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The Case of the U.S. Corn Seed Industry.

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Competition, Price Dispersion and Capacity Constraints:

The Case of the U.S. Corn Seed Industry*

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Abstract: In this paper we examine the effect of competition on price dispersion and argue that the effect is contingent on the ability of firms to meet market demand. Our comparative static results show that competition among symmetrically capacity-constrained firms leads to a price decrease in the lower tail of the price distribution and a price increase in the upper tail. In contrast, competition among symmetrically capacity-unconstrained firms, or among firms with asymmetric capacities leads to an overall price increase along the distribution function. To investigate these findings empirically, we use a novel data set from the U.S. corn seed industry with firm and farm level sales information for conventional and genetically modified corn seeds between 2004 and 2009. We estimate the empirical model using the Fixed Effect Instrumental Variable Quantile Regression, and find evidence consistent with the theory. The analysis also shows that capacity-unconstrained seed firms charge a price premium, confirming the positive relationship between product availability and pricing found in our theoretical model.

JEL classification: L11, L13, L66
Keywords: Market Structure, Capacity Constraints, Consumer Loyalty, Price Dispersion.

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1. Introduction

In generalizing the “law” of one price, economists have proposed theoretical models that predict price dispersion as an equilibrium market outcome. Examples include search-theoretic and clearinghouse models (e.g. Stigler 1961, Rothschild 1973, Reinganum 1979, Macminn 1980, Varian1980, Salop 1977, Shilony 1977, Rosenthal 1980, Narasimhan 1988, Spulber 1985, Baye and Morgan 2001, Baye et al. 2006). In search-theoretic models, price dispersion arises from the marginal search cost paid by consumers to obtain an additional quote in their search for the lowest price (e.g. Stigler 1961, Rothschild 1973, Reinganum 1979, Macminn 1980). In clearinghouse models, an information clearinghouse provides price information, and so search costs are zero. Instead, price dispersion arises due to differences in consumers' decision to access the clearinghouse (e.g. Varian1980, Salop & Stiglitz 1977, Shilony 1977, Rosenthal 1980, Narasimhan 1988), or from firm heterogeneities attributable to asymmetric consumer loyalty (e.g. Narasimhan 1988) and/or asymmetric production costs (e.g. Spulber 1985).[1]

Empirical tests of the predictions from these models almost always rely on the assumption that firms have unlimited-capacity to supply a homogenous product. However, *capacity-constrained* firms are present in many markets. For example, airline companies have a fixed number of seats available for sale for a given flight, and so can become capacity-constrained during peak travel demand. Agribusiness companies marketing to farmers have a limited number of seeds available to sell, because they make seed production decisions at least one season prior to the marketing. Theoretical and empirical analyses of price dispersion have not accommodated these real-world complexities.

In this paper, we contribute to the price dispersion literature by first presenting a clearinghouse model of price dispersion when (1) firms have asymmetric capacity-constraints to

[1] Baye et al. 2015 describes in more detail the literature on price dispersion.

supply a homogenous product, and (2) consumers are heterogeneous in preference (loyal vs. price sensitive) with same reservation prices. A clearinghouse model is more appropriate than a search-theoretic model, because in industries such as these, price dispersion is "temporal", meaning that firms may charge different prices for the same product at each point in time, but their position in the distribution of prices could change over time. As a result, the equilibrium is characterized by firms playing mixed strategies in prices. We show that our model generates "temporal" price dispersion due to such exogenous consumer heterogeneity and firm heterogeneity. In addition, our clearinghouse model provides a direct interpretation of the effect of competition on price dispersion: the equilibrium distribution of price depends on the number of firms in the market.

We then test our model's predictions relating to the effect of competition on price dispersion and the relationship between product availability and pricing. We use a novel data set from the U.S. corn seed industry, which provides firm and farm level purchase information for conventional and genetically modified corn seeds sold by different firms between 2004 and 2009. This industry has experienced considerable structural changes since the 1990s, following biotechnological breakthrough aimed at improving agricultural productivity via seed genetic modification. The corn seed market is now a major industry dominated by five large biotechnology firms,[2] yet empirical studies documenting the effect of this consolidation remain rare, due to the lack of data.

Our theoretical analysis begins with a two-stage game where the first stage follows the capacity-constraints model in Denekere (1986), while the second stage is developed based on Varian (1980)'s model of sales and Narasimhan (1988)'s model of asymmetric customer base. On the supply side, we assume a finite number of price-setting firms that compete in a market for a

[2] These are: Monsanto, DuPont, Syngenta, Dow Agrosciences, and AgReliant.

homogeneous good. Firms can be capacity-constrained or capacity-unconstrained. On the demand side, consumers are of two types: loyal and price sensitive. They have unit demand for the good and a maximum willingness to pay denoted by *r*. Each firm has its own loyal customer base and the market is equipped with a price information clearinghouse that one receives and/or provides price information at zero nominal cost (e.g. newspaper, internet search engine). The subgame-perfect equilibria are found by backward induction.

The equilibrium in the second stage of the game is a mixed strategy in price. The comparative static results predict that the effect of competition on price dispersion is contingent on firms' capacities. An increase in competition among symmetrically capacity-constrained firms leads to a price decrease in the lower tail of the price distribution and a price increase in the upper tail of the distribution. In contrast, competition among symmetrically capacity-unconstrained firms, or among firms with asymmetric capacity levels (market consisting of both capacity-constrained and capacity-unconstrained firms) leads to a price increase along the distribution function. The results also show that capacity-unconstrained firms charge higher prices at each quantile of the distribution function.

In our empirical analysis we measure price dispersion using a dispersion statistic and estimate the whole distribution of prices, using the Fixed Effect Instrumental Variable Quantile Regression (FE IV Quantile Regression). This is a generalization over previous empirical studies, which focus the analysis only on the first and second moment of the price distribution. In addition, although numerous empirical studies investigate the predictions of clearinghouse models (e.g., Barron et al. 2004, Baye et al. 2004, Haynes and Thompson 2008), the literature has focused almost entirely on markets where capacity-constrained firms are the exception, rather than the rule. Thus there is little empirical evidence on the relationship between product availability and pricing.

In this paper we fill this literature gap by studying an industry that is important for at least three reasons. First, US seed corn companies engage in both “temporal" and spatial price discrimination. Second, seed firms differ in their ability to meet the market demand for their products, and can therefore be either capacity-constrained or capacity-unconstrained. Third, the industry is characterized by a high degree of brand loyalty among farmers. Corn yield is correlated with the performance and the type of seed planted, and so corn farmers tend to be loyal to a company whose seed products yield high output on their fields.

We find empirical evidence that confirms the predictions of our theoretical clearinghouse model. An increase in competition among symmetrically capacity-unconstrained seed firms leads to a price increase at each quantile of the price distribution. Similar results are obtained when competition is between seed firms with asymmetric capacities. Additionally, we find that corn farmers may trade price and product availability, allowing capacity-unconstrained firms to charge a price premium at each quantile of the distribution function.

The reminder of the paper is organized as follows: Section 2 provides a characterization of the equilibrium in the two-stage clearinghouse model and comparative statics predictions. section 3 introduces the data relating to the U.S. corn seed industry and descriptive statistics. The econometric model of price dispersion and the estimation method are presented in section 4. Finally, we discuss the empirical findings in section 5 and conclude in section 6.

2. The model

In this section, we present a theoretical model that price dispersion is driven by imperfect information on the demand side due to exogenous differences in consumer preferences and on the supply side due to firm heterogeneities. Firms differ in their loyal customer bases and supply capacities.

We construct a two-stage game where the first stage follows the capacity-constraints model of Denekere (1986), and the second stage is developed based on Varian (1980)'s model of sales and Narasimhan (1988)'s model of asymmetric customer base. The subgame-perfect equilibria are found by backward induction: In stage two, firms choose prices independently and simultaneously following a Nash equilibrium given different capacity choices in stage one. In stage one, firms choose capacities simultaneously and independently also following a Nash Equilibrium given the corresponding equilibrium prices in the second stage.

2.1. The two stage game

On the supply side, we assume a finite number of price-setting firms, $N > 1$ which can be capacity-constrained or capacity-unconstrained. On the demand side, a continuum of consumers have unit demand for the good and a maximum willingness to pay, $r > 0$. The market is equipped with a clearinghouse that provides price information. We assume that if choosing to do so, firms and consumers can list or get access to price information at no cost.

There are two types of consumers: 1) *price sensitive shoppers* who choose to access the clearinghouse in order to be informed about prevailing market prices. They buy the product with the lowest listed price, and if no product is listed they will visit a firm randomly; And 2) *loyal consumers* who will always choose to purchase a particular brand regardless of price as long as it is less than the reservation value. They choose not to access the clearinghouse and stay uninformed about other firms' pricing practice. Each firm has its own loyal customer base and we assume that a loyal type customer will be loyal to one and only one firm. Let $L_i \geq 0$ denote the number of loyal consumers loyal to firm i.

The timing of the game is as follows. In the first stage, firms simultaneously and independently choose a capacity level $K_i, i = 1,2, \dots N$. And we assume that each firm will be able to serve at least its own loyal customers, $K_i > L_i$. The cost to install capacity K_i is normalized to zero. After the first stage, capacity decisions become common knowledge to all firms. In the second stage, firms simultaneously and independently choose a distribution of prices following the probability density function $f(p_i)$ and supply the demand they face, q_i, for price p_i, at total cost $c(q_i)$.[3]

Let the total market demand $D(p)$ given a single market price p, be defined as follows:

$$D(p) = D_s(p) + \sum_i D_{L_i} \quad .$$

where $D_s(p) > 0$ is the total demand of price sensitive shoppers, and $D_{L_i} \geq 0$ is the demand of consumers loyal to firm i. Without loss of generality we assume $D(p)$ is equal to 1.

We examine how the total market demand is allocated among firms. We assume that each firm firstly serves its loyal customer base. Then, when the lower-priced firm *cannot* meet the entire demand of price-sensitive shoppers, the sales of the remaining firms occur following Beckmann (1965)'s contingent demand rationing.[4] With this specification, all price sensitive shoppers have the same probability of being rationed by a non-lowest-priced firm.[5] Assuming firm j charges the lowest price in the market, the probability of not being served by firm j is:

[3] We assume that firms' cost functions exhibit decreasing returns to scale, i.e. $c(q_i)$ is increasing and convex: $c'(q_i) > 0$, $c(q_i) \geq 0$ for $q_i > 0$.
[4] Also called the proportional-rationing rule.
[5] Note that loyal consumers are not rationed, they purchase only from the company they are loyal to. The demand of loyal consumers is independent of the price level, provided it is below the reservation price, r.

$$\begin{cases} \left[1-\dfrac{K_j-L_j}{D_s(p_j)}\right] & ,if\ K_j-L_j \le D_s(p_j) \\ 0 & ,otherwise \end{cases}$$ [6] .

Then, the residual demand faced by any firm i charging $p_i > p_j$ is given by:

$$\begin{cases} D_s(p_i)\left[1-\dfrac{K_j-L_j}{D_s(p_j)}\right]\left(\dfrac{K_i-L_i}{\sum_{r\neq j}(K_r-L_r)}\right) & ,if\ K_j-L_j \le D_s(p_j) \\ 0 & ,otherwise \end{cases} .$$

implying that the residual demand is shared among all the firms charging a price greater than p_j. The sharing proportion depends on each firm's relative residual capacity after serving their own loyal customers.

To simplify notation, let

$$x_i = \left(1-\frac{K_j-L_j}{D_s(p_j)}\right)\frac{K_i-L_i}{\sum_{r\neq j}(K_r-L_r)} \ .$$

We then formulate the demand for firm i's product as a function of its own price p_i and for any given value of competitors' prices p_{-i} as follows:

$$D(p_i|p_{-i}) = \begin{cases} \min[K_i, L_i + D_s(p_i)]\,, & p_i < p_{-i} \\ \min\left[K_i, \max\left(L_i + \dfrac{D_s(p_i)}{n}\right), L_i + D_s(p_i) - \sum_{-i}(K_{-i} - L_{-i})\right], & p_i < p_{-i} \\ \min[K_i, L_i + D_s(p_i)\cdot x_i]\,, & p_i > p_j \end{cases}$$

Finally, the strategy space of each firm is continuous, ranging between the firm's corresponding average cost, denoted as p_i^* as it is also the firm's reservation selling price, and the consumer's

[6] In this case firm j is capacity-constrained.

reservation buying price, r. The maximum number of consumers a firm can serve is $\min[K_i, L_i + D_s(p_i)]$. Then, p_i^* is defined as:

$$p_i^* = \frac{c(\min[K_i, L_i + D_s(p_i)])}{\min[K_i, L_i + D_s(p_i)]} \quad .$$

We find the subgame-perfect equilibria of the two-stage game by backward induction. Next we focus on the second stage of the game and compute the equilibrium prices for given capacity levels.

2.1.1. The price subgame

Let K_i, K_{-i} be the capacities chosen in the first stage by firm i and its competitors $-i$. Let L_i, L_{-i} be their corresponding loyal customer base. Assume without loss of generality that firms may be symmetric or asymmetric in either feature.[7] For any price p, the following restrictions are imposed:

Assumption 1: The market demand function $D(p): \mathbb{R}_{++} \to \mathbb{R}_{++}$ is differentiable and strictly decreasing in p.

Assumption 2: The market demand function $D(p) = 0$ if $p > r$ and $D(p) > 0$ if $p < r$, and $\lim_{p \to 0} D(p) = +\infty$ and $\lim_{p \to \infty} D(p) = 0$.

Assumption 3: The market revenue function, $p * D(p): \mathbb{R}_{++} \to \mathbb{R}_{++}$ is single peaked and attains a unique maximum at the consumer's reservation price, r.

Assumption 4: The market revenue function $p * D(p)$ is strictly concave in p for $p < r$.

Assumption 5: There exists a quantity q^*such that the average cost p_i^* takes on the minimum value: for $q \leq q^*, \frac{\partial p_i^*(q)}{\partial q} \leq 0$, and for $q \geq q^*, \frac{\partial p_i^*(q)}{\partial q} \geq 0$.

