that the cost increase for an entrant when the incumbent uses processor collection is analogous to expanding supplies intensively. Figure 2 illustrates, using simulation based on a circular market, that procurement costs increase as existing processors increase production needs (capacity) in both the cases of perfect price discrimination and single-price strategies.

< insert figure 2 here>

Discussion and policy relevance

Under the current RFS, mandated parties (blenders) will be required to purchase and use a specific quantity of cellulosic biofuels or purchase Cellulosic Renewable Identification Numbers (CRINs) from another blender that has blended more cellulosic fuel than required. As the cellulosic mandate increases the required production of cellulosic fuel, three possible market responses and effects may emerge. First, new plants may locate at least partially within the procurement region of an existing plant, and in so doing force up the premium for stover and, by extension, the participation rate. As we have shown, the existing plants have available an expensive deterrent to avoid this outcome. Instead, new plants will locate at the edges of the existing collection area. A second potential response is that existing plants expand within their current collection area by increasing the price for stover. We show that this is possible, but that the slope of the marginal cost curve for these monopsonistic plants is very steep. A third alternative is to accept that participation rates for corn stover will remain low and then the additional raw material will come from sources other than corn stover. Here, we show using back-of-the-envelope calculations that the third outcome is most likely.

The simulation shows that a doubling of production from, for example, 30 million gallons to 60 million gallons increases procurement from \$41.84 to \$62.71—a 50% increase. Ogden and Anderson (2011) develop the supply curve for all possible sources of cellulose. Corn stover (agricultural wastes) occupy the lower end of the supply curve and result in costs that max out at

$3.00 per gallon. Perennial grasses then enter the feedstock supply option at up to $3.80 a gallon. Moving from $3.00 per gallon to $3.50 per gallon, production doubles from approximately 10 billion gallons of gasoline equivalent to 20 billion gallons of gasoline equivalent. The 16.6% increase from $3.00 per gallon to $3.50 per gallon is much lower than the 50% increase in costs for monopsonistic stover processors who double production. Taken together, these results suggest that there is a place for cellulosic sources other than corn stover under the existing mandate.

Conclusion

The production of cellulosic biofuel involves bulky raw material, capital-intensive processing plants, feedstock producers (suppliers) who are heterogeneous with respect to the price at which they are willing to sell raw material, and large transportation costs. These circumstances are different than the experiences of the corn ethanol industry. The first two commercial scale plants have demonstrated a willingness to accept very large feedstock collection areas and low producer participation in supplying stover. They have also introduced a collection mechanism that relies on the use of plant-owned equipment, and this runs counter to the mechanism used in the grain industry where grain producers deliver to plants.

Our analysis finds that plants are behaving rationally given their monopsonistic status. The use of a supplier-delivery model is expected in cases when there is no competition for feedstock because though the processor is indifferent, suppliers receive higher net prices in total under supplier delivery versus processor collection. We also find that processor collection can be used as a deterrent to new plants who are considering siting a plant with a procurement area that overlaps an incumbent firm. The intuition behind this is that under supplier delivery, feedstock suppliers at the edge of a processor's collection region are easily poached. Under processor collection, these producers can only be poached if the entrant processor engages in a costly price war with the incumbent processor.

The policy implications of the RFS mandate on least-cost feedstock use can be informed by our results. We learned from the experience of two processors that availability is not equal to supply. Processors' procurement radii in a circular market are larger than anticipated and participation is far lower than the 100% assumed in some of the early studies. Low participation is likely to prevail because monopsonistic processors optimally accept larger procurement area rather than pay a premium to increase participation closer to the plant. Taken together, these results suggest that stover does not represent a lowest-cost feedstock to meet the cellulosic mandate and that other feedstock sources will therefore be required.

