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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* We would like to thank Allen Sorensen, Bradford Barham, Daniel Phaneuf, Jean-Paul Chavas, Luis Cabral, as well as seminar participants in the 2016 EARIE Rising Stars Session for useful feedback. This research was supported in part by USDA AFRI grant, USDA Hatch grant, and American Bar Association grant.
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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, thus search costs are zero. In this case, 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 seed production decisions are made 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 details the literature on price dispersion.

supply a homogenous product, and (2) consumers are heterogeneous in preference (loyal vs. price sensitive). A clearinghouse model may be more appropriate than a search-theoretic model for such industries, because their price dispersion tends to be “temporal”: firms may charge different prices for the same product at each point in time, and 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, using the Fixed Effect Instrumental Variable (FEIV) Quantile Regression. 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] which provides opportunity for the empirical testing of our theory and documenting the effect of this consolidation.

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

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

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

Our theoretical analysis begins with 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.

The two-stage game

On the supply side, we assume N price-setting firms, 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 minimal or no cost (e.g. via newspaper or internet search engine).

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

[3] We assume that firms' production functions exhibit decreasing returns to scale, thus. $c(q_i)$ is increasing and convex: $c'(q_i) > 0$, $c''(q_i) \geq 0$ for $q_i > 0$.

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:

$$\begin{cases} \left[1-\frac{K_j-L_j}{D_s(p_j)}\right] & , if\ K_j-L_j \leq D_s(p_j), firm\ j\ is\ capacity-constrained; \\ 0 & ,\ otherwise. \end{cases}$$

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

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

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:

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

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

[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.

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

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.

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.[6] For any price p, we assume that the market demand function $D(p)$: $\mathbb{R}_{++} \rightarrow \mathbb{R}_{++}$ is differentiable and strictly decreasing in p. We further assume that 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 $\lim_{p \to \infty} D(p) = 0$. The market revenue function, $p * D(p)$: $\mathbb{R}_{++} \rightarrow \mathbb{R}_{++}$ is single peaked and attains a unique maximum at the consumer's reservation price, r, and is strictly concave in p for $p < r$. We also assume that 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 $q \geq q^*$, $\frac{\partial p_i^*(q)}{\partial q} \geq 0$. The equilibrium pricing strategy is static.[7] And 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, then the equilibrium is a pure strategy with each firm charging the consumer's reservation price r when $\mathrm{K_i} + \sum_{-i} \mathrm{K_{-i}} \leq \mathrm{D(p^*)}$, and a mixed strategy otherwise.

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[6] 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.

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

2) If all firms are capacity-unconstrained, the equilibrium is a mixed strategy.

3) If there is a mix of capacity-constrained and capacity-unconstrained 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 (*w*)** and the number of consumers being served by firm i is: $\min[K_i, L_i + D_s(p_i)]$.

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

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:

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

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.[8] 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 $[p^*, r]$

[8] 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.

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

In equation (1), $[1 - F(p_i)]^{N-1}$ 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.

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: $f(p_i) \geq 0$ *and* $\int_{p^*}^{r} f(p_i)\, dp_i = 1$, 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: $\Pi_l(r) = \{(r - c) \cdot \min[K_i, L_i + D_s(p_i) \cdot x_i]\}$, 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. QED.

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

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

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.

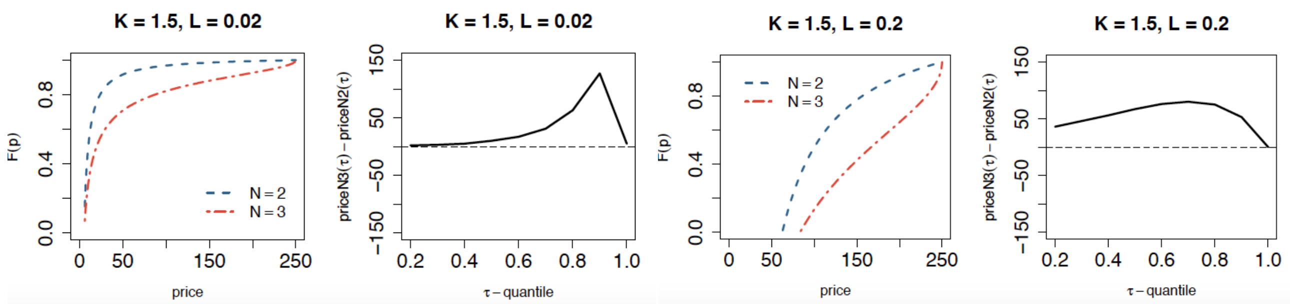
Equation (3) can be used to derive predictions about the distributional effects of competition (via N) on price, and about the relationship between product availability (via K) or loyal customer base (via L) and pricing. We rely on simulation of the equilibrium distribution function to obtain the comparative static results. We are interested in examining the competition effects on pricing associated with firms' entry or exit in a local market, and whether or not capacity constraints and the relative size of loyal customer base would affect the competition effects. In particular, we focus on the following two scenarios: [1] all firms are capacity-unconstrained with similar loyal customer base ($K_i = K_{-i} > 1,\ L_i = L_{-i}$), and [2] incumbent firms ($i1, i2$) can be capacity constrained or unconstrained ($K_{i1} < 1, K_{i2} \geq 1$) with different loyal customer base ($L_{i1} \neq L_{i2}$), while the entrant firm is unconstrained ($K_e \geq 1$). We assume the loyal customer base for the entrant firm is similar to one of the incumbent firms, say firm $i2$ ($L_{i2} = L_e$).

By varying the number of firms *N* for given *K*'s, *L*'s and other parameter values in equation (3), we simulate the price distribution under different scenarios. 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 obtain the following result:

Result 1. Under scenario (1), the effects of competition on the distribution function of prices is positive at all quantiles.

Results 1 can be illustrated in Figure 1. Both panel (a) and (b) (with varying loyal customer base) suggest 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. The residual demand from price sensitive consumers decreases as part of these shoppers has converted to loyal customer to the entrant firm. Therefore, the incentive to price low to attract the price sensitive shoppers decreases. Instead, firms focus on extracting surplus from the loyal customer base. Comparing panel (b) to panel (a), the loyal customer base size matters: the magnitude of the competition effect increases in the lower tail of price distribution but decreases in the upper tail when the size of loyal consumers increases.