[7] When $K_i = K_{-i}$ and $L_i = L_{-i}$, the capacity level and the loyal customer base are symmetric. When $K_i \neq K_{-i}$ and $L_i \neq L_{-i}$, they are asymmetric.

Assumption 6: The equilibrium pricing strategy is static.[8]

Assumption 7: There are barriers to entry, with N fixed in the short run.

Theorem 1. For each pair (K_i, K_{-i}) and (L_i, L_{-i}), there exists a unique set of Nash equilibrium in prices:

1) If all firms are capacity-constrained and $\mathrm{K_i} + \sum_{-i} \mathrm{K_{-i}} \leq \mathrm{D(p^*)}$, the equilibrium is a pure strategy with each firm charging the consumer's reservation price, r.
2) If all firms are capacity-constrained but $\mathrm{K_i} + \sum_{-i} \mathrm{K_{-i}} > \mathrm{D(p^*)}$, the equilibrium is a mixed strategy.
3) If all firms are capacity-unconstrained, the equilibrium is a mixed strategy.
4) If there is a mix of capacity-constrained and capacity-unconstrained firms such that $\mathrm{K_i} + \sum_{-i} \mathrm{K_{-i}} > \mathrm{D(p^*)}$ with $K_i \geq D(p^*)$ and $\mathrm{K_{-i}} < \mathrm{D(p^*)}$, or $K_i < D(p^*)$ for all $-i$ firms, then the equilibrium is a mixed strategy.
5) If there is a mix of capacity-constrained and capacity-unconstrained firms such that $\mathrm{K_i} + \sum_{-i} \mathrm{K_{-i}} > \mathrm{D(p^*)}$ with $K_i < D(p^*)$ and $\mathrm{K_{-i}} \geq \mathrm{D(p^*)}$ for all $-i$ firms, then the equilibrium is a mixed strategy.

Proof: See appendix A.

Given the predictions stated in Theorem 1, we now establish a mixed strategy pricing equilibrium for firm i. Let $f(p_i)$ denote the probability density function for firm i's price p_i. Each time period, the firm randomly draws a price out of $f(p_i)$.

When firm i happens to draw the lowest price in the market, the event is considered a **win**

[8] The static equilibrium assumes a repeated game with infinite horizon. However, history (past prices) does not matter in the firms' equilibrium actions.

(w) and the number of consumers being served by firm i is:

$$\min[K_i, L_i + D_s(p_i)] \quad .$$

When firm i fails to draw the lowest price, the event is considered a **loss (l)** and the number of consumers the firm will serve is:

$$x_i \cdot \min[K_i, L_i + D_s(p_i)] \quad .$$

When firm i and one or more other firms draw the same lowest price, the event is considered a **tie** and each lowest priced firm gets:

$$\min\left[K_i, \max\left(L_i + \text{ } equal\ share\ of\ D_s(p_i)\ consumers, L_i + D_s(p_i) - \sum_{-i}(K_{-i} - L_{-i})\right)\right] \quad .$$

Proposition 1: The equilibrium pricing strategy has a continuous probability distribution.

Proof: Similar to Varian (1980), assume that at the equilibrium, firm i may charge some $\tilde{p}_i$ with positive probability.[9] Then, given a tie at $\tilde{p}_i$, firm i can deviate and charge a lower price $(\tilde{p}_i - \varepsilon)$. Firm i will trade an ε portion of its existing profit margin for additional profits from the sales attracted away from its tied competitors. This outcome is contradictory to the equilibrium concept. Therefore, in the equilibrium, there is no mass point along the price density function. The equilibrium pricing strategy has a continuous probability distribution. QED.

Let $F(p_i)$ denote firm i's cumulative distribution function. $F(p_i)$ is continuous on $[p^*, r]$ Then, for p_i, the **expected profit** of firm i is given by:

$$\int_{p^*}^{r} \left\{\Pi_w(p_i) \cdot [1 - F(p_i)]^{N-1} + \Pi_l(p_i) \cdot \left[1 - \left(1 - F(p_i)\right)^{N-1}\right]\right\} f(p_i) dp_i \quad . \qquad (1)$$

where

[9] Note that $f(p^*) = 0$ because when p^* is the lowest price, profits are zero, and if there is a tie at p^*, profits will be negative.

$$\Pi_w(p_i) = \{(p_i - c) \cdot \min[K_i, L_i + D_s(p_i)]\}$$

$$\Pi_l(p_i) = \{(p_i - c) \cdot \min[K_i, L_i + D_s(p_i) \cdot x_i]\}$$

and

$[1 - F(p_i)]^{N-1}$ is the probability that firm i charges the lowest price among the N firms, and $[1 - [1 - F(p_i)]^{N-1}]$ is the probability that there is at least one other firm with a lower price than firm i. We omit the event of a tie since it was proven in Proposition 1 that the probability of a tie is zero.

The objective of firm i is to maximize expected profits (as shown in equation (1)) by choosing the density function $f(p_i)$ subject to the constraints:

$$\mathrm{f}(p_i) \geq 0 \; and \; \int_{p^*}^{r} f(p_i)\, dp_i = 1 \quad ,$$

taking as given the strategies of the other firms and the behavior of consumers. A mixed pricing strategy is a Nash Equilibrium if and only if all the prices charged with positive probability density ($f(p_i) > 0$), yield the same expected profit. Without entry in the short run, each firm may expect at least the profits in the *loss* event:

$$\Pi_l(r) = \{(r - c) \cdot \min[K_i, L_i + D_s(p_i) \cdot x_i]\} \quad ,$$

Then, the equilibrium density function for prices $f(p_i)$ is the solution to the following problem:

$$\Pi_w(p_i) * [1 - F(p_i)]^{N-1} + \Pi_l(p_i) \cdot \left[1 - \left(1 - F(p_i)\right)^{N-1}\right] = \Pi_l(r) \quad .$$

Rearranging terms and solving for the cumulative distribution function one obtains:

$$1 - \mathrm{F}(p_i) = \left[\frac{\Pi_l(p_i) - \Pi_l(r)}{\Pi_l(p_i) - \Pi_w(p_i)}\right]^{\frac{1}{N-1}} \quad . \qquad (2)$$

The denominator in the right hand side is negative for any $p_i \in [p^*, r]$. Hence, the numerator must be negative so that profits in the event of *loss* under a price equal with the consumer's reservation buying price, r are definitely greater than profits in the event of *loss* under any other price less than r. To guarantee a proper cumulative distribution function, $F(p_i)$ has to be an increasing function of p_i. This is true whenever:

Proposition 2: $\left[\frac{\Pi_l(p_i)-\Pi_l(r)}{\Pi_l(p_i)-\Pi_w(p_i)}\right]$ is strictly decreasing in p_i.

Proof: Taking the derivative with respect to p_i I show that $[\Pi_l(p_i) - \Pi_w(p_i)]\{\min[K_i, L_i + D_s(p_i) \cdot x_i]\} + [\Pi_l(p_i) - \Pi_l(r)]\{\min[K_i, L_i + D_s(p_i)] - \min[K_i, L_i + D_s(p_i) \cdot x_i]\} < 0$, when $[\Pi_l(p_i) - \Pi_w(p_i)] < 0$, and $[\Pi_l(p_i) - \Pi_l(r)] < 0$, which is obviously true. Therefore, the expression derived in equation (2) is a legitimate candidate for a cumulative distribution function.

Proposition 3: In equilibrium, for $p_i \in [p^*, r]$ the cumulative distribution function of firm i's pricing is:

$$\mathrm{F}(p_i) = 1 - \left[\frac{(r - p_i) \cdot \min[K_i, L_i + D_s(p_i) \cdot x_i]}{(p_i - c)\{\min[K_i, L_i + D_s(p_i)] - \min[K_i, L_i + D_s(p_i) \cdot x_i]\}}\right]^{\frac{1}{N-1}} \quad . \tag{3}$$

Proof: Deviating to a price lower than the firm's reservation selling price, $p^*$is not advantageous since only negative profits can be obtained. Similarly, pricing above the consumer's reservation buying price, r is not a profitable deviation because there is zero demand at any such price. Finally, since $\lim_{p_i \to r} F(p_i) = 1$ and $\lim_{p_i \to p^*} F(p_i) = 0$ and $F(p_i)$ is increasing in p_i, F is a well defined cumulative distribution function. QED.

Alternatively, expression (3) can be written in terms of p^*. Note that if firm charges $p_i = p^*$, the event will be a *win* and its profits satisfy $\Pi_w(p_i^*) = \Pi_l(r)$. I have:

$$p_i^* = \frac{r \cdot \min[K_i, L_i + D_s(p_i) \cdot x_i]}{\min[K_i, L_i + D_s(p_i)]} \quad .$$

Plugging the expressions for $\Pi_w(p_i)$, $\Pi_l(p_i)$ and $\Pi_l(r)$into (2) yields:

$$\mathrm{F}(p_i) = 1 - \left[\frac{(r - p_i) \cdot p_i^*}{(p_i - c) \cdot (r - p_i^*)}\right]^{\frac{1}{N-1}} \quad . \tag{3'}$$

Plugging p^* into equation (3') and taking the derivative with respect to p, I obtain the equilibrium probability density function:

$$f(p_i) = \frac{1}{N-1} \frac{(r-c)}{(p_i - c)^2} \left[\frac{(r-p_i)}{(p_i - c)}\right]^{\frac{1}{N-1}-1} \left[\frac{\min[K_i, L_i + D_s(p_i) \cdot x_i]}{\min[K_i, L_i + D_s(p_i)] - \min[K_i, L_i + D_s(p_i) \cdot x_i]}\right]^{\frac{1}{N-1}}. \tag{4}$$

Or, expressed in terms of p^* as:

$$f(p_i) = \frac{1}{N-1} \frac{(r-c)}{(p_i - c)^2} \left[\frac{(r-p_i)}{(p_i - c)}\right]^{\frac{1}{N-1}-1} \left[\frac{p_i^*}{(r - p_i^*)}\right]^{\frac{1}{N-1}}. \tag{4'}$$

Proposition 4. Firm i plays a pure strategy in prices and charge the consumers' reservation buying price, r whenever the total production capacity in the market is less or equal with the market size ($K_i + \sum_{-i} K_{-i} \leq 1$).

Proof: Assume to the contrary that whenever $K_i + \sum_{-i} K_{-i} \leq 1$, firm i prices according to the equilibrium distribution function $F(p_i)$ for $p_i \in [p^*, r]$. Now, it is clear that any price less than r will result in lower profits because when all $-i$ firms sell to capacity there are still price sensitive consumers in the market. Thus, it is profit maximizing for firm i to charge a single price, namely the consumers' reservation value, r. QED

2.2. Comparative Statics

Our clearinghouse model can be used to derive predictions about the distributional effects of competition on price, and about the relationship between product availability and pricing. The model can generate four scenarios:

Scenario 1: symmetric capacity, symmetric loyalty ($K_i = K_{-i},\ L_i = L_{-i}$).

Scenario 2: asymmetric capacity, asymmetric loyalty ($K_i \neq K_{-i},\ L_i \neq L_{-i}$).

Scenario 3: asymmetric capacity, symmetric loyalty ($K_i \neq K_{-i},\ L_i = L_{-i}$).

Scenario 4: symmetric capacity, asymmetric loyalty ($K_i = K_{-i},\ L_i \neq L_{-i}$).

In this section, we will rely on simulation of the equilibrium distribution function to obtain the comparative static results under each of the four scenarios. Detailed information on how these simulations are performed is presented in the following subsections. In this paper, we will present results for the first two scenarios, and those for the other two scenarios are available upon request.

2.2.1. Scenario 1: Symmetric Capacity and Symmetric Loyalty

In this scenario, competition is between firms with symmetric capacity levels. Proposition (4) shows that firms play mixed strategies in pricing whenever $K_i + \sum_{-i} K_{-i} > 1$. This generates two cases:

Case 1a.: $K_i = K_{-i} < 1$ (symmetric capacity-constrained firms).

Case 1b.: $K_i = K_{-i} > 1$ (symmetric capacity-unconstrained firms).

Thus, competition can be between symmetric capacity constrained-firms <u>or</u> symmetric capacity-unconstrained firms. We simulate the benchmark case by setting the number of firms at $N = 2$, the capacity level at $K_i = 0.7$ for case 1a and 1.5 for case 1b. We also set the size of loyal consumers at $L_i = 0.02$. The total cost is set at $c = 0$ and the reservation price at $r = 250$. We further assume “no business stealing effect”: When a new firm enters the market, its loyal customer base comes only from the price sensitive consumers but not from those loyal customers of the incumbent firms. We then generate the predictions of competition effects by increasing N from 2 to 3 in both case 1a and case 1b; the capacity effects by changing K_i from 0.7 and 1.5 in the two cases to 0.6 and 1 correspondingly; and the loyalty effects by increasing L_i from 0.02 to 0.2 in both case 1a and case 1b.

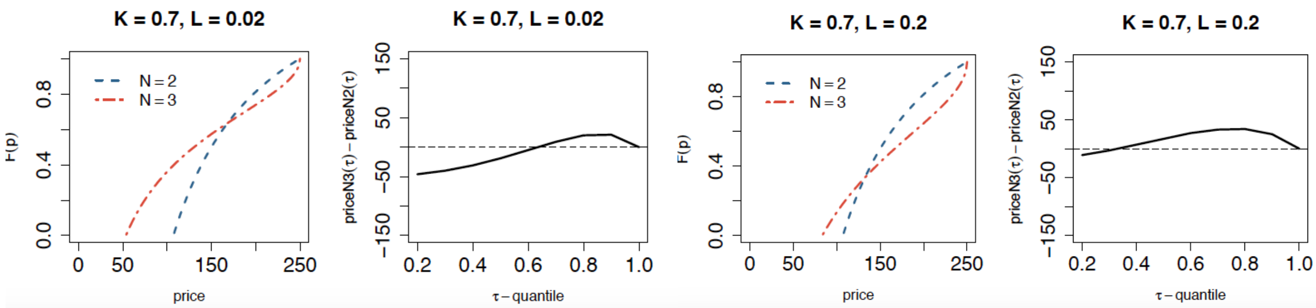
We obtain the following result:

Result 1. The effect of competition on pricing differs by firms' capacities:

Case 1a: As the number of capacity-constrained firms increases, price decreases in the low quantiles but increase in the high quantiles.