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Tables and Figures

Table 1. Optimal Price, Collection Distance and Expenditures for Three Collection Scenarios Absent Competition

	Perfect Price Discrimination (Processor Collection)	Single-Price Monopsonist (Processor Collection)	Single-Price Monopsonist (Supplier Delivered)
Price	$p^* = \left(\frac{tQ}{b}\right)^{0.5}$	$p^* = \left(\frac{tQ}{2b}\right)^{0.5}$	$p* = \left(\frac{2tQ}{b}\right)^{0.5}$
Collection Distance	$R^* = \left(\frac{Q}{bt}\right)^{0.5}$	$R^* = \left(\frac{2Q}{bt}\right)^{0.5}$	$R^* = \left(\frac{2Q}{bt}\right)^{0.5}$
Expenditure	$(t/b)^{0.5} Q^{1.5}$	$\sqrt{2}(t/b)^{0.5} Q^{1.5}$	$\sqrt{2}(t/b)^{0.5} Q^{1.5}$
Land-Unit Payment	$0.5(t/b)^{0.5} Q^{1.5}$	$\frac{\sqrt{2}}{2}(t/b)^{0.5} Q^{1.5}$	$\frac{2\sqrt{2}}{3}(t/b)^{0.5} Q^{1.5}$
Transportation	$0.5(t/b)^{0.5} Q^{1.5}$	$\frac{\sqrt{2}}{2}(t/b)^{0.5} Q^{1.5}$	$\frac{\sqrt{2}}{3}(t/b)^{0.5} Q^{1.5}$

Table 2. Comparison of Optimal Price, Collection Distance and Expenditures when Competing Firms Choose the Same Collection Strategy

	$\left(C_I^{PP}(d), C_E^{PP}(d)\right)$	$\left(C_I^{SS}(d), C_E^{SS}(d)\right)$
Price	$p^* = \frac{2Q}{bd}$	$p_i^* = \frac{2Q}{bd} + \frac{td}{4}$
Collection Distance	$R^* = 0.5d$	$R^* = 0.5d$
Expenditure	$\frac{2Q^2}{bd} + \frac{tdQ}{4}$	$\frac{2Q^2}{bd} + \frac{tdQ}{4}$

Table 3. Simulation Results Comparing Collection Distances, Participation, and Net Prices to Suppliers for Three Collection Mechanisms Without Competition for Feedstocks

Comparison Between Different Collection Mechanism									
Response to price change (b)	Perfect Price Discrimination			Processor Collection			Supplier Delivery		
	Radius	% of supply	Farm Gate Price	Radius	% of supply	Farm Gate Price	Radius	% of supply	Plant price
0.005	43.4	12.0%	24.0	54.7	7.5%	15.1	54.7	22.6%	45.3
0.0075	37.9	15.7%	20.9	47.8	9.9%	13.2	47.8	29.7%	39.6
0.01	34.5	19.0%	19.0	43.4	12.0%	12.0	43.4	35.9%	35.9
0.015	30.1	24.9%	16.6	37.9	15.8%	10.5	37.9	47.1%	31.4
0.02	27.3	30.2%	15.1	34.5	19.0%	9.5	34.5	57.1%	28.5
0.03	23.9	39.6%	13.2	30.1	24.9%	8.3	30.1	74.8%	24.9
0.04	21.7	47.9%	12.0	27.4	30.2%	7.5	27.4	90.6%	22.6
0.05	20.2	55.6%	11.1	25.4	35.0%	7.0	25.4	100%	21.0

Notes: 1. The estimated (simulated) collection radius is 15 miles when we assume the participation rate is 100%.