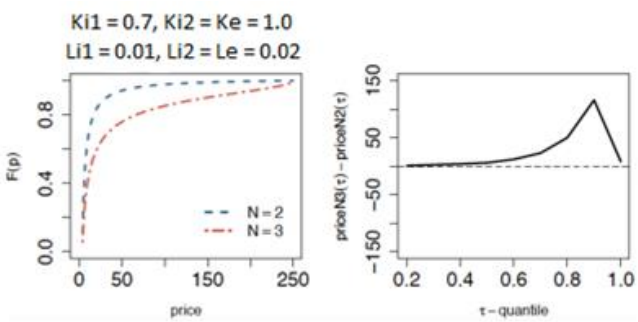
(a) (b)

Figure 1: Effect of competition and loyalty for capacity-unconstrained firms. Panel (a)-(b): Cumulative distribution function (left) and its corresponding quantile function (right), c = 0, r = 250. The results are robust to changing from 1.5 to 1.

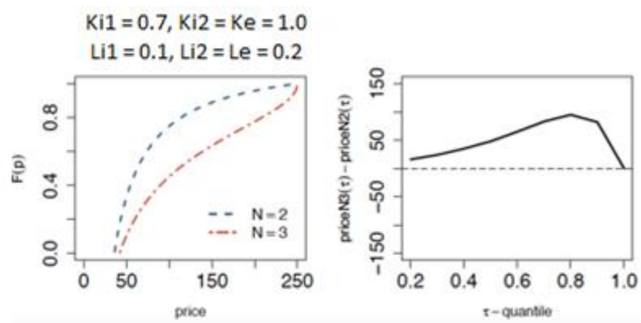
Result 2. Under scenario (2), the effects of competition on the distribution function of prices differ by incumbent firms' capacities:

1. *Response of the capacity-constrained incumbent firm ($i1$): The increased competition from capacity-unconstrained firms leads to an overall price increase in all quantiles.*
2. *Response of the capacity-unconstrained incumbent firm ($i2$): The increased competition from capacity-unconstrained firms leads to an overall price increase in all quantiles when the capacity of firm ($i1$) and the size of loyal consumers in the market are sufficiently large.*

Figure 2 shows *the response of the capacity-constrained incumbent firm* ($i1$). We observe that entry by a capacity-unconstrained firm triggers higher prices paid by all consumers in the market. It seems that incumbent firm $i1$ may focus on extracting more surplus from its loyal customers and withdraw from competing for the price sensitive shoppers. When varying the loyal customer base, we found qualitatively consistent result, yet the magnitude of the competition effect will be greater when the size of loyal consumers in the market is larger. Panel (b) vs. (a) also show similar patter as in result 1 that the price increase effect is larger in the lower tail of the price distribution when more loyal consumers exist in the market.



(a)



(b)

Figure 2: Effect of competition and loyalty: Response of the capacity-constrained firm ($i1$). Panel (a)-(b): Cumulative distribution function (left) and its corresponding quantile function (right).

Figure 3 shows the *response of the capacity-unconstrained firm* ($i2$). When incumbent firm $i1$ is small relative to incumbent firm $i2$, the entrant of another capacity-unconstrained firms leads to a lower price charged by firm $i2$ to all consumers in the market (illustrated in panels a and b). Comparing panel b to panel a, an increase in the loyal customer base would narrow the price jump, but does not alter the overall trend.

However, when the incumbent firm $i1$ is big relative to incumbent firm $i2$, , then effects of the entry of another capacity-unconstrained firm will be different, and will depend critically on the size of loyal customer base. When the loyal customer base is relatively small, the competition effect will be such that firm $i2$ charging a higher price in the upper quantiles only (illustrated in panel c). And when the size of loyal customer base becomes large, then firm $i2$ would charge a higher price to all consumers in the market upon the entry of the new firm (see panel d). Comparing panel b to panel d, it may suggest a switch of pricing strategy from competing for the price sensitive shoppers mainly to extracting surplus from the loyal customers only.