Case 1b: As the number of capacity-unconstrained firms increases, price increases in all quantiles.

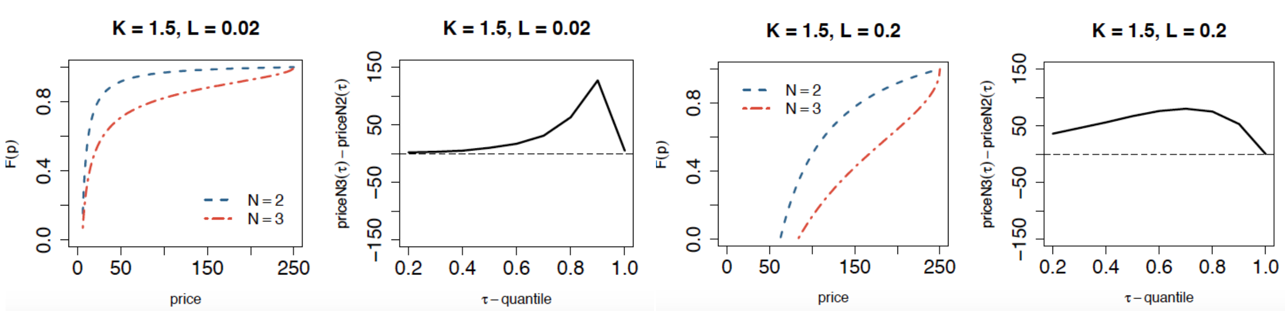
Figure 1 illustrates the results for Case 1a. We observe that an increase in the number of competitors has a *non-uniform effect* on the distribution function. Price sensitive shoppers pay a lower price than the loyal customers and increased competition seems to drive the gap further wide. Note that we assume entry in the industry does not lead to business stealing in the loyal customer base. When a new firm enters the market, the residual demand from price sensitive consumers decreases because some of these shoppers become loyal customer to the entrant firm. As a result, the incentive to price low to attract the price sensitive group decreases. The decreased competition for the price sensitive shoppers in turn leads to a price increase in order to extract more surplus from the loyal consumers. When varying the loyal customer base ($L = 0.2$), we found qualitatively consistent results, yet the magnitude of the competition effect will be larger when the size of loyal consumers in the market is larger. In addition, a large number of loyal consumers results in a greater impact in the lower tail of the price distribution.



(a) (b)

Figure 1: Effect of competition and loyalty for capacity-constrained firms. Panel (a)-(b): Cumulative distribution function (left) and its corresponding quantile function (right). The results are robust to changing K_i from 0.7 to 0.6.

Figure 2 illustrates the results for Case 1b. We now find that an increase in the number of firms has a *uniform positive effect* on the distribution function, leading to an increase in prices for all quantiles. Consumers pay a higher price after the entry of the new firm. This result may suggest that firms focus on extracting surplus from the loyal customer base. Again, the magnitude of the competition effect increases with the size of loyal consumers in the market. The impact is greater in the lower tail of the price distribution when the number of loyal consumers in the market is relatively high.



(a) (b)

Figure 2: Effect of competition and loyalty for capacity-unconstrained firms. Panel (a)-(b): Cumulative distribution function (left) and its corresponding quantile function (right). The results are robust to changing K_i from 1.5 to 1.

2.2.2. Scenario 2: Asymmetric Capacity and Asymmetric Loyalty

In this scenario, competition is among firms with asymmetric capacity levels. According to Proposition 4, firms play mixed strategies in pricing when $K_i + \sum_{-i} K_{-i} > 1$. This setup generates the following four cases:

Case 2a.: $K_i < 1$, $K_{-i} < 1$. (all capacity-constrained firms).

Case 2b.: $K_i \geq 1$, $K_{-i} \geq 1$ (all capacity-unconstrained firms).

Case 2c.: $K_i < 1$, $K_{-i} \geq 1$. (capacity-constrained firm facing with competition from capacity-unconstrained firms).

Case 2d.: $K_i \geq 1$, $K_{-i} < 1$. (capacity-unconstrained firm facing with competition from capacity-constrained firms).

While we have obtained the results for all four cases, we will present here only case 2c. as it provides useful hypothesis for our empirical testing later.[10] The other results are reported upon request.

Again we simulate the benchmark case by setting the number of firms at $N = 2$, the capacity level at $K_i = 0.7$, $K_{-i} = 1$, and the size of loyal consumers at $L_i = 0.01$, $L_{-i} = 0.02$. The total cost is set at $c = 0$ and the reservation price at $r = 250$. And we impose the "no business stealing effect" the same as before. We then generate the predictions of competition effects by increasing N from 2 to 3, with the capacity and loyal consumers of the new firm set at the same levels with firm $-i$; the capacity effects by changing K_i from 0.7 to 0.3; and the loyalty effects by increasing L_i, L_{-i} from 0.01, 0.02 to 0.1, 0.2. Further, we look at the setting where the entrantfirm does not set the lowest price in the market, as it is again more useful for our hypothesis testing.[11]

[10] Our data suggests that capacity-unconstrained firms represent around 75 percent of new firm entries in a given market.
[11] Note that under this assumption, Case 2c. and Case 2d. yield similar results, differing only in the magnitude of the effect.

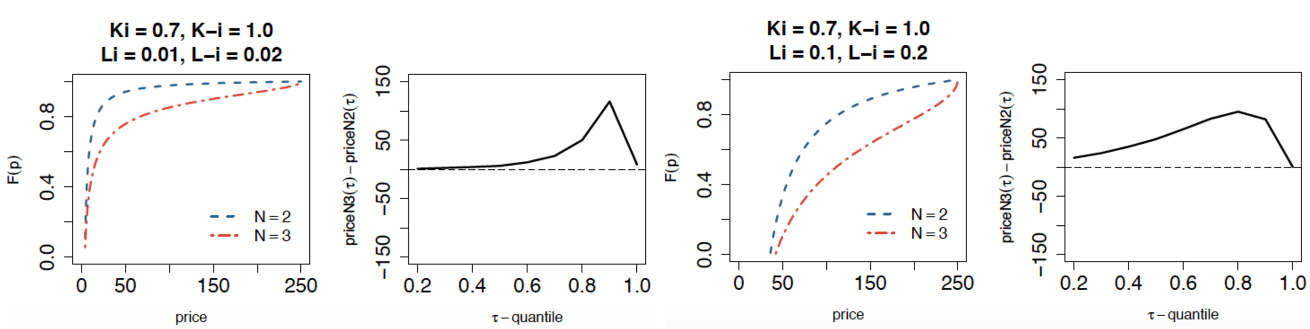
Our results for case 2c. are as follows:

Result 2. The effects of competition on the distribution function of prices differ by firms' capacities and size of loyal customer base:

1. *Response of the capacity-constrained firm: The increased competition from capacity-unconstrained firms leads to an overall price increase in all quantiles.*

2. *Response of the capacity-unconstrained firm: The increased competition from capacity-unconstrained firms leads to an overall price increase in all quantiles when the capacity of the capacity-constrained firm and the size of loyal consumers in the market are sufficiently large.*

Figure 3 illustrates *the response of the capacity-constrained firm* (firm i). We observe that an increase in the number of capacity-unconstrained firms leads to higher prices paid by all consumers in the market. It seems that firm i may focus on extracting more surplus from its loyal customers and withdraw from the price sensitive shoppers. When varying the loyal customer base ($L_i = 0.1, L_{-i} = 0.2$), we found qualitatively consistent result, yet the magnitude of the competition effect will be larger when the size of loyal consumers in the market is larger. Figure 3(a) vs. 3(b) also show that the impact is larger in the lower tail of the price distribution when more loyal consumers exist in the market.



(a) (b)

Figure 3: Effect of competition and loyalty: Response of the capacity-constrained firm. Panel (a)-(b): Cumulative distribution function (left) and its corresponding quantile function (right). The results are robust to changing K_i from 0.7 to 0.3.

Figure 4 illustrates the *response of the capacity-unconstrained firm* ($firm\ -i$). When incumbent firm i is of relatively low capacity ($K_i = 0.3$), the increase in the number of capacity-unconstrained firms, leads to a lower price charged by firm $-i$ to all consumers in the market. An increase in the loyal customer base (e.g. L_i from 0.01 to 0.1 and L_{-i} from 0.02 to 0.2) would narrow the price jump, but does not alter the overall trend. However, when the incumbent firm i's capacity is relatively large ($K_i = 0.7$) while the loyal customer base is relatively small ($L_i = 0.01$ and $L_{-i} = 0.02$), then an increase in number of firm $-i$ with $K_{-i} = 1$ will lead to a price increase charged by firm – i in the high quantile. And when the size of loyal customer base also increases, then the trend would overturn completely: now firm – i would charge a higher price to all consumers in the market after the entry of the new firm. It may suggest a switch of pricing strategy from competing for the price sensitive shoppers to extracting surplus from the loyal customers. Again, figure 4(c) vs. 4(d) indicate that a larger share of loyal consumers will result in a greater impact on the lower tail of the price distribution.

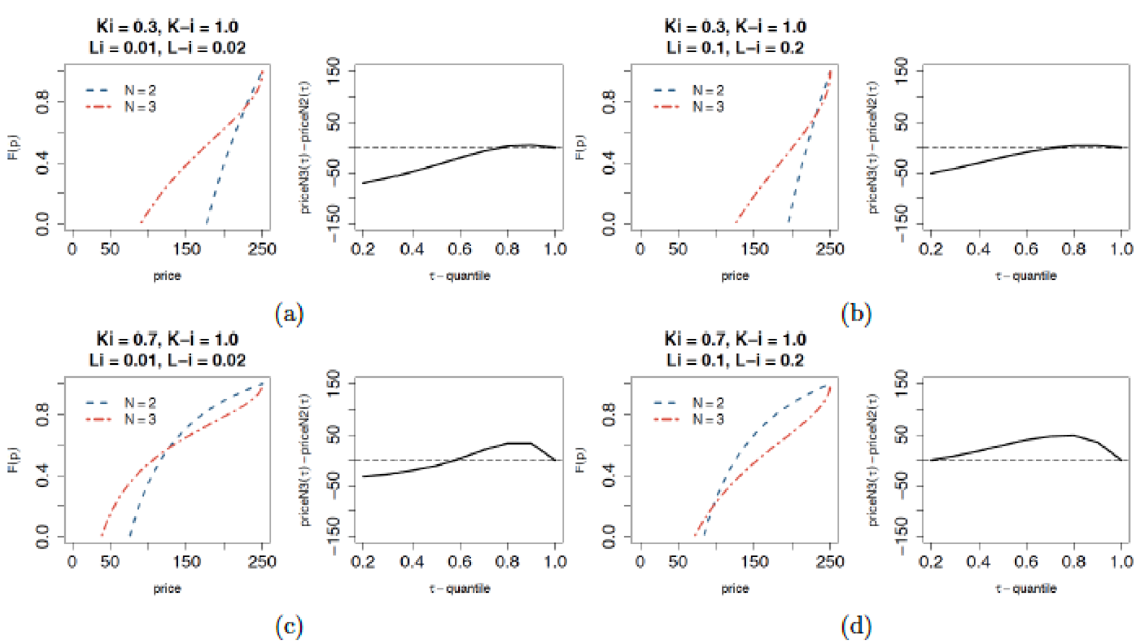
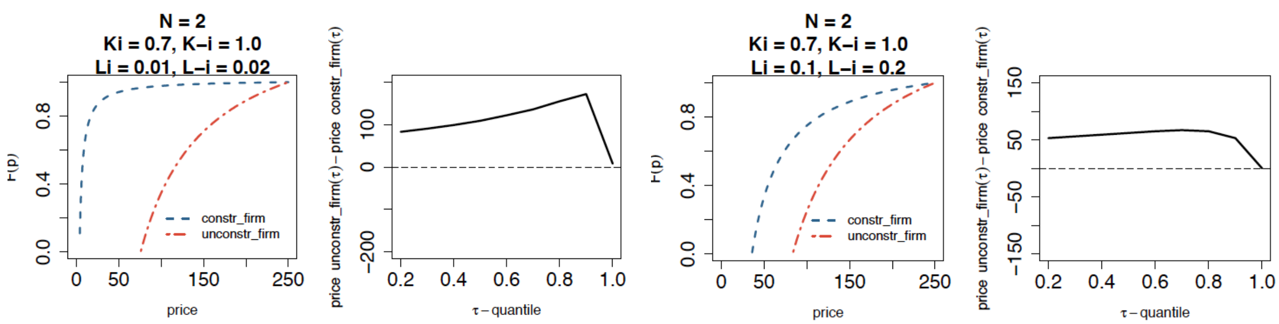


Figure 4: Effect of competition and loyalty: Response of the capacity-unconstrained firm. Panel (a)-(d): Cumulative distribution function (left) and its corresponding quantile function (right).

The results above also generate another implication:

Result 3. There is a positive relationship between product availability and pricing: Capacity-unconstrained firms charge a higher price at each quantile.

Figure 5 compares the pricing strategies by firm i and firm $-i$ as illustrated in figures 3 and 4 above. We observe that the distribution function of the capacity-unconstrained firm ($firm - i$) stochastically dominates the distribution of the capacity-constrained firm ($firm\ i$). Thus, consumers pay higher prices when they buy from a capacity-unconstrained firm. This result is robust to varying sizes of the loyal customer base for each company, although the magnitude of the price difference will be smaller when the size of loyal consumers in the market is larger.



(a) (b)

Figure 5: Relationship between product availability and pricing. Panel (a)-(b): Cumulative distribution function (left) and its corresponding quantile function (right).