2. Participation rate for supplier delivery indicates the maximum value that would be observed in the collection area.

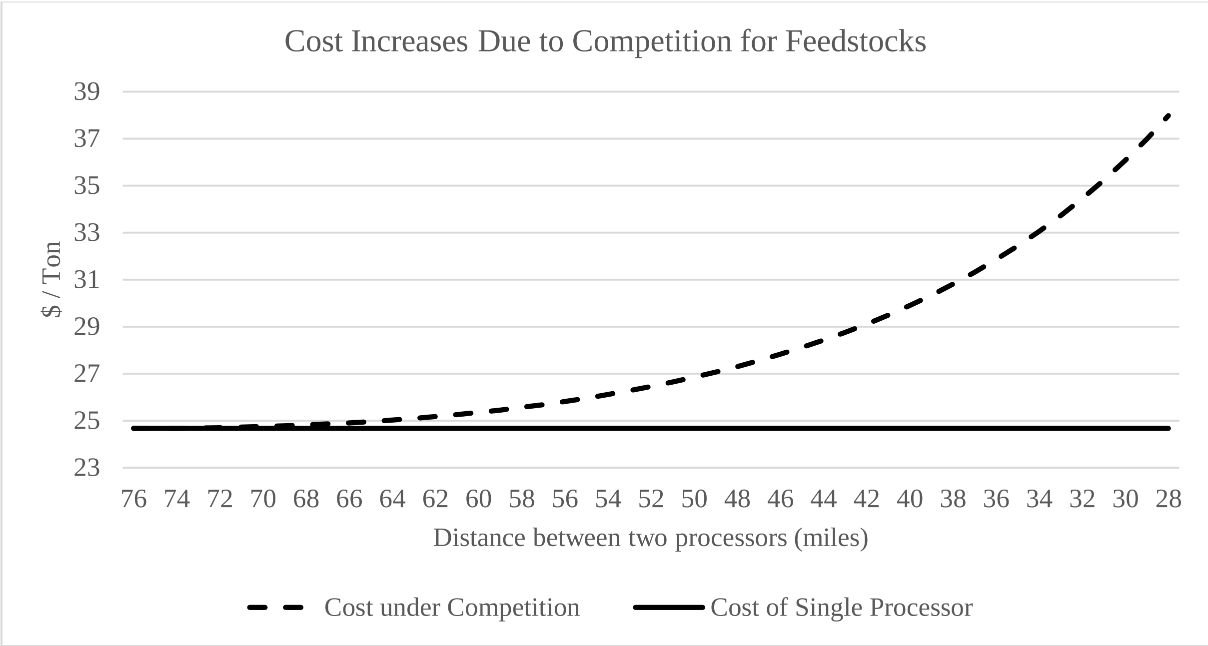


Figure 1. Collection costs based on the distance between processors using processor collection