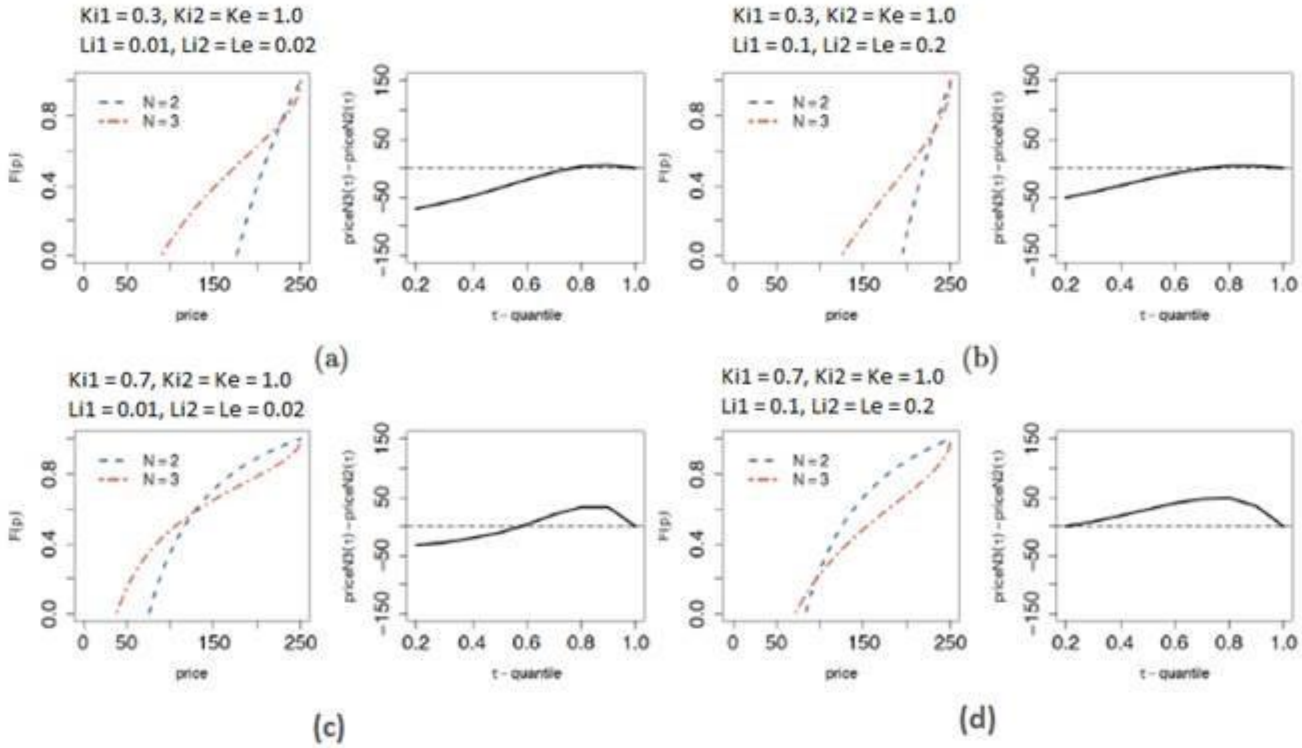


Figure 3: Effect of competition and loyalty: Response of the capacity-unconstrained firm ($i2$). Panel (a)-(d): Cumulative distribution function (left) and its corresponding quantile function (right).

The results above 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.

Result 3 is presented in Figure 4 by comparing the pricing strategies of firm $i1$ and firm $i2$ as illustrated in Figures 2 and 3 above. We observe that the distribution function of the capacity-unconstrained firm ($i2$) stochastically dominates the distribution of the capacity-constrained firm ($i1$). 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.

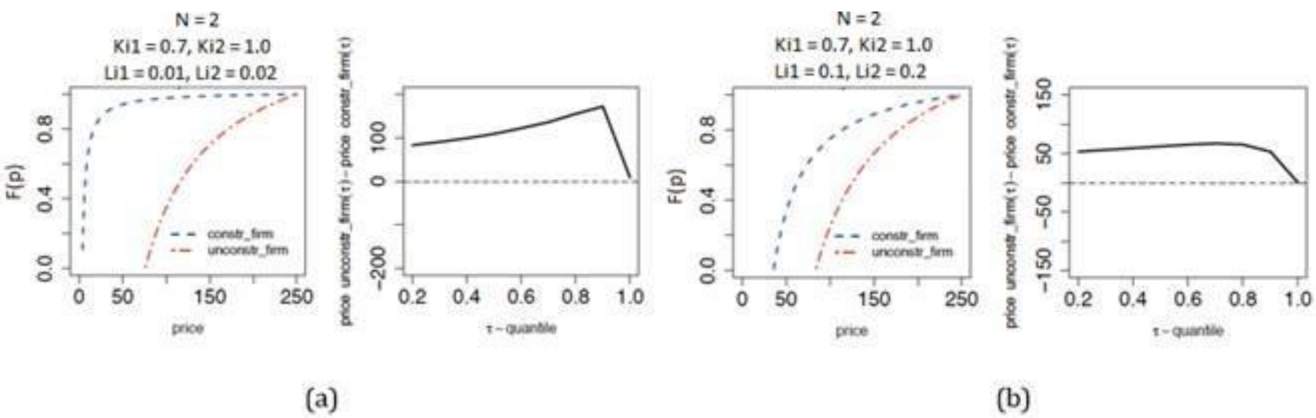


Figure 4: Relationship between product availability and pricing. Panel (a)-(b): Cumulative distribution function (left) and its corresponding quantile function (right).

3. The U.S. Corn Seed industry

The analysis in section 2 provides several hypotheses that can be empirically tested. 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. In this study, we use data from the U.S. corn seed industry to implement the empirical estimation.

The seed industry provides an excellent case for our study for three reasons. First, seed companies engage in both temporal and spatial price discrimination. They charge different prices for the same seed product over time and across regions. Second, seed firms differ in their ability to meet the market demand for their products, thus can be either capacity-constrained or capacity-unconstrained. Finally, the industry is characterized by a mix of brand loyal farmers and price sensitive farmers. [9] C

U.S. corn growers plan year $t+1$ production in year t, usually from August$_t$ to April$_{t+1}$, and start seed planting around May$_{t+1}$. From June$_{t+1}$ to September$_{t+1}$ they address in-season

[9] We consulted with UW-Extension specialists, regional sales managers, and farmers in the state of Wisconsin to confirm the existence of capacity constraints and brand loyalty in the seed industry. A five-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)

challenges and opportunities, and finally, harvest their fields between October_{t+1} and 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 farm location, seed pricing, seed performance, farmer's relation to the seed company, and the expected seed availability at different points in time (due to capacity constrains seeds may not be available throughout the planning period).

In this study, we rely on a data set collected by GfK Kynetec (hereafter dmrk), St. Louis, MO, which 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 interviews during the month of June of each year. The data includes information on seed company identity, type of seed (conventional or type of genetically modification technology), special feature of seed, intended end use, net price, seed quantity per transaction, time of order and time of payment, and source of purchase.

In this study we focus on the most agriculturally productive corn area of the US, the Corn Belt region. We define the local market (competition region) at the Crop Reporting District level (**CRD**). By USDA definition, regions in a given CRD share similar agro-climatic conditions, hence are likely targeted by similar seed varieties. To account for regional differences, we divide the data into the Fringe of Corn Belt (where farmers are likely to substitute between different crops), and the Core of Corn Belt (where corn is the predominant crop and substitution is less likely). 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.