3. Empirical estimation: The U.S. Corn Seed industry

The analysis in section 2 provides several hypotheses that can be empirically tested. We now use data from the U.S. corn seed industry to implement the empirical estimation. This industry has experienced considerable structural changes since the 1990s, following biotechnological breakthrough aimed at improving agricultural productivity via seed genetic modification. The corn seed market is now a major industry dominated by five large vertically integrated biotechnology-seed firms. However, empirical studies documenting the effect of competition on price dispersion, or the relationship between product availability and pricing are rare, likely due to the lack of data.[12] The seed industry provides an excellent case for our study for three reasons. Firstly, seed companies engage in both temporal and spatial price discrimination. They discriminate by charging different prices for the same seed product at each point in time and across regions. Secondly, seed firms differ in their ability to meet the market demand for their products, thus can be either capacity-constrained or capacity-unconstrained.[13] Thirdly, the industry is characterized by a high degree of brand loyalty among corn farmers.[14] Corn yield is correlated with the performance and the type of seed planted, thus corn farmers tend to be loyal to a company whose seed products yield high output on their fields.

The U.S. corn growers usually plan their production in year $t + 1$ from August$_t$ to April$_{t+1}$. They start the planting in May$_{t+1}$ and from June$_{t+1}$ to September$_{t+1}$ they address in-season challenges and harvest their fields from October$_{t+1}$ to November$_{t+1}$. The planning stage is a complicated process, as growers have to choose the right corn seed for their land. The decision will be affected by many factors such as the farmer's location, pricing, seed performance, farmer's relation to the seed company, and the expected seed availability at different time point (i.e. due to capacity constrains seeds may not be available throughout the planning period). In this study, we rely on a data set collected by dmrkynetec (hereafter dmrk), St. Louis, MO[15], which

[12] To our understanding, Shi et al. 2010 are the only one to examine pricing decisions in this market. In a multiproduct context, they analyze the linkages between pricing and substitution/complementarity relationships among products with different bundled characteristics.

[13] We consulted with UW-Extension specialists, seed regional sales managers, Wisconsin farmers, as well as agricultural forums and social networks to confirm the existence of seed capacity constraints. We found that some hybrids are likely to be supplied in limited amount, especially the new hybrids.

[14] A 5-year panel of farmers selected from our data indicates that 26 percent of farmers buy **all** their seed input from only one company (note the statistic is not disaggregated at the seed type level). The UW-Extension specialists, seed regional sales managers and the Wisconsin farmers we asked also confirmed this finding.

[15] Dmrkynetec changed its name to GfK Kynetec in May 1999. The company is the leading global provider of innovative market research in biotechnology.

provides farm-firm-level seed purchase information for the U.S. corn seed industry between 2004 − 2009. The data is collected using computer assisted telephone survey during the month of June of each year of respondents from a stratified sampling, in which large corn growers are oversampled. The observation includes information on seed company identity, type of seed (conventional or type of genetically modification technology), special feature of seed (e.g. designed for ethanol production), intended end use, net price, seed quantity and corn acreage, time of order and time of payment (calendar month), and source of purchase.

Since seed is a local product subject to varying agro-climatic conditions, we focus on the Corn Belt region in the Midwest US. In order to account for regional differences, the data is divided into the Fringe of Corn Belt (where farmers are likely to substitute between different crops), and the Core of Corn Belt (where substitution is less likely and corn is the predominant crop). This distinction allows us to assess if there are spatial differences relating to the effect of competition on price dispersion and the relationship between product availability and pricing. Figure 7 provides a graphical illustration of the two regions.

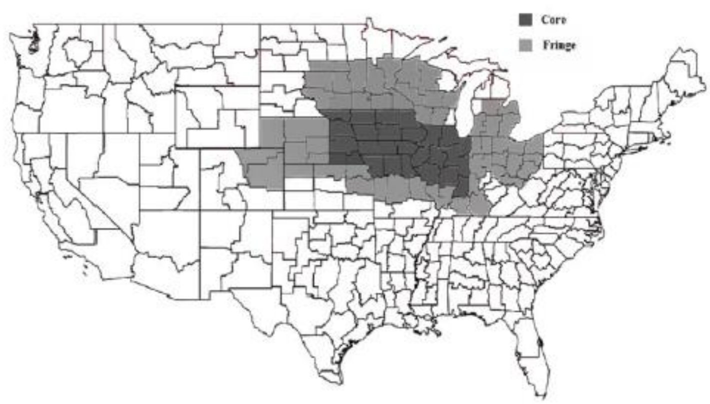


Figure 6: Map of Core and Fringe regions of U.S. Corn Belt (Source: Stiegert et al. (2010))

There are two types of seed companies in our data: the independent regional seed companies (e.g. Beck's Hybrids, Unity Seeds), and the biotechnology companies that vertically integrated with seed companies (e.g. Monsanto, Syngenta, DuPont/Pioneer, Dow Agro). These companies are classified as capacity-constrained or capacity-unconstrained by their ability to satisfy market demand. We classify a company as being capacity-constrained if all its sales occur in the period August – December each year prior to the planting season, and capacity-unconstrained otherwise. Table 1 presents the distribution of capacity-constrained and –unconstrained firms in the Core and Fringe regions by year from 2004 to 2009. The share of capacity-constrained firms varies between $25-32$ percent in the Core region, while the corresponding share is $25-28$ percent in the Fringe region. The share stays stable over time in both regions, except for a dip in 2007 in the Core region.

Table 1: Share of capacity-constrained firms (by region and year)

Year	**Fringe**			**Core**		
	total firms	*capacity-constrained firms*	*share (%)*	*total firms*	*capacity-constrained firms*	*share (%)*
2004	165	41	25	139	42	30
2005	172	49	28	141	43	31
2006	172	48	28	146	46	32
2007	179	45	25	137	34	25
2008	156	40	26	123	38	31
2009	147	38	26	112	36	32

We further divide capacity-constrained companies between regional and biotech to see if the constraints come mostly from the size of the firm. This division allows us to rule out concerns of capacity endogeneity (i.e. that price does not affect capacity decisions). Figure 7 presents the distribution of capacity-constrained firms by group and region from 2004 to 2009. It shows that regional capacity-constrained firms in the Fringe and Core regions account for the majority of capacity-constrained companies in the sample. We also explored the origins of the capacity-constrained biotech firms and found to be mostly former regional seed companies acquired by one of the biotech firms. These findings suggest that capacity constraints are likely to be generated by firm size and not by strategic pricing decisions.

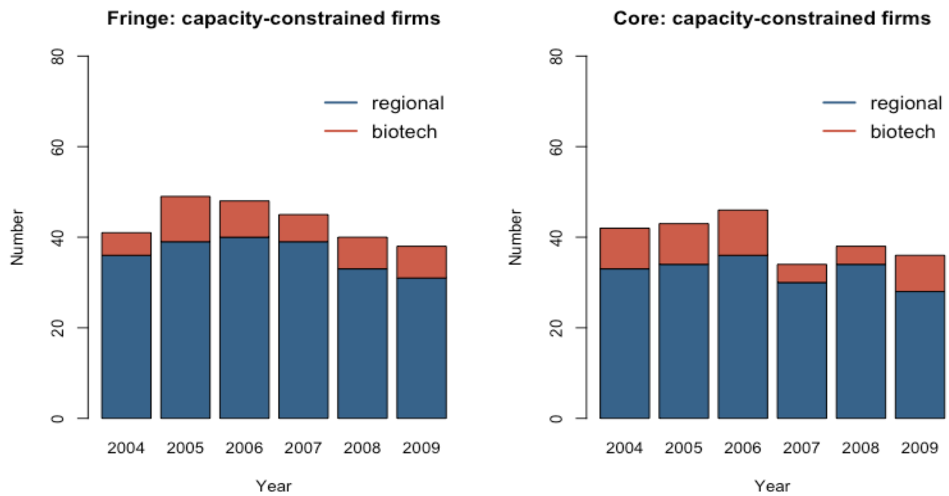


Figure 7: Number of regional and biotech capacity-constrained firms (by region and year)

Seeds sold in the market differ primarily by weather the genetically modification (GM) technology is incorporated. GM seeds were introduced in the U.S. corn field since 1995 and have soon gained the acceptance among farmers, especially after 2004. There are two major groups of genes/traits in GM corn seeds: insect resistance and herbicide tolerance. The insect resistance (IR) traits are designed to control for damages caused by the European corn borer (ECB), and rootworms (RW). The herbicide tolerant (HT) traits are designed to offer more effective weed control tolerant to the nonselective post-emergence herbicides, such as glyphosate (HT1), glufosinate (HT2), and non-glypohsate/non-glufosinate herbicides (HT3).

The GM traits where initially introduced as a single trait, but then got stacked one and another. We group the seeds in our analysis into four types: conventional (non-GM), GM IR single-stacked (ECB, RW), GM IR double-stacked (ECB + RW), GM IR & HT multi-stacked[16]. We treat the IR traited GM seeds differently from the IR & HT stacked ones in order to capture the price differences inherently implied by the technology. Moreover, we define the local market (competition region) at the Crop Reporting District level (**CRD**) as defined by USDA. By USDA definition, regions in a given CRD share similar agro-climatic conditions, hence are likely targeted by similar seed varieties. Finally, our analysis includes only transactions in CRDs with more than ten farms sampled in every year, with positive net prices, and known seed hybrid numbers. We also exclude seeds with intended use as "corn for seed"[17], and the purchase source as "seed left over from last year". In total, our data include 53,567 and 62,005 farm-firm-level sales observations from 55 and 26 CRDs out of 13 and 6 states in the Fringe and Core regions, respectively.[18]

3.1. Scenario Samples

The theoretical model in section 2 describes different scenarios by firms' capacity constraints. However, not all scenarios can be supported by our data. Given the distribution of capacity-constrained and –unconstrained seed firms in the two regions, we divide the data into the following two scenario samples:

Scenario 1: Competition exists among symmetrically capacity-unconstrained firms. We define a CRD as unconstrained if the market share of the unconstrained seed companies in a year is greater or equal to 98 percent.[19] This yields an unbalanced panel sample with 36,608 and 40,292

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[16] Includes GM IR& HT double-, triple-, and quadruple-stacked.

[17] Seed companies contract farmers to grow crops for seeds that will be sold in the following season.

[18] The states with CRDs in the Fringe region are: Colorado, Illinois, Indiana, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, Wisconsin. The states with CRDs in the Core region are: Illinois, Indiana, Iowa, Missouri, Nebraska, South Dakota.

[19] The 98 percent threshold was chosen arbitrarily to represent that firms competing in a region are very likely to be symmetrically capacity-unconstrained.

observations from 53 and 26 CRDs out of 13 and 6 states in the Fringe and Core regions, respectively. We denote this sample as **unconstr_sample**.

Scenario 2: Competition exists among firms with asymmetric capacities (co-presence of capacity-constrained and capacity-unconstrained firms). We define a CRD as asymmetric if the market share of the unconstrained seed companies in a year is less than 98 percent. This yields an unbalanced panel sample with 16,959 and 21,713 observations from 44 and 23 CRDs out of 12 and 6 states in the Fringe and Core regions, respectively. We denote this sample as **asymm_sample**.

3.2. Evidence of price dispersion

Table 2 presents detailed summary statistics of seed prices by seed types (conventional vs. various GM), regions (Fringe vs. Core of Corn Belt), and sample scenarios (unconstr_sample vs. asymm_sample). We report the 0.1, 0.5, and 0.9-quantiles of the net price[20], and the median Gini coefficient[21] for conventional seeds and various GM seed (IR single-, HT single-, IR double-, IR & HT double-, IR&HT triple-, IR & HT quadruple-stacked). The law of one price is easily rejected by statistics in Table 2. Seed price varies greatly for any given seed type, region, and scenario sample. Price dispersion is generally present in the market. The median Gini coefficient is equal with twice the expected absolute difference between two seed prices drawn randomly from the population. The reported Gini coefficients are consistent with the price dispersion pattern illustrated by the price statistics by quantiles. For example, in the unconstr_sample, the median Gini coefficient for conventional seeds sold in the Fringe region is 0.13, corresponding to an expected price difference of 26 percent of the mean net price for any two randomly selected

[20] The k^th^-quantile of the net price is a value p such that the probability that the price will be less than p is at most k and the probability that the net price will be greater than p is at most $1 - k$.
[21] The Gini coefficient, G is computed following Dixon *et al.* 1987, Damgaard and Weiner 2000: for price values $p_i, i = 1, \dots, N$, and mean price $\bar{p}$, $G = \frac{\sum_{i=1}^{N}\sum_{j=1}^{N}|p_i - p_j|}{2N^2\bar{p}}$.

farm-firm-level seed purchases in a given CRD. This is equivalent with a $25 expected price difference.

Similar to Shi et al. 2010, we also observe that GM seeds are priced at a price premium over conventional seeds, and GM seeds with multiple trait-stacking systems are generally priced more than GM seeds with a single trait. This observation is consistent with our expectation that there exists price difference inherently implied by the technology.

Table 2: Detailed summary statistics of seed prices in $ per 50 lb/bag (by region and type of seed).