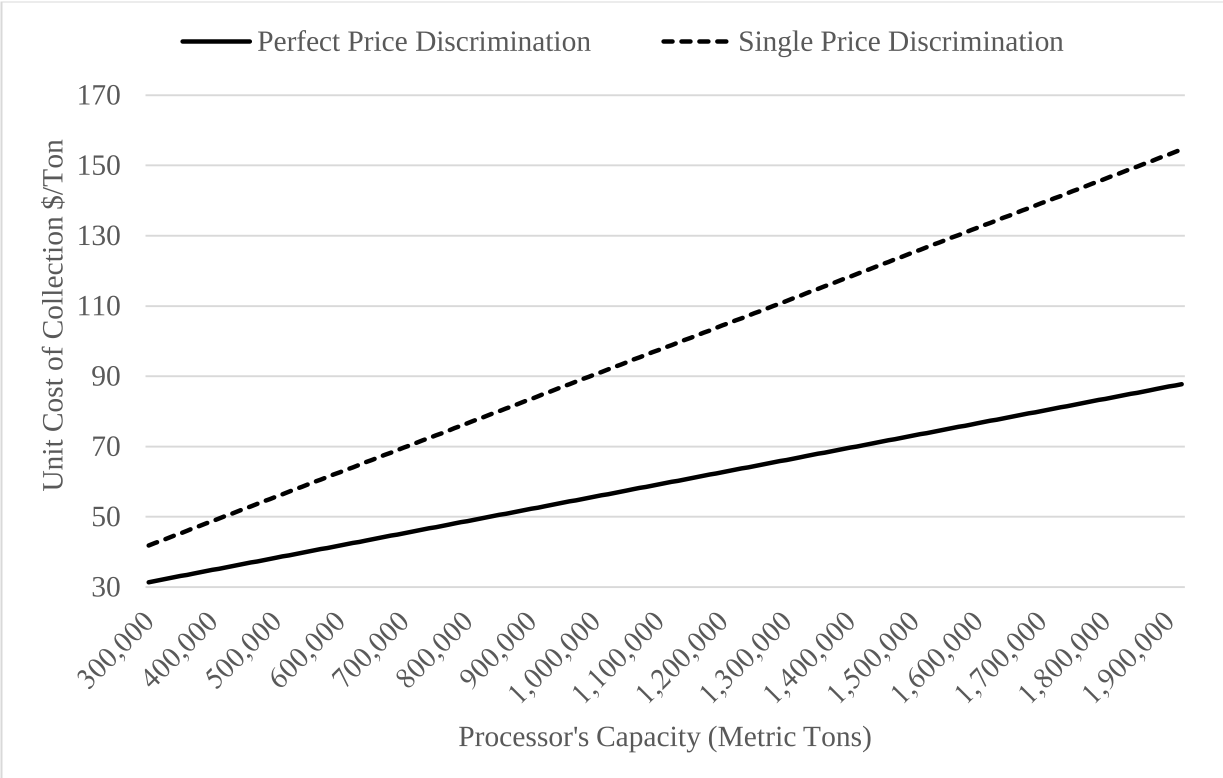


Figure 2. Marginal cost curve to meet processing requirements when the collection radius is fixed.

Title: “Mathematical appendix for biomass for bioenergy: optimal collection mechanisms and pricing when feedstock supply does not equal availability.”

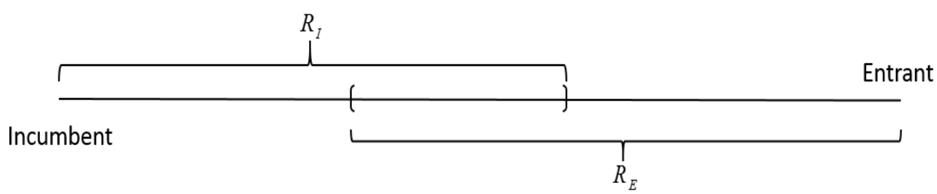
Date: September 28, 2018

Note: This appendix contains details and derivations of the strategic choices of the incumbent and entrant firms as they consider processor collection and supplier delivery procurement and pricing.

Comparing Collection Costs by Strategy

Case 1: Collection costs when both incumbent and entrant use processor collection

The price strategies and collection distances for the incumbent and entrant are (p_I, R_I) and (p_E, R_E), respectively, with total collection quantities, $Q_I = bp_I R_I$ and $Q_E = bp_E R_E$. Both the incumbent and the entrant use processor collection, and the one that offers the higher price will capture all willing suppliers in an overlapping collection area. Because we want to consider firm choices under competition, we limit our analysis to the case where $p_I = p_E = p$ in equilibrium.[17] The collection distance in this scenario is illustrated as follows:



The quantity of feedstock collected by the incumbent is:

(1) $Q_I = bp(d - R_E) + 0.5bp(R_I + R_E - d) = 0.5bpd + 0.5bp(R_I - R_E).$

Similarly, the quantity collected by entrant is:

(2) $Q_E = bp(d - R_I) + 0.5bp(R_I + R_E - d) = 0.5bpd + 0.5bp(R_E - R_I).$

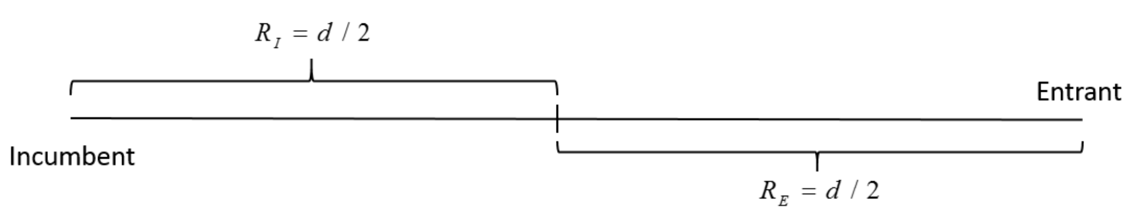
[17] The spatial pricing literature is clear that an equilibrium cannot be an overlapping market because a buyer can increase the price by a small amount and capture all of the suppliers. It can be shown that for both $p_I > p_E$ and $p_I < p_E$ there is no competition because any potential overlapping feedstock draw region is dominated by the higher price processor and the equilibrium result is the strategy for the single processor model. We present the mechanics of this adjustment for readers who are unfamiliar with the spatial pricing literature.

Given that $Q_I = Q_E$ and $R_I = R_E$, the above simply to $Q = 0.5bpd$. Therefore, the optimal price response function for each is $p^* = \frac{2Q}{bd}$.