For statistical validity, we screen the data to include only transactions in CRDs with more than ten farmers sampled in every year, with positive net prices, known seed hybrid numbers, and known order and payment time. We also exclude transactions with intended use as "corn for seed"[10], and purchase source as "seed left over from last year". In total, our analysis includes 53,413 and 61,835 farm-firm-level sales observations from 55 and 26 CRDs out of 13 and 6 states in the Fringe and Core regions, respectively.[11]

There are over 100 seed companies operating in the markets, with a decreasing trend in both Core and Fringe regions of the Corn Belt (see Table 1). 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$_t$ – December$_t$, and capacity-unconstrained otherwise. Table 1 suggests that throughout the study period, over a quarter of the total firms are capacity constrained. However, they supply only between 1.5 – 2.7 percent of the corn acreage in the Core region, and between $1.7 - 2.3$ percent of the corn acreage in the Fringe region. The capacity constrained firms seem to be small in size compared to those capacity unconstrained firms.

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

	Fringe			**Core**		
Year	*# of firms*	*# of capacity-constrained firms*	*Acreage share of capacity- constrained firms (%)*	*# of firms*	*# of capacity-constrained firms*	*Acreage share of capacity-constrained firms (%)*
2004	164	41	2.0	138	42	1.8
2005	171	49	2.3	140	43	2.7
2006	171	48	2.2	145	46	1.7
2007	178	45	2.3	136	34	1.5
2008	155	40	2.1	122	38	1.8
2009	146	38	1.7	111	36	2.3

Finally, it is important to recognize that price dispersion might be attributed to heterogeneity among seed products. Seeds sold in the market differ primarily by whether the genetically modification (GM) technology is incorporated. GM seeds were introduced in the U.S.

[10] Seed companies contract farmers to grow crops for seeds that will be sold in the following season.
[11] 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.

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, glufosinate, and other herbicides.

The GM traits were initially introduced as a single trait, but then got stacked one and another. To account for product heterogeneity, 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[12]. We treat the IR traited GM seeds differently from the IR & HT stacked ones to further capture price differences inherently implied by the GM technology.

3.1. Scenario Samples

The theoretical model in section 2 is tested using the seed market data presented above. Given the distribution of capacity-constrained and capacity–unconstrained seed firms in the two regions, we divide the data in two scenario samples. In **Scenario 1** competition is between symmetrically capacity-unconstrained firms; and in **Scenario 2** competition exists among firms with asymmetric capacities, that is both capacity-constrained and capacity-unconstrained firms exist in the market.

We define a CRD as symmetrically unconstrained if the market share of the unconstrained seed companies in a year is greater or equal to 98 percent, and as asymmetric otherwise.[13] This yields an unbalanced panel sample of symmetrically unconstrained firms with 36,385 and 40,178 observations in the Fringe and Core regions, respectively. We denote this sample as

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

[13] The 98 percent threshold was chosen arbitrarily to represent that firms competing in a region are very likely to be symmetrically capacity-unconstrained. The empirical results are robust to different threshold levels.

unconstr_sample. The asymmetrically constrained sample is also an unbalanced panel sample, with 17,028 and 21,657 observations 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[14], and the median Gini coefficient[15] for conventional seeds and various GM seed. 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 samples; thus, price dispersion is generally present in the market. For example, the Gini coefficient is in the 0.1-0.2 range, corresponding to an expected price difference between 20 percent and 40 percent of the mean net price for any two randomly selected seed purchases in a given sample. Moreover, GM seeds are on average 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.

[14] 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 $1-k$.

[15] The Gini coefficient, G is computed following Dixon *et al.* 1987, Damgaard and Weiner 2000: for price values $p_i, i = 1, \ldots, N$, and mean price $\bar{p}$, $G = \frac{\sum_{i=1}^{N}\sum_{j=1}^{N}|p_i - p_j|}{2N^2\bar{p}}$.

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

Seed Type	Fringe					Core				
	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	8,951	0.13	68	93	120	9,447	0.12	70	95	120
asymm_sample	5,767	0.13	67	90	119	6,666	0.11	71	92	116
GM IR single-stacked:										
unconstr_sample	3,024	0.1	89	112	135	5,052	0.09	90	113	135
asymm_sample	1,267	0.1	85	110	133	2,723	0.1	86	110	133
GM HT single-stacked:										
unconstr_sample	7,983	0.15	91	125	181	5,803	0.16	92	129	187
asymm_sample	3,351	0.16	87	127	189	3,229	0.17	85	125	192
GM IR double-stacked:										
unconstr_sample	198	0.11	110	139	173	585	0.09	110	134	156
asymm_sample	128	0.11	104	130	166	340	0.10	106	131	159
GM IR & HT double- stacked:										
unconstr_sample	7,196	0.11	102	126	162	8,066	0.10	104	127	161
asymm_sample	2,219	0.12	100	126	170	3,285	0.10	100	124	154
GM IR & HT triple- stacked:										
unconstr_sample	7,547	0.13	128	180	240	9,265	0.14	130	180	250
asymm_sample	3,602	0.13	130	185	249	4,582	0.15	130	186	261
GM IR & HT quad- stacked:										
unconstr_sample	1,486	0.11	143	193	238	1,960	0.12	140	189	246
asymm_sample	693	0.11	143	193	235	832	0.12	143	200	248

4. Econometric Specification

Our theoretical model in section 2 suggests that there should be distributional effects to competition, which may interact with the product availability and loyal customer base. 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 (likely price-sensitive shoppers) may respond differently to competition relative to those farmers likely to pay prices in the upper tail (likely loyal consumers).

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

$$\ln\big(P(k)\big)_{ict} = \beta_{0(k)} - \beta_{1(k)}\ HHI_{ct} \times 100 + \Upsilon^{1}{}_{(k)}\ \boldsymbol{M} + \Upsilon^{2}{}_{(k)}\boldsymbol{F} + \Upsilon^{3}{}_{(k)}\ \boldsymbol{C} + \Upsilon^{4}{}_{(k)}\ \boldsymbol{S} + \Upsilon^{5}{}_{(k)}\ \boldsymbol{X} + \alpha_{c(k)} + \epsilon_{ict} \quad (5)$$

where $P(K)_{ict}$ is the k^{th} - price quantile for seed supplied by firm i in CRD c at time t; HHI_{ct} is the Herfindahl-Hirschman Index (HHI) in CRD c at time t; **M**, **F**, **C**, **S**, **X** are vectors of other covariates related to discriminatory pricing, grouped into market attributes (**M**), farmer attributes (**F**), company attributes (**C**), seed attributes (**S**), and other variables (**X**); α_j captures the CRD fixed effect accounting for regional heterogeneity, beta and gamma's are the parameter coefficients, and ϵ_{ijt} is an unobservable error term[16]. We further account for spatial price discrimination by estimating separate regressions for the Fringe and Core regions. Summary statistics of selective variables are presented in Table 3.