			Fringe					**Core**		
Seed Type	*N*	*Gini*	*0.1-q*	*0.5-q*	*0.9-q*	*N*	*Gini*	*0.1-q*	*0.5-q*	*0.9-q*
Conventional:										
unconstr_sample	9,042	0.13 (26%)	68	93	120	9.499	0.12 (24%)	70	95	120
asymm_sample	5,775	0.13 (26%)	66	90	118	6,687	0.11 (22%)	71	91	116
GM IR single-stacked:										
unconstr_sample	3,030	0.10 (20%)	89	112	135	5,083	0.09 (18%)	90	113	135
asymm_sample	1,266	0.10 (20%)	85	110	133	2,728	0.10 (20%)	86	110	133
GM HT single-stacked:										
unconstr_sample	8,037	0.15 (30%)	91	125	181	5,818	0.16 (32%)	92	129	187
asymm_sample	3,329	0.16 (32%)	87	126	189	3,243	0.17 (34%)	85	125	192
GM IR double-stacked:										
unconstr_sample	199	0.11 (22%)	110	139	172	585	0.09 (18%)	110	134	156
asymm_sample	127	0.10 (20%)	105	130	167	341	0.10 (20%)	106	131	159
GM IR & HT double-stacked:										
unconstr_sample	7,212	0.11 (22%)	102	126	162	8,079	0.10 (20%)	104	127	161
asymm_sample	2.216	0.12 (22%)	100	125	170	3,295	0.10 (20%)	100	124	154

Table 2 – continued from previous page

Seed Type	Fringe N	Gini	0.1-q	0.5-q	0.9-q	Core N	Gini	0.1-q	0.5-q	0.9-q
GM IR & HT triple-stacked:										
unconstr_sample	7,593	0.13 (26%)	128	180	240	9,268	0.14 (28%)	130	180	250
asymm_sample	3,560	0.13 (26%)	130	186	249	4,585	0.15 (30%)	130	186	261
GM IR & HT quadruple-stacked:										
unconstr_sample	1,495	0.11 (22%)	143	193	238	1,960	0.12 (24%)	140	189	246
asymm_sample	685	0.11 (22%)	142	194	235	832	0.12 (24%)	143	200	248

3.3. Changes in market structure

We observe significant changes in market concentration across regions and over time. Market concentration is measured by the Herfindahl-Hirschman Index (HHI) computed at the CRD level. Figure 8 shows the evolution of the average HHI over time. Between 2004 – 2009, the average HHI in the unconstr_sample and asymm_sample varies between 0.18 – 0.24 and 0.14 – 0.21 in the Fringe region, and between 0.14 – 0.19 and 0.12 – 0.17 in the Core region. The variation in individual CRDs is larger, ranging from 0.06 to 0.81 across samples and regions.

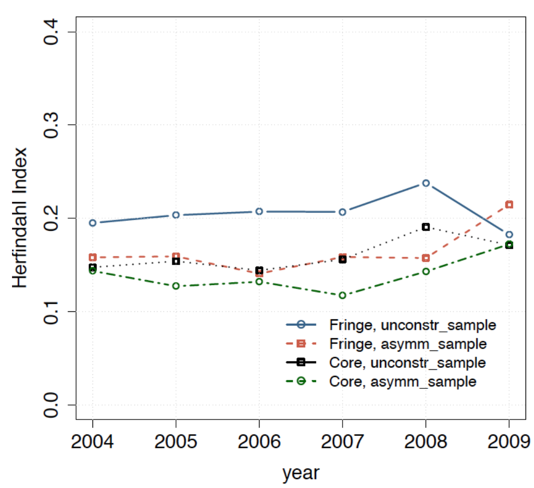

Figure 8: Changes in market concentration (by time, region, and type of seed company.)

4. Econometric Specification

Our theoretical model in section 2 suggests that there should be distributional effects to competition. The empirical estimation is implemented building on the equilibrium distribution function derived in equation (4). We use quantile regression analysis, which allows for the variables of interest (firm-specific and market-level factors) to have heterogeneous effects at different points in the distribution function of price. The analysis of distributional effects is important for antitrust policy as farmers likely to pay prices in the lower tail of the price distribution (price-sensitive shoppers) may respond differently to competition relative to those farmers likely to pay prices in the upper tail (loyal consumers). Additionally, we would also like to condition on price heterogeneities attributed to different regional agro-climatic conditions by introducing additive fixed effects for estimating the parameters.

We consider two linear in parameters econometric specifications corresponding to Scenarios 1 and 2 as follows:

Specification for Scenario 1:

$$\ln\big(P(k)\big)_{ict} = \beta_{0(k)} - \beta_{1(k)}\ HHI_{ct} \times 100 + \Upsilon_{(k)} \boldsymbol{X} + \alpha_{c(k)} + \epsilon_{ict} \tag{5}$$

Specification for Scenario 2:

$$\begin{aligned}\ln\big(P(k)\big)_{ict} = \ & \beta_{0(k)} - \beta_{1(k)}\ HHI_{ct} \times 100 + \beta_{3(k)}\ \text{Biotech}_{\text{ijt}} \\ & + \beta_{2(k)}\ \text{unconstr\_firm} + \beta_{3(k)}\ \text{unconstr\_firm} \times \text{Biotech}_{\text{ict}} \\ & + \Upsilon_{(k)} \boldsymbol{X} + \alpha_{c(k)} + \epsilon_{ict}\end{aligned} \tag{6}$$

where $P(K)_{ict}$ is the k^{th} - price quantile for seed supplied by firm i in CRD c at time t; HHI is defined as HHI $= \sum_{i=1}^{N} s_i^2$, where N is the number of firms in a CRD, and s_i is the market share of firm i computed as the firm-specific seed acreage divided by the total seed acreage in a CRD;[22] **X** is a vector of covariates with details given below; α_j captures the CRD fixed effect accounting for regional heterogeneity, Beta's are the parameter coefficients, and ϵ_{ijt} is an unobservable error term[23]. Note that for scenario 2, we include a dummy $unconstr\_firm$ (=1 if the seed company is capacity-unconstrained and zero otherwise) to capture the relationship between product availability and pricing. We also allow the possibility that the vertically integrated biotechnology seed companies may play a different pricing strategy. We introduce an interaction term of $unconstr\_firm \times Biotech_{ict}$, where $Biotech_{ict}$ (=1 if the transaction belongs to a capacity-unconstrained firm owned by a biotechnology firm (Monsanto, Syngenta, DowAgrosciences, or DuPont).

Following Borenstein 1991, the relevant covariates in **X** include variables relating to discriminatory pricing such as farmer attributes, company attributes, seed attributes, seed product density, purchase source, temporal pricing (i.e. sales in a given calendar month), and a time trend. We account for spatial price discrimination by estimating separate regressions for the Fringe and Core regions. Summary statistics are presented in Table 3.

Table 3: Descriptive statistics of variables used in the analysis.

	Mean		Standard Deviation		Min		Max	
Variable	**Fringe**	**Core**	**Fringe**	**Core**	**Fringe**	**Core**	**Fringe**	**Core**
Net Price *($50lb bag)*								
unconstr_sample	133	136	44.95	46.69	30	8	352	380
asymm_sample	131	131	49.36	49.86	3	6	356	350
HHI								
unconstr_sample	0.21	0.16	0.09	0.04	0.07	0.08	0.81	0.32
asymm_sample	0.17	0.14	0.07	0.04	0.06	0.07	0.50	0.33

[22] Firm-specific seed acreage refers to firm-specific sales for all seed types (conventional and GM).
[23] Note that we are interested in the distribution of the price variable $\ln(P_{ict(K)})$, relative to CRD fixed effects, $\alpha_{c(k)}$ (our parameters will reflect the estimation of the conditional distribution of $[\ln(P_{ict(K)}) - \alpha_{c(K)}]$).

Table 3 – continued from previous page

Variable	Mean		Standard Deviation		Min		Max	
	Fringe	**Core**	**Fringe**	**Core**	**Fringe**	**Core**	**Fringe**	**Core**
$\boldsymbol{Biotech}$								
unconstr_sample	0.80	0.80	0.40	0.40	0	0	1	1
asymm_sample	0.74	0.73	0.44	0.44	0	0	1	1
$\boldsymbol{Loyal}$								
unconstr_sample	0.78	0.83	0.41	0.38	0	0	1	1
asymm_sample	0.79	0.84	0.41	0.36	0	0	1	1
$\boldsymbol{PctLoyal}$ (%)								
unconstr_sample	78	83	9.66	6.15	27	61	97	97
asymm_sample	79	84	9.67	7.71	19	56	97	97
$\boldsymbol{Conv}$								
unconstr_sample	0.25	0.24	0.43	0.42	0	0	1	1
asymm_sample	0.34	0.31	0.47	0.46	0	0	1	1
$\boldsymbol{GM\ IR\ single\ stacked}$								
unconstr_sample	0.08	0.13	0.28	0.33	0	0	1	1
asymm_sample	0.07	0.13	0.26	0.33	0	0	1	1
$\boldsymbol{NewSeed \times Conv}$								
unconstr_sample	0.09	0.07	0.28	0.26	0	0	1	1
asymm_sample	0.12	0.11	0.33	0.31	0	0	1	1
$\boldsymbol{ProdDensity}$ (%)								
unconstr_sample	6	11	2.65	2.86	1	2	12	16
asymm_sample	5	10	1.68	3.02	1	2	8	15
$\boldsymbol{TimeDiff}$								
unconstr_sample	1.78	1.65	2.95	2.73	0	0	11	11
asymm_sample	1.91	1.66	2.98	2.56	0	0	11	11
$\boldsymbol{SeedCompany}$								
unconstr_sample	0.26	0.27	0.44	0.44	0	0	1	1
asymm_sample	0.31	0.30	0.46	0.46	0	0	1	1
$\boldsymbol{MyselfDealer}$								
unconstr_sample	0.11	0.14	0.31	0.34	0	0	1	1
asymm_sample	0.13	0.14	0.34	0.35	0	0	1	1
$\boldsymbol{FarmerDealer}$								
unconstr_sample	0.30	0.31	0.46	0.46	0	0	1	1
asymm_sample	0.28	0.29	0.45	0.45	0	0	1	1
Observations								
unconstr_sample	36,608	40,292	36,608	40,292	36,608	40,292	36,608	40,292
asymm_sample	16,959	21,713	16,959	21,713	16,959	14,464	16,959	21,713

Farmer attributes: We distinguish between price sensitive and loyal farmers. Anecdotal evidence suggest that loyal consumers are likely to order early in the season (August – December), whereas price sensitive farmers shop around for the entire season and tend to order later in order to obtain seeds on sale. We construct a dummy variable $Loyal = 1$ if the seed was ordered in the period August – December, and $Loyal = 0$ otherwise. We also include a variable $PctLoyal$, defined as the percentage of annual number of transactions occurred in August – December. The variable may help to further discerning the effect of relative loyal customer base size for all firms. Our statistics suggest that about 78 percent of all orders in the Fringe region, and about 83 percent in the Core region are placed in the August – December period for each sample scenario.

In addition, seed companies often offer cash discounts in an effort to enhance their price discrimination schemes.[24] We construct the variable $TimeDiff$ to measure the difference between payment time and order time. On average, farmers pay for seed orders within about 2 months, with individual variability ranging from 0 to 11 months.

Company attributes: We account for the two types of seed companies that sell corn seeds in the U.S. We expect biotechnology companies to take advantage of their position as developers of GM seed technologies and charge a price premium for their products. In the Core and Fringe regions, the average share of biotech firms is larger in the unconstr_sample than in the asymm_sample.

Seed attributes: Seed attributes include seed type (conventional vs. various GM; GM IR single-stacked, GM IR double-stacked, GM IR&HT multi-stacked (*Conv, GM IR single-, GM IR double-, GM IR & HT multi-stacked*) whether the output to be used for ethanol ($EtnUse$), whether the seed hybrids have special features for ethanol production ($EtnSeed$), and whether the seed is new to

[24]An example of cash discount reported on a seed company website is as follows: 8 percent for payments no later than November 10, and 6 percent for payments no later than January 5.

the market ($NewSeed = 1$ if it had never presented in the dmrk data since 1994; and zero otherwise).

New seeds may be associated with higher uncertainty on seed performance from the farmer's perspective, thus could affect farmers' willingness to pay for the seed if they are risk averse. For all samples and regions, around 50 percent of seeds are new in the market, indicating that seed companies are continuously involved in the innovation process. We also interact the variables $NewSeed$ and $Conv$ to assess if farmers are more risk averse to conventional seeds as opposed to GM seeds.

Farmers in the unconstr_sample and the asymm_sample seem to purchase different mix of seeds. In the Core region, they tend to purchase less conventional seed and more GM IR & HT multi-stacked seeds in the unconstr_sample than in the asymm_sample. The average share of conventional seed sale is 24 percent in the unconstr_sample, but 31 percent in the asymm_sample. Similar patterns are observed in the Fringe region.

Ethanol end-use of seeds and seed hybrids specially designed with higher levels of fermentable starch (HLFS) and/or extractable starch (HLES) (suitable for ethanol production) are characteristics likely associated with price differences due to the different procurement prices of output corn for ethanol production compared to other end uses. We construct two dummy variables $EtnUse$ and $EtnSeed$, each taking values 1 or zero according to whether the stated end use being ethanol use or not, and whether the seed featuring HLFS or HLES or not. Our statistics show that in both Core and Fringe regions, capacity-unconstrained firms competing with comparable firms are more likely to specialize in seeds with special features for ethanol production as opposed to regions where the companies are asymmetric. For example, in the Core region 24 percent of seeds are $EtnSeed$ in the unconstr_sample, and only 17 percent in the asymm_sample.

Seed Product Density: A high product density can affect seed prices due to substitutability between products. We define the variable $ProdDens$ as the percentage of seed hybrids in a given CRD relative to the total number of seed hybrids in a Corn Belt region. The product density is higher in CRDs in the Core region than that in the Fringe region. For example, the average product density in the unconstr_sample is about 11 percent in the Core region and about 6 percent in the Fringe region. The variation in individual CRDs is larger, ranging from 2 to 17 percent in the Core region, and 1 to 12 percent in the Fringe region.

Seed Purchase Source: The purchase source can capture possible price differences due to alternative marketing strategies. Three dummy variables are constructed to account for the most popular categories: $SeedC = 1$ if the seed is bought directly from the seed company or its representative, $MyselfD = 1$ if the corn grower is a dealer for the seed company, and $FarmerD = 1$ if the seed is bought from a farmer who is a dealer or agent. Although the data identifies 14 possible purchasing sources, over 60 percent of transactions where classified into these three categories in each sample scenario and region.

Temporal pricing: We consider temporal pricing as a source of price variation, which refers to sales as demand is revealed for a particular type of seed. Thus, prices may fluctuate throughout the season, increasing or decreasing according to the probability at the time the seed is sold that demand will exceed capacity. To capture temporal pricing, we consider two month trend variables: $priorJAN$ defined as the number of months prior to January[25] and $postJAN$ defined as the number of months post January[26]. Our statistics show that most orders are placed in the period November – January.