The total collection costs for each processor is calculated by integrating total feedstock and transportation costs in the non-overlapping area and allocating each processor one-half of the feedstock, and therefore costs, in the overlapping area, such that:

(3) $C_i^{PP} = \int_0^{d-R} bp(p+tr)dr + \frac{1}{2}\int_{d-R}^{R} bp(p+tr)dr$

Substituting $p^* = \frac{2Q}{bd}$ into the solution of the above integral and choosing R to minimize expenditures implies an optimal distance, $R^* = 0.5d$. Thus, relative to the case of no competition, each processor optimally collects more intensely from suppliers close to it by increasing the collection price and therefore supplier participation. The intuition is that it is less expensive to pay marginally more more to ensure sufficient supplies within a nearby and exclusive draw area than to collect stover from a distant draw area that is shared with another firm. The resulting equilibrium collection distance is illustrated:

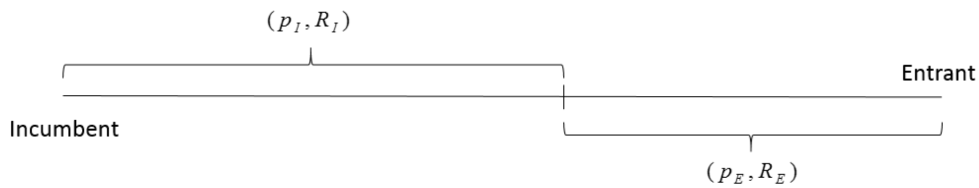


Total collection costs for the incumbent and entrant are:

(4) $C_i^{PP} = \int_0^{d/2} bp(p+tr)dr = \frac{2Q^2}{bd} + \frac{tdQ}{4}, \quad \text{i} = I, E$

Case 2: Collection costs when incumbent and entrant use supplier delivery

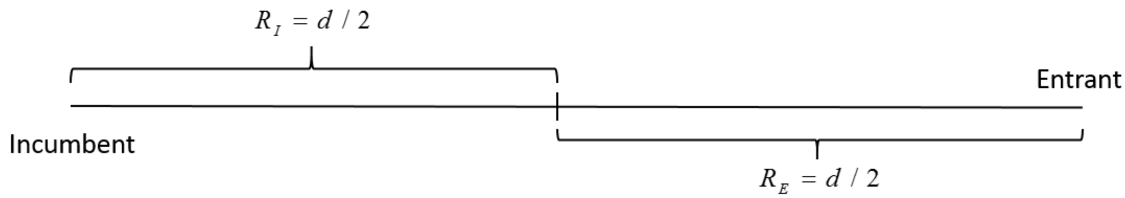
Again, we begin with (p_I, R_I) and (p_E, R_E) as the respective pricing and collection distance strategies for the incumbent and entrant. The collection scenario for each processor is illustrated generally in the following figure:



Suppliers who are r_I distance to the incumbent firm and r_E distance to entrant, where $r_I + r_E = d$, receive net price $p_I - tr_I$ for feedstock delivered to the incumbent and receive net price $p_E - tr_E$ for feedstock delivered to the entrant. Thus, a supplier at the edge of each processors' collection area, R_I distance from the incumbent and R_E distance from the entrant, receives the same net price from each processors: $p_I - tR_I = p_E - tR_E$. Given $d = R_I + R_E$, the collection distance for incumbent is $R_I = \frac{d}{2} + \frac{p_I - p_E}{2t}$ and the collection distance for entrant is $R_E = \frac{d}{2} - \frac{p_I - p_E}{2t}$. Each processor's quantity collected is expressed using distances:

(5) $Q_i = \int_0^{Ri} b(p_i - tr)dr = bp_i R_i - 0.5btR_i^2$.