[16] Note that we are interested in the distribution of the price variable $\ln(P_{ict(K)})$, relative to CRD fixed effects, $\alpha_{c(k)}$, thus our parameters will reflect the estimation of the conditional distribution of $[\ln(P_{ict(K)}) - \alpha_{c(K)}]$.

Table 3: Descriptive statistics of selective control variables.

Variable	Mean		Std Dev		Min		Max	
	Fringe	Core	Fringe	Core	Fringe	Core	Fringe	Core
MARKET ATTRIBUTES								
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	0.35
Product Density (%)								
unconstr_sample	6	11	2.64	2.86	1	2	12	16
asymm_sample	5	10	1.68	3.03	1	2	8	15
FARMER ATTRIBUTES								
Loyal Farmer								
unconstr_sample	0.78	0.83	0.41	0.38	0	0	1	1
asymm_sample	0.79	0.84	0.40	0.36	0	0	1	1
Share of Loyal Farmers in a CRD (%)								
unconstr_sample	78	83	9.66	6.11	27	61	97	97
asymm_sample	79	84	9.52	7.73	20	57	97	97
Number of Loyal Farmers in a CRD at the firm level								
unconstr_sample	40	64	46.68	68.27	0	0	202	266
asymm_sample	27	50	42.14	51.37	0	0	257	218
Difference between Order Time and Payment Time (in months)								
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
COMPANY ATTRIBUTES								
Biotech Company								
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
SEED ATTRIBUTES								
Seed is Conventional								
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
Seed with Special Feature for Ethanol Production								
unconstr_sample	0.25	0.24	0.43	0.43	0	0	1	1
asymm_sample	0.19	0.17	0.39	0.37	0	0	1	1
Seed is Intended for Ethanol Production								
unconstr_sample	0.11	0.10	0.31	0.30	0	0	1	1
asymm_sample	0.07	0.08	0.25	0.27	0	0	1	1
New Seed								
unconstr_sample	0.49	0.48	0.50	0.50	0	0	1	1
asymm_sample	0.55	0.49	0.5	0.5	0	0	1	1
New Seed is Conventional								
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
Observations								
unconstr_sample	36,385	40,178						
asymm_sample	17,028	21,657						

Market attributes: We use HHI to measure the market concentration computed at the CRD level 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. On average, the market in the Fringe region is more concentrated than that in the Core region, with HHI at 0.21 vs. 0.16 for the unconstrained sample, and at 0.17 vs. 0.14 for the asymm_sample. The variation in individual CRDs is larger, ranging from 0.06 to 0.81 across samples and regions. Firms seem to compete more fiercely in the Core region, where the maximum HHI is only in the low 0.30s.

Another market attribute is the crowdedness of seed product varieties. When farmers face with many seed products with similar technologies, they have high substitutability in demand for various seed products. Such a feature will affect seed pricing chosen by firms. We construct a product density variable to measure such market crowdedness. We calculate it as the percentage of seed hybrids in a given CRD market relative to the total number of various seed hybrids present in all CRD markets in the Fringe and Core region. Similar to the HHI, the product competition in the Core region is higher than that in the Fringe region, with an almost doubling crowded product space: 11 percent vs. 6 percent for the the unconstr_sample, and 10 percent vs. 5 percent for the asymm_sample.

Farmer attributes: We distinguish between price sensitive and loyal farmers. Anecdotal evidence suggests that loyal farmers are likely to order early in the season (August – December), whereas price sensitive farmers shop around for the entire season (from August_t to April_{t+1}) and tend to order later in order to obtain seeds on sale. We construct a dummy variable to reflect that loyal farmers are likely to order early. If loyal, the seed was ordered in the period August – December. Otherwise, the seed was order on or after January. About 83 percent of orders in the Core region and about 78 percent in the Fringe are placed early in the season.

We constructed two more variables as proxies for the size of loyal customer base in the local market. One relates to the share of loyal farmers in a CRD defined as the percentage of transactions in each CRD occurred in $August_t$ to $December_t$ over those in the entire season; the other one relates to the number of loyal farmers in a CRD at the firm level, defined as the company specific total number of transactions occurred in $August_t$ to $December_t$ at the CRD level. On average loyal farmers in the unconstrained sample places more orders per company than those in the asymm-sample: 40 vs. 27 in the Fringe region and 64 vs. 50 in the Core region.

In addition, seed companies often offer cash discounts for farmers who pay in advance.[17] It may serve as part of their price discrimination schemes. We try to capture such an effect by counting the timing difference between the date that the order is being placed and the date that the payment is made. Table 3 suggests that on average it takes farmers in the Fringe region longer (about 2 months) to make the payment than those in the Core region (about one and a half months). Yet at the individual level, there is much larger time variance, ranging from on-site payment (no time difference) to 11 months.

Company attributes: We differentiate seed companies by vertical structure affiliation. A firm is either independent (e.g. Beck's Hybrids, Unity Seeds), or belonging to a vertically integrated biotechnology-seed firm (e.g. Asgrow is part of Monsanto's corn seed division). In both scenario samples, biotech companies dominate independent companies in the market, having an average market share of 80% and 73-4% in the unconstr_sample and asymm_sample, respectively. However, at the local market level, their share ranges from zero to 100%, indicating a large variance within the sample. For Scenario 2 only, we also distinguish between capacity constrained and -unconstrained firms. Further, we allow for the possibility that vertically

[17]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.

integrated biotechnology seed companies that are unconstrained may play a different pricing strategy by introducing the corresponding interaction terms.