Finally, we include a time variable $Year$ to capture the time trend effect that might be associated with technology advances, inflations and other potential time consistent structural changes.

[25] Can take values between 0 and 5.
[26] Can take values between 0 and 7.

4.2. Econometric Estimation

One challenge to the identification strategy in the econometric specification (5) - (6) is related to the assumption that the error term and the explanatory variables are contemporaneously uncorrelated. However, both market concentration - as measured by HHI - and seed prices are likely endogenous as they are jointly determined in the model. A firm's decision to enter the market is affected by its marketing strategies. Econometricians can hardly observe all determinants of these strategies. Therefore the market concentration measurement HHI may be correlated with unobserved factors affecting the response variable. For example, a seed company may have a good understanding of the demand side. This knowledge of the customer base will be correlated with the decision to enter the market and affects prices being charged - yet, such private information cannot be observed in our data set. If so, the standard quantile regression (QR) proposed by Koenker 1978 will provide biased and inconsistent estimates for the behavioral parameters.

We consider an alternative econometrics approach, the fixed effect instrumental variable quantile regression with fixed effects (FE IV QR) proposed by Harding and Lamarche (2009). The FE IV QR builds on Chernozhukov 2008's model. It facilitates the estimation of covariate effects at different quantiles while controlling for additive fixed effect as introduced in Koenker (2004) that may be affecting the response and are correlated with the independent variables.

The Wu-Hausman test applied to the econometric specifications (5)-(6) is used to test the null hypothesis of exogeneity of HHI. The test statistics in the unconstr_sample and asymm_sample are significantly different from zero with a p-value of less than 0.0001 in the Fringe and Core regions. We reject the null hypothesis of exogeneity of HHI in both regions. Thus, we propose an instrument for the HHI variable: the lagged value of HHI ($lagHHI$). The use of this instrument is motivated by the presence of lags in the seed production process. The production process of seeds takes on average 8 months. As a result, firm managers may use information on market concentration in the previous year to decide seed production quantity for next year market.

The lagged value of HHI is an appropriate instrument if it is uncorrelated with the error term (the orthogonality condition) but correlated with the endogenous regressor HHI (not a "weak instrument"). Since the model is "exactly identified", the orthogonality condition holds by construction in equation (5)-(6). To test for "weak instruments", we examine the reduced form regression and evaluate the explanatory power of $lagHHI$. The values of the F statistics for the null hypothesis $lagHHI = 0$ in the unconstr_sample and asymm_sample are 207.64 and 86.72 in the Fringe region, respectively 463.33 and 430.31 in the Core region. The p-value is less than 0.0001 in all samples. Using the simple rule-of-thumb of $F = 10$ proposed by Stock 2003, the results suggest that our instrument may not be weak.

Another challenge to the identification is the homoscedasticity assumption that the error term is independent and identically distributed with mean zero and variance σ^2. The Breusch-Pagan test result applied to the econometric specifications (5)-(6) reject null of homoskedasticity assumption in both the unconstr_sample and the asymm_sample, and for both the Fringe region and the Core region. The Chi statistics are in the range of 321 and 1416 with p-values less than 0.0001.

To account for the heteroskedasticity of the error terms, we estimate the FE IV QR model using the "xy-pair" bootstrap method robust standard errors (Effron 1994). Besides, we expect that the correlation of the error terms in a CRD is likely to be driven by a common shock process, thus we add CRD-specific fixed effects to control for the within-cluster correlation of the error (e.g. following Cameron 2015).

5. Empirical Findings

Table 5 - 8 report the econometric results of our analysis of distributional effects of competition on price and the relationship between product availability and pricing. We estimate the model using FE IV QR method, with bootstrap robust standard errors. The results will be discussed for each sample scenario and for both regions. For comparison purpose, we also present the results from 2SLS IV as a way to illustrate the likely misleading results if only a mean regression is conducted.

5.1. The case of unconstr_sample

Estimation results for the effect of competition on price dispersion in the unconstr_sample are presented in Table 5 for the Fringe region and Table 6 for the Core region. We report the bootstrapped standard errors[27] (FE IV QR) and the heteroskedastic-robust standard errors (2SLS IV) in parentheses.

5.1.1. Distributional effects of competition

The negative of the $HHI \times 100$ is reported to capture the effect of an increase in competition on the log of net price. The results show strong statistical evidence that firms operating in the unconstrained CRDs are governed by different pricing strategies in the Fringe versus the Core regions.

In the Fringe region, increasing competition does not have a statistically significant effect on the price quantiles. In contrast, the effect of an increase in competition is *positive* for all quantiles in the Core region. The value of the estimate ranges between 14.5 percent ($12.47 per bag) at the 0.1-quantile and 8.3 percent ($16.85 per bag) at the 0.9-quantile.

[27] Obtained by sampling 1000 samples with replacement from the original sample.

We test for equality of the slope parameters using the Wald test statistics. Table 9 reports the test results for the null hypothesis for 0.1- vs. 0.5-quantile; 0.5- vs. 0.9-quantile; and 0.1- vs. 0.9-quantiles. In the Core region, the null is rejected in favor of the alternative for 0.1- vs. 0.5-quantile and 0.1- vs. 0.9-quantile but not for 0.5- vs. 0.9-quantiles. The competition effect differs along the pricing distribution function in this region. In comparison, the 2SLS IV results find a significant impact of an increase in competition on mean price in both Fringe and Core region. The FEIVQR method provides a much richer description of the distributional effects of competition.

Our results in the Core region confirm with *Result* 1 illustrated in the theoretical prediction of Case 1b. as introduced in section 2.2.1. An increase in the number of capacity-unconstrained firms has a *positive effect* on the distribution function, leading to an increase in prices for all quantiles. We find the effect is with a greater magnitude in the lower quantiles, implying that seed firms in this region may benefit from a large number of loyal farmers. They focus on extracting surplus from the loyal group and avoid competition in the price sensitive farmers when facing with new entry to the market.

5.1.2. Distributional effects of other covariates

The positive sign on the lower quantiles for the *Loyal* variable indicates that an increase in firms' loyal customer base may *raise* the price of seeds. In the Fringe region, the effect is significant only at the mean. It is significant at the mean and across the entire distribution of prices in the Core region. The results in the Core region confirm our theoretical prediction of Case 1b. as introduced in section 2.2.1 relating to the effect of an increase in the value of the loyal customer base parameter (L).

The $PctLoyal$ effect is positive and statistically significant in the Fringe and Core regions. The economic magnitude is relatively small in the Fringe region, yet larger and statistically different across quantiles in the Core region. The $TimeDiff$ effect show that a one-month increase in the difference between payment time and order time slightly increases prices in the two regions. Also, biotechnology companies charge a price premium at the mean and across the entire distribution of prices, with a similar magnitude between the Fringe and Core regions.

The negative sign on the $Conv$ variable confirms that GM seeds are sold at a price premium over conventional seeds (e.g. following Shi et al. 2010). We found the effect is statistically significant at the mean and all quantiles in the Fringe and Core regions. We also found that GM seeds with single-stacking insect resistance systems, or GM seeds with insect resistance and herbicide tolerance multi-stacking systems are generally priced more than GM seeds with a single-stacking herbicide tolerance trait. The mean and most quantiles of the *GM IR-single*, and *GM IR & HT multi-stacked* coefficients are positive and statistically significant for both regions. In contrast, GM seeds with double-stacking insect resistance traits are priced lower in the Core region. The coefficient *GM IR-double* is significantly negative at the mean and across the entire distribution of prices. There is no significant price difference in the Fringe region.

Additionally, we found that farmers in the Core region associate conventional new seeds with higher performance uncertainty as opposed to GM. The $NewSeed$ and $NewSeed \times Conv$ coefficients are negative and statistically significant. In contrast, farmers in the Fringe region are averse with experimenting only with new conventional seeds. The $NewSeed \times Conv$ coefficient is *negative* and statistically significant.

The $EtnSeed$ coefficient has a non-uniform effect on the distribution function of prices in the Core region. The effect is significant and *positive* at the lower quantiles and *negative* at the upper quantiles. The mean effect is positive. These results may indicate that price-sensitive farmers find profitable to plant seeds featuring HLFS and/or HLES; They are willing to pay a price premium for these varieties. We also found the $EtnUse$ coefficient is statistically significant and *negative* at the mean and all price quantiles in this region. Farmers pay a lower price for seeds if the stated end use is ethanol production. These results contrast with the effect in the Fringe region. The $EtnSeed$ and $EtnUse$ coefficients do not necessarily show relevant results at the mean or across quantiles.

The $ProdDens$ effect is statistical significant and negative at the mean in the Fringe region, and at the mean and across the entire distribution function of prices in the Core region. This may suggest that the cross-elasticity of demand among corn seed brands is more pronounced in the Core region. The $SComp, MyselfD, FarmerD$ effects are negative in the Fringe region, but *positive* in the Core region. These results may reflect that farmers in the Fringe have a better bargaining position, but also possibly the presence of price discrimination across regions and across different purchase sources.

The estimates for the $priorJan$ and $postJan$ variables indicate that seed companies may engage in temporal price discrimination. Farmers located in the Core region can save on their input costs if they order seeds early in the season (price increases with each additional month), whereas farmers in the Fringe can save if they order earlier or later in the season (the price increase has a pick in January). Finally, we find the time trend effect is positive and significant across regions, indicating that technology advancements, inflation and other potential time consistent structural changes justify part of the observed price variation.

Table 5: FEIVQR and 2SLS IV Regression Results – Fringe region, unconstr_sample

	Dependent variable:					
	Log Net Price					
	Mean (robust SE)	0.1-q (boot SE)	0.3-q (boot SE)	0.5-q (boot SE)	0.7-q (boot SE)	0.9-q (boot SE)
Effect of competition:						
$-HHI \cdot 100$	0.0034***	0.028	0.021	0.023	0.047	0.014
	(0.005)	(0.018)	(0.020)	(0.035)	(0.044)	(0.018)
Other variables:						
$Biotech$	0.070***	0.101***	0.072***	0.068***	0.063***	0.037***
	(0.004)	(0.014)	(0.011)	(0.006)	(0.005)	(0.004)
$Loyal$	0.009*	0.009	0.021	0.014	−0.001	−0.005
	(0.005)	(0.010)	(0.011)	(0.008)	(0.006)	(0.007)
Pct_Loyal	0.003***	0.003***	0.003***	0.003***	0.002**	0.002
	(0.0003)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
$Conv$	−0.304***	−0334***	−0.295***	−0.279***	−0.290***	−0.290***
	(0.005)	(0.018)	(0.023)	(0.027)	(0.018)	(0.007)
IR single - stacked	0.014**	−0.003	−0.004	0.007	0.016	0.050***
	(0.005)	(0.012)	(0.016)	(0.015)	(0.013)	(0.008)
IR double - stacked	−0.009	0.043	0.020	0.001	−0.028	−0.041
	(0.014)	(0.036)	(0.030)	(0.024)	(0.022)	(0.035)
IR & HT multi - stacked	0.136***	0.116***	0.115***	0.125***	0.144***	0.158***
	(0.004)	(0.007)	(0.006)	(0.005)	(0.005)	(0.009)
$EtnSeed$	0.039***	0.070**	0.049	0.042	0.028	−0.014
	(0.005)	(0.034)	(0.045)	(0.039)	(0.031)	(0.015)
$EtnUse$	0.004	0.019	0.003	−0.003	0.007	0.003
	(0.004)	(0.021)	(0.025)	(0.020)	(0.010)	(0.005)
$NewSeed$	−0.001	0.011	0.000	−0.002	−0.004	−0.002
	(0.003)	(0.011)	(0.012)	(0.008)	(0.006)	(0.005)
$NewSeed \times Conv$	−0.051***	−0.049**	−0.050	−0.057***	−0.049***	−0.041***
	(0.007)	(0.024)	(0.032)	(0.026)	(0.016)	(0.010)
$ProdDensity$	−0.030***	−0.007	−0.027	−0.049	−0.057	−0.022
	(0.005)	(0.056)	(0.069)	(0.056)	(0.051)	(0.022)
$priorJan$	−0.009***	−0.012**	−0.013*	−0.009*	−0.003	−0.004**
	(0.002)	(0.005)	(0.007)	(0.005)	(0.002)	(0.002)
$postJan$	−0.009*	−0.025*	−0.010*	−0.010	−0.004	0.002
	(0.003)	(0.007)	(0.006)	(0.008)	(0.003)	(0.003)
$Year$	0.105***	0.095***	0.103***	0.113***	0.111***	0.114***
	(0.001)	(0.005)	(0.004)	(0.005)	(0.005)	(0.002)
$Constant$	5.969***	4.713	5.308	6.731	7.802	5.778
	(0.198)	(1.402)	(1.914)	(2.474)	(2.489)	(0.970)
CRD dummies	YES	YES	YES	YES	YES	YES
No. of observations	36,608					

Note: Statistical significance is noted by an asterisk (∗) at the 10% level, two asterisks (∗∗) at the 5% level, and three asterisks (∗∗∗) at the 1% level. Results for the difference between payment and order time ($TimeDiff$) and purchase source effects ($SComp, MyselfD, FarmerD$) are not reported here but are discussed in the text. Non-IV results where also obtained and differ from the ones re