Given they have the same production requirements, $Q_I = Q_E$, and the derived expressions for R_I and R_E, it follows that $p_I = p_E$ and $R_I = R_E = 0.5d$. The equilibrium collection distance is illustrated as follows:



Optimal price response functions and total costs are found by substituting the known distances into the expressions of processors quantity:

(6) $p_i^* = \dfrac{2Q}{bd} + \dfrac{td}{4}$ and $C_i^{SS} = \int_0^{d/2} bp^*(p^* - tr)dr = \dfrac{2Q^2}{bd} + \dfrac{tdQ}{4}$

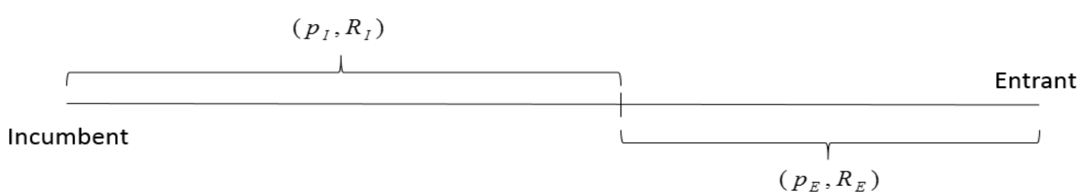
Price, collection distance, and expenditure functions are given in Table 2 for both cases where processors select the same collection mechanism. Total collection costs are equivalent to the scenario where both firms use processor collection, but the feedstock price is higher in this case compared with the processor collection strategy. Intuitively, both processors increase their feedstock price to collect more from those suppliers close to them and avoid competing in an overlapping area. Note that prices and costs in the supplier delivery model with competition are no less than that which will exist absent competition with a supplier delivery strategy.

Case 3: Collection costs when one processor uses processor collection, the other uses supplier delivery

Assume the incumbent uses processor collection and the entrant uses supplier delivery. The pricing strategies are (p_I, R_I) and (p_E, R_E), respectively, and the incumbent therefore chooses $Q_I = bp_I R_I$, implying $p_I = \dfrac{Q_I}{bR_I}$. The entrant chooses the opposite strategy—a supplier delivery mechanism—and has collection quantity of $Q_E = \int_0^{R_E} b(p_E - tr)dr = bp_E R_E - 0.5btR_E^2$, which implies a price, $p_E = \dfrac{Q_E + 0.5btR_E^2}{bR_E}$. Invoking the same requirement of the land unit at the fringe of the processors' collection area, the supplier at the edge of the incumbent's area— R_I distance from the processor's plant using processor collection and R_E distance from the processor using supplier delivery—receives the same net price and is indifferent between the two. Recalling $p_I = p_E - tR_E$, $R_E = d - R_I$, and $Q_I = Q_E$, we know:

(7) $$p_I = p_E - t(d - R_I) = \frac{Q}{b(d - R_I)} - \frac{1}{2}t(d - R_I) = \frac{Q}{bR_I}.$$

Rearranging the above expression and invoking $d = R_I + R_E > R_I$, it must be true that $d - R_I < R_I$, and, therefore, $R_I > \dfrac{d}{2} > R_E$. This result is key: the collection distance under processor collection is always larger than that under supplier delivery when processors use different collection methods.



The optimal collection distance for each processor is function of the distance between them and collection quantities: $R_I^*(d,Q)$ and $R_E^*(d,Q)$. Similarly, the feedstock prices offered by each to suppliers can be expressed as $p_I^*(d,Q)$ and $p_E^*(d,Q)$. Taken together, the total feedstock and collection costs for an incumbent using processor collection is

$C_I^{PS} = p_I^* Q + 0.5 \frac{tQ^2}{bp_I^*}$, and the total feedstock cost for the potential entrant contemplating supplier delivery is $C_E^{SP} = p_E^* Q$.

Biomass for Bioenergy: Optimal Collection Mechanisms and Pricing when Feedstock Supply Does Not Equal Availability

Research Highlights

We examine the collection and pricing choices for a cost-minimizing cellulosic biofuel processor, who initially has monopsony power in feedstock procurement (corn stover) in their collection area and chooses between processor-collection pricing and supplier-delivery pricing. We find:

- Societal welfare is greatest under supplier delivery; the use of a supplier-delivery model is expected in cases when there is no competition for feedstock because though the processor is indifferent, suppliers receive higher net prices in total under supplier delivery versus processor collection.
- A processor can use the processor-collection mechanism as an effective deterrent to entry by a competing firm.
- Based on simulations and experiences of processor with low participation by producers of stover, low participation prevails because monopsonistic processors optimally accept larger procurement area rather than pay a premium to increase participation closer to the plant.
- Our results suggest that corn stover does not represent a lowest-cost feedstock to meet the cellulosic mandate and that other feedstock sources will therefore be required.