Seed attributes: Seeds differ by technology (conventional vs. various GM), whether the seed hybrid has special features for ethanol production (has higher levels of fermentable starch (HLFS) and/or extractable starch (HLES)), and intended output use being ethanol or not.

The average share of conventional seed in the Core region is 24 percent in the unconstr_sample and 31 percent in the asymm_sample. Similar patterns are observed in the Fringe region. The conventional seed share decreases quickly over time, reflecting the general adoption of GM seeds by U.S. corn farmers. Seeds with special features for ethanol production have a larger share in the unconstr_sample than in the in the asymm_sample for both Core and Fringe regions: 25% vs. 19% and 24% vs. 17%, respectively. However, less than half of these seeds have indicated intended output use in ethanol production.

We also control for whether the seed is new to the market (i.e. if it had never presented in the dmrk data since 1994). Seed company's pricing strategy as well as farmer's willingness to pay are likely different for seeds new to the market. Around 50 percent of seeds are new in the market across samples and regions, indicating that seed companies are continuously involved in developing new seed varieties. We also interact the variables related to new seed and conventional to assess if farmers are more (or less) risk averse to conventional new seeds as opposed to GM seeds.

Other variables: We control for price dispersion attributed to other factors such as purchase sources, time of order, and year trends. Purchasing sources include "directly from the seed company or its representative", "Myself being a dealer for the seed company", "other farmer who is a dealer or agent", and "others". Over 60 percent of transactions were classified into one of these first three categories.

The pattern that prices fluctuate throughout the season may be increasing or decreasing according to the probability at the time of order that demand will exceed capacity. We construct a two time-trend variables to control for such an effect. Using Janurary$_t$ as the benchmark, those orders being placed prior to or after this month will take the corresponding values that equals to the month distances to Janurary$_t$. For example, if an order is placed in August$_{t-1}$, then $priorJAN = 5$ and $postJAN = 0$. If an order is placed in February$_t$, then $priorJAN = 0$ and $postJAN = 1$. Our data suggests that most orders are placed in the period November$_{t-1}$ – January$_t$.

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

5. Econometric Estimation

As suggested in our theoretical model, we will examine the whole distribution function of pricing. We will use quantile regression approach to accomplish our research objectives. One challenge to the identification strategy in the econometric specification (5)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 (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 specification (5) 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 for both 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 (HHI_{t-1}). 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 HHI_{t-1} is an appropriate instrument if it is uncorrelated with the error term (the orthogonality condition) but correlated with the endogenous regressor HHI_t (not a "weak instrument"). Since the model is "exactly identified", the orthogonality condition holds by construction in equation (5). We use the Arelano and Bond (1991) estimator to test for first, second and third serial correlation in the idiosyncratic errors. The null hypothesis of "*no serial correlation*" in all samples cannot be rejected in favor of the alternative. The p-value exceeds 0.10 for all levels of correlation tested.

To test for “weak instruments”, we examine the reduced form regression and evaluate the explanatory power of HHI_{t-1}. The values of the F statistics for the null hypothesis in the unconstr_sample and asymm_sample are 259.78 and 68.63 in the Fringe region, and 558.34 and 499.47 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 constant variance. The Breusch-Pagan test result applied to the econometric specification (5) rejects null of homoskedasticity assumption in all samples. The Chi statistics are in the range of 330 and 1402 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 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).

6. Empirical Findings

Tables 4 - 6 report the econometric results of our analysis of distributional effects of competition on price, as well as 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.

6.1. The case of unconstr_sample

Estimation results in the unconstr_sample are presented in Table 4 for the Fringe and Core regions. We report the bootstrapped standard errors[18] (FE IV QR) and the heteroskedastic-robust standard errors (2SLS IV) in parentheses.

Market attributes: 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.

The effect of an increase in competition is statistically significant and negative across the distribution function of price in the Fringe region, while being positive in the Core region. In the Fringe region, the estimates suggest that a one-percentage point increase in HHI may lead to a decrease in the seed price by 0.9 percent ($0.72 per bag) at the 0.1-quantile, and by 1.9 percent ($3.03 per bag) at the 0.9-quantile. This price effect is much stronger in the Core region with a 10.2 percent increase ($8.63 per bag) at the 0.1-quantile and a 7.3 percent increase ($11.95 per bag) at the 0.9-quantile. We test for equality of the slope parameters across quantiles using the Wald test statistics. Table 6 reports the test results for selected quantile pairs. In the Fringe region, the null is rejected in favor of the alternative for all quantile cases, while in the Core region, the slope differs between the upper tail and lower tail, but remains the same across quantiles in the middle portion of distribution. In general, the competition effect differs along the pricing distribution function in these regions.

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

The 2SLS IV results find a significant positive impact of an increase in competition on mean price in both Fringe and Core region.[19] Thus, 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.

The product density effect is statistically significant and positive across the entire distribution function of prices in the Fringe region, but significant and negative in the Core region. This may suggest that the cross-elasticity of demand among corn seed brands is definitely more pronounced in the Core region.

Farmer attributes: Being a loyal farmer has a positive and significant effect at the mean and across the distribution of prices in the Core region, yet not significant in the Fringe region. Additionally, the share of loyal farmers in a CRD positively impacts prices. This effect is positive and statistically significant in both regions. The economic magnitude is relatively small and significant only in the lower tail in the Fringe region, yet larger and statistically different across quantiles in the Core region. The total number of transactions per firm occurred in $August_t$ to $December_t$ at the CRD level positively effects prices as well; the corresponding coefficient is statistically significant in the Fringe and Core regions but has a small magnitude. These results

[19] The 2SLS IV estimates are larger than the OLS estimates in both regions, implying that the OLS estimates are downward biased (e.g. if pricing and knowledge of the demand side are negatively correlated).

indicate that an increase in the firms' loyal customer base may raise the price of seeds for farmers in the two regions. Thus, they 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).

We also find that a one-month increase in the difference between payment time and order time slightly increases prices in the Core region.

Company attributes: We find evidence of distributional price effects associated with the type of seed company. Biotechnology companies charge a price premium at the mean and across the entire distribution of prices in both regions, with a higher magnitude in the lower tail of the price distribution.