Table 6: FEIVQR and 2SLS IV Regression Results – Core region, unconstr_sample

	Dependent variable:					
	Log Net Price					
	Mean (robust SE)	0.1-q (boot SE)	0.3-q (boot SE)	0.5-q (boot SE)	0.7-q (boot SE)	0.9-q (boot SE)
Effect of competition:						
$-HHI \cdot 100$	0.117***	0.145***	0.093***	0.088***	0.097***	0.083***
	(0.008)	(0.020)	(0.007)	(0.008)	(0.008)	(0.007)
Other variables:						
$Biotech$	0.091***	0.087***	0.088***	0.090***	0.092***	0.081***
	(0.005)	(0.007)	(0.006)	(0.008)	(0.011)	(0.012)
$Loyal$	0.050***	0.045***	0.058***	0.071***	0.082***	0.072***
	(0.007)	(0.009)	(0.008)	(0.011)	(0.016)	(0.017)
Pct_Loyal	0.009***	0.008***	0.010***	0.020***	0.028***	0.027***
	(0.001)	(0.003)	(0.002)	(0.003)	(0.003)	(0.003)
$Conv$	−0.306***	−0.309***	−0.301***	−0.289***	−0.290***	−0.298***
	(0.007)	(0.008)	(0.009)	(0.011)	(0.015)	(0.017)
IR single - stacked	0.046***	0.056***	0.053***	0.041***	0.022	0.042***
	(0.008)	(0.010)	(0.010)	(0.012)	(0.017)	(0.018)
IR double - stacked	−0.125***	−0.010	−0.105***	−0.164***	−0.251***	−0.356***
	(0.015)	(0.021)	(0.019)	(0.024)	(0.037)	(0.038)
IR & HT multi - stacked	0.160***	0.166***	0.161***	0.159***	0.163***	0.171***
	(0.006)	(0.008)	(0.007)	(0.009)	(0.012)	(0.013)
$EtnSeed$	0.0003	0.038***	0.005	-0.008	-0.020**	-0.037***
	(0.005)	(0.006)	(0.006)	(0.007)	(0.009)	(0.010)
$EtnUse$	−0.042***	−0.015	−0.045***	−0.060***	−0.093***	−0.109***
	(0.007)	(0.008)	(0.009)	(0.011)	(0.015)	(0.017)
$NewSeed$	−0.020****	0.000	−0.021***	−0.023***	−0.033***	−0.044***
	(0.005)	(0.006)	(0.006)	(0.007)	(0.010)	(0.010)
$NewSeed \times Conv$	−0.039***	−0.051***	−0.030**	−0.049***	−0.066***	−0.049**
	(0.010)	(0.014)	(0.013)	(0.014)	(0.020)	(0.023)
$ProdDensity$	−0.069***	−0.069***	−0.083***	−0.122***	−0.184***	−0.209***
	(0.005)	(0.009)	(0.007)	(0.011)	(0.018)	(0.020)
$priorJan$	−0.018***	0.003***	0.015***	0.028***	0.037***	0.034***
	(0.002)	(0.003)	(0.003)	(0.003)	(0.005)	(0.005)
$postJan$	0.011***	0.003	0.015***	0.028***	0.037***	0.034***
	(0.004)	(0.005)	(0.005)	(0.007)	(0.009)	(0.009)
$Year$	0.161***	0.176***	0.186***	0.192***	0.220***	0.235***
	(0.004)	(0.009)	(0.004)	(0.006)	(0.011)	(0.010)
$Constant$	6.038***	6.029***	6.424***	6.835***	8.065***	9.148***
	(0.096)	(0.150)	(0.126)	(0.166)	(0.350)	(0.389)
CRD dummies	YES	YES	YES	YES	YES	YES
No. of observations	40,292					

Note: Statistical significance is noted by an asterisk ($*$) at the 10% level, two asterisks ($**$) at the 5% level, and three asterisks ($***$) at the 1% level. Results for the difference between payment and order time ($TimeDiff$) and purchase source effects ($SComp, MyselfD, FarmerD$) are not reported here but are discussed in the text. Non-IV results where also obtained and differ from the ones reported here.

5.2. The case of asymm_sample

Estimation results for the effect of competition on price dispersion in the asymm_sample are reported in Table 7 for the Fringe region and Table 8 for the Core region; Again bootstrapped standard errors used in the FE IV QR model and the heteroskedastic-robust standard errors used in the 2SLS IV model are reported in the corresponding parentheses.

5.2.1. Distributional effects of competition

In contrast to the unconstr_sample, the results now offer strong statistical evidence that the seeds sold in the asymmetric CRDs are governed by similar pricing strategies in the Fringe and Core regions.

The effect of a one point increase in competition as measured by $-HHI \times 100$ is *positive* and statistically significant at the mean and almost across the entire distribution function of prices in both Fringe and Core regions. The values of the estimates range between 3.9 percent ($3.08 per bag) at the 0.1-quantile and 2.6 percent ($ 3.9 per bag) at the 0.7-quantile in the Fringe region, and between 1.6 percent ($ 1.6 per bag) at the 0.3-quantile and 7.7 percent ($ 15.94 per bag) at the 0.9-quantile in the Core region .

The Wald test statistics reported in Table 9 suggests the null hypotheses of equality between the HHI coefficient for 0.1- vs. 0.9-quantile is rejected in favor of the alternative in the Fringe region. It is rejected for 0.1- vs. 0.5-quantile, 0.5- vs. 0.9-quantile and 0.1- vs. 0.9-quantile in the Core region. Thus, for both regions, the competition effects in the lower and the upper tail of the price distribution are different. Again such details are covered underneath the mean regression based on the 2SLSIV estimates, which find a statistically significant competition effect on both regions.

Our results here are consistent with *Result 2* developed in the theoretical predictions of Case 2c. in section 2.2.2. Depending on the type of seed companies entering the local market (capacity - unconstrained), the size of the incumbent firms and the number of loyal farmers in the market, an increase in competition among firms with asymmetric capacity levels increases prices paid by almost all corn growers. In the Fringe region, we find the effect is with a greater magnitude in the lower price quantiles suggesting the presence of a larger number of loyal farmers. This result contrasts with the Core region, where the effect is with a greater magnitude in the upper quantiles.

Additionally, our findings in the Core region suggest that the magnitude of the distributional effects of competition is larger when only symmetrically capacity-unconstrained firms, as opposed to both capacity-constrained and –unconstrained firms co-exist in a region. This contrasts with the findings in the Fringe region, where competition between symmetrically capacity-unconstrained firms has a lower positive effect on the price distribution function. These results may be important for antitrust policy. For example, competition in an industry where consumers have heterogeneous preferences (loyal vs. price sensitive) and firms competing in the market are mostly big companies with no capacity constraints, can be less harmful to consumers if there is little evidence of substitutability across different industry products (e.g. corn vs. soy bean seeds – as it is the case in the Core of Corn Belt).

5.2.2. Relationship between product availability and pricing

The $unconstr\_firm$ and $unconstr\_firm \times Biotech$ terms are included in the regression specification (6) for assessing the relationship between product availability and pricing. The results show strong evidence that product availability and pricing are positively correlated.

In the Fringe region, the $unconstr\_firm$ term is positive and significant across quantiles, ranging from 10.3 percent ($8.13 per bag) at the 0.1-quantile to 5.2 percent ($7.8 per bag) at the 0.7-quantile. The mean effect is closer to the 0.3-quantile with a value of 7.7 percent ($10.07 per bag). Additionally, capacity-unconstrained firms belonging to vertically integrated biotechnology seed companies seem to charge less for product availability in the lower tail of the price distribution, with a value of 9.1 percent ($ 7.18 per bag) at the 0.1-quantile. There is no difference in price at the upper quantiles. The 5.9 percent ($ 7.72 per bag) value of the mean coefficient is closer to the 0.1-quantile.

The Wald test statistics reported in Table 9 suggests the null hypothesis of equality between the $unconstr\_firm$ parameters for the 0.5- vs. 0.9-quantile, and 0.1- vs. 0.9-quantile is rejected in favor of the alternative at 5-10% significance level. It is rejected only at the 0.1- vs. 0.9-quantile for the $unconstr\_firm \times Biotech$ parameter at 5% significance level.

In the Core region, the $unconstr\_firm$ term presents patterns similar with the Fringe region. It is positive and statistically different across quantiles, ranging from 6.7 percent ($ 5.43 per bag) at the 0.1-quantile to 4.4 percent ($6.34 per bag) at the 0.7-quantile. The mean coefficient is closer to the median at 4.6 percent ($6.04 per bag). However, capacity-unconstrained firms belonging to biotech firms seem to not play a strategy similar to the one in the Fringe region. They charge less for product availability at the lower quantiles, yet they charge an additional price premium at the upper quantiles. The value of the coefficient ranges from -4.6 percent ($ -4.6 per bag) at the 0.3-quantile to 7.5 percent ($15.52 per bag) at the 0.9-quantile. The mean coefficient is closer to the median with a value of - 3.2 percent (- $4.21 per bag).

Table 9 suggests the null hypothesis of equality between the slope parameters 0.5 vs. 0.9-quantile and 0.1 vs. 0.9-quantile for the $unconstr\_firm$ and $unconstr\_firm \times Biotech$ terms is rejected in favor of the alternative with a p-value between 1-5%.

These findings confirm *Result 3* in section 2.2.2 of our theoretical model relating to the relationship between product availability and pricing. Farmers in the two regions are willing to pay higher prices for increased product availability. Capacity-unconstrained firms other than the vertically integrated biotech seed giants are able to extract more surplus from all farmers in the Fringe and Core regions. Additionally, the biotech capacity-unconstrained firms are able to extract additional profits from farmers in the Core region who tend to pay prices in the upper tail of the price distribution (loyal consumers). However, they extract less additional profits from farmers in the Fringe and Core regions who tend to pay prices in the lower tail of the price distribution (price sensitive shoppers).

5.1.2. Distributional effects of other covariates

The positive sign on the lower quantiles of the $Loyal$ variable indicates that an increase in firms' loyal customer base may increase the price of seeds paid by price sensitive farmers. In the Fringe and Core region, the $Loyal$ effect is positive at some of the lower quantiles and mean level. They confirm the theoretical prediction of Case 2c., Figure 3 and 4, as introduced in section 2.2.2, relating to the effect of an increase in the value of the loyal parameter (L).

The coefficient relating to $PctLoyal$ variable is not statistically significant in the Fringe region, yet significantly negative in the Core region. This is very similar to what we found in the unconstr_sample, except for the magnitude of the coefficient in the Core region, which is larger when firms competing in the market have symmetric capacity-unconstrained levels.

Biotechnology companies charge a price premium at the mean and the lower price quantiles in the Fringe region, and at the mean and almost across the entire distribution of prices in the Core region. This results contrast with the unconstr_sample results, where biotech companies are able to extract a price premium from all consumers in the market in both regions.

The estimates corresponding to the variable *Conv*, *GM IR-single*, and *GM IR & HT multi-stacked* are similar in magnitude and sign with the results in the unconstr_sample. However, the *GM IR-double* coefficient is now significantly negative in both Fringe and Core regions. The magnitude of the coefficient in the Core region is larger than in the unconstr_sample, indicating that farmers benefit from competition between firms of asymmetric sizes.

The $NewSeed$ and $NewSeed \times Conv$ coefficients show that farmers in the two regions are in general averse with experimenting with new conventional seeds but not necessarily with the genetically modified varieties.

The $EtnSeed$ coefficient has now a uniform effect on the distribution function of prices. In the Fringe and Core regions, the effect is positive and significant at the lower quantiles and mean level, and not significant otherwise. These results indicate that price-sensitive farmers may find profitable to pay a price premium for seeds featuring HLFS and/or HLES. Seed companies in the two regions also charge a premium to all types of farmers if the stated use of seed is for ethanol production. The $EtnUse$ coefficient is statistically positive at the mean and across the entire distribution of prices in the Fringe and Core regions.

We also found the $ProdDens$ effect in the Core region is comparable with the results reported in the unconstr_sample – yet, the magnitude is smaller. Additionally, we also find evidence of product density effects in the Fringe region. The effect is statistical significant and negative at the mean and some quantiles. Some statistical significant price differences arise across purchase sources as well. Farmers may pay a lower price for seeds if they buy directly from the seed company, or if they are a dealer for the seed company in both the Fringe and Core regions. Additionally, the sign of the $priorJan$ and $postJan$ estimates indicate that seed companies competing in a market with firms of asymmetric capacity levels engage in temporal price discrimination as well. Fringe and Core farmers may pay a lower price for seed orders placed early or later in the season. Finally, we find the time trend effect $Year$ is comparable with the unconstr_sample.

Table 7: FEIVQR and 2SLS IV Regression Results – Fringe region, asymm_sample

	Dependent variable:					
	Log Net Price					
	Mean (robust SE	0.1-q (boot SE)	0.3-q (boot SE)	0.5-q (boot SE)	0.7-q (boot SE)	0.9-q (boot SE)
Effect of competition:						
$-HHI \cdot 100$	0.049***	0.039***	0.025***	0.030***	0.026***	0.016
	(0.011)	(0.014)	(0.010)	(0.011)	(0.010)	(0.011)
Other variables:						
Biotech	0.115***	0.148***	0.099**	0.098**	0.052	0.051
	(0.022)	(0.049)	(0.045)	(0.041)	(0.047)	(0.042)
unconstr_firm	0.077***	0.103***	0.063***	0.062***	0.053**	0.022
	(0.016)	(0.037)	(0.024)	(0.024)	(0.026)	(0.023)
unconstr_firm × *Biotech*	−0.059***	−0.091*	−0.036	−0.037	0.007	0.002
	(0.023)	(0.050)	(0.046)	(0.043)	(0.047)	(0.043)
Loyal	0.015**	0.036***	0.017	0.020*	0.012	−0.004
	(0.007)	(0.014)	(0.012)	(0.012)	(0.013)	(0.014)
Pct_Loyal	0.001	0.005	0.001	0.003	0.003	0.002
	(0.001)	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)
Conv	−0.337***	−0.360***	−0.341***	−0.315***	−0.312***	−0.287***
	(0.007)	(0.015)	(0.011)	(0.012)	(0.013)	(0.013)
IR single - stacked	0.002	0.019	0.012	-0.008	-0.010	0.023*
	(0.008)	(0.017)	(0.012)	(0.016)	(0.016)	(0.013)
IR double - stacked	−0.086***	−0.119***	−0.082**	−0.094**	−0.087**	−0.083***
	(0.021)	0.043	0.041	0.042	0.035	0.032
IR & HT multi - stacked	0.154***	0.161***	0.156***	0.143***	0.147***	0.145***
	(0.005)	(0.011)	(0.008)	(0.009)	(0.009)	(0.008)
EtnSeed	0.042***	0.079***	0.050***	0.034***	0.021	0.000
	(0.005)	(0.012)	(0.010)	(0.010)	(0.013)	(0.012)
EtnUse	0.073***	0.099***	0.063**	0.079***	0.087***	0.067**
	(0.009)	(0.030)	(0.027)	(0.029)	(0.026)	(0.026)
NewSeed	−0.011*	−0.002	−0.011	−0.018	−0.026**	−0.009
	(0.005)	(0.014)	(0.011)	(0.013)	(0.013)	(0.011)
NewSeed × *Conv*	−0.019**	−0.011	−0.016	−0.025**	−0.020	−0.029**
	(0.009)	(0.018)	(0.015)	(0.014)	(0.015)	(0.014)
ProdDensity	−0.063***	−0.083*	−0.051	−0.103*	−0.121*	−0.099
	(0.012)	(0.048)	(0.047)	(0.062)	(0.062)	(0.062)
priorJan	−0.011***	−0.020***	−0.009	−0.010*	−0.013**	−0.007
	(0.002)	(0.006)	(0.005)	(0.006)	(0.005)	(0.006)
postJan	−0.013***	−0.019**	−0.002	−0.010*	−0.014**	−0.013**
	(0.004)	(0.008)	(0.005)	(0.006)	(0.007)	(0.006)
Year	0.111***	0.123***	0.111***	0.123***	0.127***	0.120***
	(0.003)	(0.016)	(0.012)	(0.012)	(0.011)	(0.010)
Constant	6.637***	8.021***	6.369***	7.965***	8.460***	7.342***
	(0.426)	(1.994)	(1.823)	(2.285)	(2.183)	(2.083)
CRD dummies	YES	YES	YES	YES	YES	YES
No. of observations	16,959					

Table 8: FEIVQR and 2SLS IV Regression Results – Core region, asymm_sample

	Dependent variable:					
	Log Net Price					
	Mean (robust SE	0.1-q (boot SE)	0.3-q (boot SE)	0.5-q (boot SE)	0.7-q (boot SE)	0.9-q (boot SE)
Effect of competition:						
$-HHI \cdot 100$	0.029***	−0.003	0.016**	0.024***	0.030***	0.077***
	(0.005)	(0.008)	(0.007)	(0.003)	(0.005)	(0.014)
Other variables:						
Biotech	0.091***	0.133***	0.109***	0.082***	0.085***	-0.013
	(0.018)	(0.039)	(0.019)	(0.031)	(0.020)	(0.029)
unconstr_firm	0.046***	0.067***	0.075***	0.048***	0.044***	0.009
	(0.009)	(0.016)	(0.010)	(0.015)	(0.011)	(0.017)
unconstr_firm × *Biotech*	−0.032*	−0.063	−0.046**	−0.024	−0.029	0.075**
	(0.018)	(0.040)	(0.020)	(0.031)	(0.020)	(0.030)
Loyal	0.016***	0.018	0.016**	0.026***	0.006	-0.003
	(0.005)	(0.010)	(0.007)	(0.006)	(0.006)	(0.008)
Pct_Loyal	−0.010***	−0.006***	−0.010***	−0.011***	−0.011***	−0.013***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Conv	−0.325***	−0.338***	−0.319***	−0.298***	−0.292***	−0.277***
	(0.005)	(0.010)	(0.006)	(0.005)	(0.006)	(0.008)
IR single - stacked	0.055***	0.068***	0.056***	0.054***	0.061***	0.072***
	(0.006)	(0.010)	(0.007)	(0.008)	(0.007)	(0.009)
IR double - stacked	−0.040***	−0.035**	−0.029**	−0.028**	−0.027***	−0.010
	(0.009)	(0.016)	(0.012)	(0.012)	(0.010)	(0.015)
IR & HT multi - stacked	0.186***	0.211***	0.188***	0.169***	0.161***	0.165***
	(0.004)	(0.009)	(0.006)	(0.006)	(0.005)	(0.007)
EtnSeed	0.012***	0.049***	0.021***	0.012**	-0.001	-0.006
	(0.004)	(0.007)	(0.005)	(0.005)	(0.005)	(0.005)
EtnUse	0.028***	0.024**	0.029***	0.021***	0.022***	0.025***
	(0.006)	(0.011)	(0.006)	(0.006)	(0.008)	(0.008)
NewSeed	−0.013***	−0.010	−0.007	−0.003	−0.007*	−0.002
	(0.004)	(0.006)	(0.004)	(0.004)	(0.004)	(0.005)
NewSeed × *Conv*	−0.022***	−0.020*	−0.017**	−0.033***	−0.021***	−0.020**
	(0.007)	(0.012)	(0.008)	(0.008)	(0.008)	(0.009)
ProdDensity	−0.030***	−0.019***	−0.026***	−0.026***	−0.038***	−0.086***
	(0.003)	(0.005)	(0.003)	(0.002)	(0.004)	(0.014)
priorJan	−0.005***	−0.004	0.004*	−0.004**	0.000	−0.003
	(0.002)	(0.003)	(0.002)	(0.002)	(0.002)	(0.002)
postJan	−0.005	−0.016***	−0.008**	−0.002	0.004	−0.001
	(0.003)	(0.005)	(0.004)	(0.003)	(0.003)	(0.003)
Year	0.157***	0.110***	0.141***	0.156***	0.163***	0.196***
	(0.005)	(0.008)	(0.006)	(0.003)	(0.004)	(0.008)
Constant	5.885***	4.806***	5.537***	5.877***	6.183***	7.602***
	(0.119)	(0.189)	(0.143)	(0.095)	(0.140)	(0.369)
CRD dummies	YES	YES	YES	YES	YES	YES
No. of observations	21,713					

Note for Table 7 and 8: Statistical significance is noted by an asterisk ($*$) at the 10% level, two asterisks ($**$) at the 5% level, and three asterisks ($***$) at the 1% level. Results for the difference between payment and order time ($TimeDiff$) and purchase source effects ($SComp, MyselfD, FarmerD$) are not reported here but are discussed in the text. Non-IV results where also obtained and differ from the ones reported here.

Table 8: Wald test for equality of slope parameters in FEIVQR[28]

	$\beta_{0.1} - \beta_{0.5}$		$\beta_{0.5} - \beta_{0.9}$		$\beta_{01} - \beta_{0.9}$	
	Wald_test	p_val	Wald_test	p_val	Wald_test	p_val
unconstr_sample						
Fringe region						
$-HHI \times 100$	0.070	0.792	0.226	0.635	5.109	0.024
Core region						
$-HHI \times 100$	9.948	0.002	0.843	0.359	11.037	0.001
11.037						
asymm_sample						
Fringe region						
$-HHI \times 100$	0.542	0.462	2.015	0.156	2.900	0.089
$unconstr\_firm$	1.744	0.187	3.532	0.060	5.100	0.024
$unconstr\_firm\ x\ Big4$	1.634	0.201	1.222	0.269	3.705	0.054
Core region						
$-HHI \times 100$	12.136	0.0005	16.436	0.0001	27.443	0.000
$unconstr\_firm$	1.062	0.303	4.670	0.031	7.124	0.008
$unconstr\_firm\ x\ Big4$	0.782	0.377	7.408	0.006	8.232	0.004

6. Conclusions

In this study, we add insight into how firms price differently for identical products, and contribute to the understanding of the relationship between product availability and pricing. A clearinghouse model of price dispersion is proposed to explain the role of firm capacity constraints and differences in consumer preferences in the formation of "temporal" price dispersion for a homogenous product. The comparative static results are investigated empirically for the U.S. corn seed industry. The data provides farm-firm-level purchase information for conventional and genetically modified corn seeds sold by different firms between 2004-2009 in

[28] The Wald test results for coefficients other than $-HHI \times 100$, $unconstr\_firm$, $unconstr\_firm \times Biotech$ are available upon request.

the Fringe and Core regions of the U.S. Corn Belt. The empirical model is estimated using the IV FE Quantile Regression.

The research findings yield several major conclusions. First, our model predicts a positive relationship between competition and pricing. Competition among symmetrically capacity-unconstrained firms, or among firms with asymmetric capacity levels leads to a price increase along the distribution function. For the former case, we find evidence consistent with the theory in the Core of Corn Belt, a region where corn is the predominant crop. In contrast, the predictions for the later case are confirmed in both Core and Fringe of Corn Belt regions. These findings suggest also the existence of spatial price discrimination that may be attributed to differences in substitutability among crops. Second, our model indicates that product availability and pricing move in the same direction. Applied to our data, we find evidence of price premiums charged by capacity-unconstrained firms in both Fringe and Core regions. Third, we investigate whether an increase in the firms' loyal customer base leads to an increase in price along the distribution function. We found this pattern is highly significant when competition is among symmetrically capacity-unconstrained firms located in the Core region. It is also significant for other forms of competition or in the Fringe region but only for specific price quantiles. Fourth, we find that seed companies engage in temporal price discrimination. Farmers in the Core region may pay lower prices if they order seeds early in the season, and farmers in the Fringe region benefit by placing orders earlier or later in the season.

Such effects on the distribution function of prices may be of concern to policy makers interested in the development of antitrust and consumer protection law or policy. For example, current antitrust laws are concerned that some mergers/ acquisitions change the functioning of markets in ways that can lead to higher prices and other inefficiencies. However, for some industries a new entrant may not be beneficial to consumers if firm capacity constraints and consumer brand loyalty play a significant role. It may actually induce collusion with the incumbent firms, which will harm all consumers by charging prices specially designed to attract surplus from the loyal customer base. Policies designed to prevent anticompetive mergers/acquisitions may have unintended consequences if failing to account for these particularities.

Our analysis could be extended in several directions. First, it would be useful to test empirically the predictions of our theoretical model when firms competing in the market have symmetric capacity-constrained levels. Due to data limitations we could not provide this evidence. Second, it will be useful to relax the assumption of product homogeneity and develop an industry model for differentiated products. Finally, there is a need to explore empirically the role of capacity constraints and brand loyalty in other sectors of the economy.

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Appendix A

Proof Theorem 1:

1) If all firms are capacity-constrained and $\mathrm{K_i} + \sum_{-i} \mathrm{K_{-i}} \leq \mathrm{D(p^*)}$, no firm has sufficient capacity to meet the entire market demand and the total capacity in the market is at most equal with the market demand. The Nash equilibrium price is $p_i = p_{-i} = r$. A deviant firm cannot benefit by charging a higher price since at prices greater than the reservation price no consumer will buy. A deviant firm has no incentive to name a lower price, as sales will not change since each firm is selling its full capacity at the equilibrium price. The equilibrium is in pure pricing strategies.

2) If all firms are capacity-constrained but $\mathrm{K_i} + \sum_{-i} \mathrm{K_{-i}} > \mathrm{D(p^*)}$, no firm has sufficient capacity to meet the entire market demand and the total capacity in the market exceeds the market demand. Assume that all firms charge a single price p such that $p^* < p < r$. A deviant firm can charge a slightly lower price $p - \epsilon > p^*$ and make positive profits because it will get a fraction of the price sensitive shoppers provided it does not exceed its capacity level. Assume now that all firms charge p^*. In this case a deviant firm can charge a higher price and make positive profits by serving at least its share of loyal customers. I conclude that there is no symmetric equilibrium with all firms charging the same price. The equilibrium is in mixed pricing strategies.

3) When $K_i \geq D(p^*)$ and $K_{-i} \geq D(p^*)$ for all i and $-i$, , each firm has sufficient capacity to meet the entire market demand. Assume that all firms charge a single price p such that $p^* < p < r$. A deviant firm can charge a slightly lower price $p - \epsilon > p^*$ and make positive profits because it will get all of the price sensitive shoppers. Assume now that all firms charge p^*. In this case each firm will get an equal share of the market and make negative profit. I conclude that there is no symmetric equilibrium with all firms charging the same price. The equilibrium is a mixed pricing strategy by all firms.

4) When $K_i + \sum_{-i} K_{-i} > D(p^*)$ with $K_i \geq D(p^*)$ and $K_{-i} < D(p^*)$ for all $-i$ firms, firm *i*'s competitors do not have enough capacity to meet the entire market demand.

a) $p_i = p_{-i} = p^*$, is not an equilibrium. A type $-i$ firm can charge a higher price and make positive profits by serving at least its share of loyal consumers. Also, firm i has an incentive to deviate and charge a higher price: if its competitors price at the average cost $p_{-i} = p^*$ and sell K_{-i} units, then the optimal strategy for firm i is to act as a monopolist on its residual demand function by selling at the reservation price, $p_i = r$.

b) $p_i = p_{-i} = p > p^*$ and $p > r$, is not an equilibrium. No consumer is willing to buy. The market demand is zero.

c) $p_i = p_{-i} = p > p^*$ and $p < r$, is not an equilibrium. Firm i does not have any incentive to price aggressively and will act as a monopolist on its residual demand curve and charge at the reservation price $p_i = r$.

d) $p_i > p_{-i} > p^*$, is not an equilibrium because any $-i$ firm can increase profits by charging just below p_i .

I conclude that there is no symmetric equilibrium with all firms charging the same price. The equilibrium is in mixed pricing strategies.

5) When $K_i + \sum_{-i} K_{-i} > D(p^*)$ with $K_i < D(p^*)$ and $K_{-i} \geq D(p^*)$ for all $-i$ firms, firm *i*'s competitors have enough capacity to meet the entire market demand.

a) $p_i = p_{-i} = p^*$, is not an equilibrium. Any $-i$ firm can deviate and charge a higher price by serving at least its share of loyal consumers.

b) $p_i = p_{-i} = p > p^*$ and $p > r$, is not an equilibrium. No consumer is willing to buy. The market demand is zero.

c) $p_i = p_{-i} = p > p^*$ and $p < r$, is not an equilibrium. Firm i has an incentive to deviate and charge a lower price $p - \epsilon$ if its capacity exceeds the number of loyal consumers.

d) $p_{-i} > p_i > p^*$, is not an equilibrium because firm i can increase profits by charging just below p_i.

I conclude that there is no symmetric equilibrium with all firms charging the same price. The equilibrium is in mixed pricing strategies.