Seed attributes: The variable corresponding to conventional seed and the variables controlling for various GM technology show that GM seeds are sold at a price premium over conventional seeds, and that GM seeds with multiple technologies are generally priced more.

We also find that farmers in the Core and Fringe region are not willing to pay a price premium to plant seeds specially designed for ethanol production, that is featuring HLFS and/or HLES. However, farmers in the Fringe region may pay a price premium for seeds if the stated end use is ethanol production. Additionally, farmers in the two regions associate conventional new seeds with higher performance uncertainty as opposed to GM.

Other variables: The variables corresponding to purchase source are positive, negative or change signs across the price distribution 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 variables capturing the timing of transaction (prior or after January) indicate that seed companies may engage in temporal price discrimination. Loyal and price sensitive farmers located in the Core region can save on their input costs if they order seeds early in the season, whereas loyal farmers in the Fringe can save if they order earlier and price sensitive farmers if they order later. Finally, we find the time trend effect is positive and significant across regions – with a greater magnitude in the Core - indicating that technology advancement, inflation and other potential time consistent structural changes justify part of the observed price variation.

Table 4: FEIVQR and 2SLS IV Regression Results – Core and Fringe region, unconstr_sample

	Dependent variable: Log Net Price							
	Fringe region				**Core region**			
	FEIVQR			**2SLSIV**	**FEIVQR**			**2SLSIV**
	0.1-q	**0.5-q**	**0.9-q**	**Mean**	**0.1-q**	**0.5-q**	**0.9-q**	**Mean**
MARKET ATTRIBUTES								
(-) HHI * 100	-0.009 *	-0.042 ***	-0.019 ***	0.027 ***	0.102 ***	0.081 ***	0.073 ***	0.107 ***
	(0.005)	(-0.007)	(0.003)	(0.004)	(0.015)	(0.007)	(0.007)	(0.008)
Product Density	0.079 **	0.062 ***	0.015 ***	-0.030 ***	-0.053 ***	-0.122 ***	-0.192 ***	-0.067 ***
	(0.039)	(0.010)	(0.004)	(0.004)	(0.007)	(0.011)	(0.019)	(0.004)
FARMER ATTRIBUTES								
Loyal farmer	-0.005	0.006	0.004	0.0002	0.032 ***	0.051 ***	0.054 ***	0.037 ***
	(0.009)	(0.007)	(0.006)	(0.005)	(0.008)	(0.011)	(0.016)	(0.007)
Share of loyal farmers in a CRD	0.001 *	0.0005	0.00009	0.003 ***	-0.0001	0.016 ***	0.023 ***	0.007 ***
	(0.001)	(0.000)	(0.000)	(0.000)	(0.002)	(0.003)	(0.003)	(0.001)
Number of loyal farmers in a CRD at the firm level	0.0005 *	0.00004	0.0003 ***	0.001 ***	0.001	0.001 ***	0.001 ***	0.0007 ***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
COMPANY ATTRIBUTES								
Biotech company	0.065 ***	0.055 ***	0.029 ***	0.035 ***	0.039 ***	0.041 ***	0.039 ***	0.056 ***
	(0.008)	(0.006)	(0.005)	(0.004)	(0.007)	(0.008)	(0.011)	(0.005)
SEED ATTRIBUTES								
Seed is conventional	-0.346 ***	-0.328 ***	-0.284 ***	-0.292 ***	-0.286 ***	-0.283 ***	-0.291 ***	-0.300 ***
	(0.014)	(0.008)	(0.007)	(0.005)	(0.007)	(0.010)	(0.015)	(0.007)
Seed has special feature for ethanol production	0.005	-0.0036 ***	-0.042 ***	0.014 ***	-0.013 ***	-0.052 ***	-0.073 ***	-0.031 ***
	(0.019)	(0.007)	(0.004)	(0.004)	(0.006)	(0.008)	(0.011)	(0.005)
Seed output is intended for ethanol production	0.051 ***	0.036 ***	0.002	0.002	-0.013 *	-0.058 ***	-0.103 ***	-0.038 ***
	(0.021)	(0.020)	(0.005)	(0.004)	(0.007)	(0.010)	(0.015)	(0.006)
New seed	0.002	-0.014 **	-0.002	0.015 ***	0.015 ***	-0.006	-0.024 ***	-0.006
	(0.011)	(0.008)	(0.005)	(0.003)	(0.005)	(0.006)	(0.010)	(0.004)
New seed is conventional	-0.028	-0.010	-0.03 ***	-0.059 ***	-0.054 ***	-0.054 ***	-0.056 ***	-0.046 ***
	(0.021)	(0.011)	(0.009)	(0.007)	(0.011)	(0.014)	(0.021)	(0.010)
Constant	2.575 ***	1.980 ***	4.061 ***	5.732 ***	5.982 ***	7.005 ***	8.931 ***	6.077 ***
	(0.907)	(0.306)	(0.077)	(0.159)	(0.147)	(0.179)	(0.394)	(0.091)
CRD Dummies	YES	YES	YES	YES	YES	YES	YES	YES
# of Observations	**36,385**				**40,178**			

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 not reported here but discussed in the text include: the difference between order time and payment time, different types of GM seeds (IR single-stacked, IR double-stacked, IR & HT multi-stacked), temporal pricing (prior or after January), purchase source effects, and a time trend.

6.2. The case of asymm_sample

Estimation results in the asymm_sample are reported in Table 5 for the Fringe and 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.

Market attributes: 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 across the distribution function of prices in both Fringe and Core regions. The values of the estimates range between 3.9 percent ($2.95 per bag) at the 0.1-quantile and 2.0 percent ($3.10 per bag) at the 0.9-quantile in the Fringe region, and between 2.1 percent ($2.40 per bag) at the 0.3-quantile and 8.3 percent ($13.48 per bag) at the 0.9-quantile in the Core region. The Wald test statistics reported in Table 6 suggests the null hypotheses of equality between the HHI coefficient for 0.1- vs. 0.5-quantile, 0.5- vs. 0.9-quantile and 0.1- vs. 0.9-quantile is rejected in favor of the alternative in the Core region. It is not rejected in the Fringe region. Thus, the competition effects in the lower and the upper tail of the price distribution are different only in the Core region.

The 2SLS IV results find a positive and significant competition effect on both regions.[20] These results confirm that the FEIVQR method provides a much richer description of the distributional effects of competition.

Our results here are consistent with *Result 2* developed in the theoretical predictions of Case 2c. in section 2.2.2. If the size of the incumbent firms and the number of loyal farmers in the

[20] The 2SLS IV estimates are larger than the OLS estimates in the Fringe and Core regions, implying that the OLS estimates are downward biased (e.g. if pricing and knowledge of the demand side are negatively correlated).

market is sufficiently large, an increase in competition among firms with asymmetric capacity levels increases prices paid by corn growers. In the Fringe region, we find the effect is with a greater magnitude at 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 at the upper quantiles.

Additionally, our findings in the Core region suggest that the magnitude of the positive distributional effects of competition is larger when only symmetrically capacity-unconstrained firms compete, as opposed to both capacity-constrained and –unconstrained firms. This contrasts with the findings in the Fringe region, where competition between symmetrically capacity-unconstrained firms has a negative 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 beneficial 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 Fringe region of the Corn Belt).

Our results also indicate that contrary to the unconstrained sample, the cross-elasticity of demand among corn seed brands moves in the same direction in both regions. The coefficient corresponding to the product density variable is negative and significant in both Fringe and Core regions.

Farmer attributes: An increase in firms' loyal customer base may increase the price of seeds paid by price sensitive farmers in both regions. The coefficient is significant and positive at some quantiles. The coefficient corresponding to the share of loyal consumers in a CRD is also positive and significant across the price distribution function in both regions but the magnitude is small.

The company specific total number of transactions occurred in $August_t$ to $December_t$ at the CRD level does not affect prices in the Fringe region but may have a negative impact in the Core region. The findings in the Fringe region confirm the theoretical prediction of Case 2c., Figure 3 and 4, as introduced in section 2.2.2, relating to the positive effect of an increase in the value of the loyal parameter (L). The coefficient measuring the difference between payment time and order time is positive and significant in both regions but has a small magnitude.

Company attributes: Biotechnology companies charge a price premium at the mean and the lower price quantiles in both regions. We also find strong evidence that product availability and pricing are positively correlated. In the Fringe region the term related to unconstrained firm is positive and significant in the lower tail of the price distribution, ranging from 9.3 percent ($7.03 per bag) at the 0.1-quantile to 5.0 percent ($5.32 per bag) at the 0.3-quantile. The mean effect is closer to the 0.3-quantile. Additionally, capacity-unconstrained firms belonging to vertically integrated biotechnology seed companies seem to charge less for product availability on average. The value is 7.4 percent ($9.71 per bag) and is closer to the lower tail of the price distribution.

The Wald test statistics reported in Table 6 suggests the null hypothesis of equality across quantiles, for the parameters related to the unconstrained firm and its interaction with the biotech firm variable, is rejected in favor of the alternative only at the 0.1- vs. 0.9-quantile-quantile with 10% significance.

In the Core region, the coefficient related to unconstrained firm is positive and statistically different across quantiles, ranging from 6.9 percent ($5.72 per bag) at the 0.1-quantile to 3.6 percent ($5.22 per bag) at the 0.7-quantile. The mean coefficient is closer to the median. However, capacity-unconstrained firms belonging to biotech firms charge less for product availability across the distribution function of prices. The value of the coefficient ranges from −9.6 percent (-$7.95 per bag) at the 0.1-quantile to −6.4 percent (-$9.27 per bag) at the 0.7-

quantile. The mean coefficient is closer to the median. Table 6 suggests the null hypothesis of equality between the unconstrained firm slope parameters 0.1 vs. 0.5-quantile, 0.5 vs. 0.9-quantile, and 0.1 vs. 0.9-quantile is rejected in favor of the alternative with a p-value between 1-10%. The null hypothesis for the parameter corresponding to the interaction between unconstrained firm and biotech variables is rejected only for the 0.5 vs. 0.9-quantile and 0.1 vs. 0.9-quantile with p-value between 5-10%.

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 price sensitive farmers in the Fringe and from all farmers in the Core region. Additionally, the biotech capacity-unconstrained firms do not extract additional profits from farmers located in the Fringe region, and may offer a price reduction for farmers located in the Core region.

Seed attributes: Similar to the unconstr_sample, the estimates corresponding to different types of seeds suggest price premiums associated with the GM technology.

The coefficient on seeds with special features for ethanol production is positive and significant only in the lower tail of the price distribution in the Fringe region, and negative and significant only in the upper tail in the Core region. These results indicate that price-sensitive farmers located in the Fringe region may find profitable to pay a price premium for seeds featuring HLFS and/or HLES; and loyal farmers in the Core region may demand a price reduction for these seeds even when competition is between firms of different sizes. We also find indications that seed companies may charge a premium to all types of farmers in both regions if the stated use of seed is for ethanol production. Note that the result in the Core region is in contrast with the unconstr_sample findings, which predict a significantly negative sign across the price distribution.

Finally, farmers in the two regions are in general averse to experimenting with new conventional seeds but not necessarily with the genetically modified varieties.

Other variables: Some statistically 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 in both the Fringe and Core regions, or if they are a dealer for the seed company in the Fringe region. Additionally, our 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 in sign with the unconstr_sample.

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

	Dependent variable: Log Net Price							
	Fringe region				Core region			
	FEIVQR			2SLSIV	FEIVQR			2SLSIV
	0.1-q	0.5-q	0.9-q	Mean	0.1-q	0.5-q	0.9-q	Mean
MARKET ATTRIBUTES								
(-) HHI * 100	0.039 **	0.034 ***	0.020 *	0.052 ***	-0.003	0.021 ***	0.083 ***	0.031 ***
	(0.015)	(0.013)	(0.011)	(0.013)	(0.008)	(0.004)	(0.011)	(0.005)
Product density	-0.110 *	-0.125	-0.113	-0.067 ***	-0.020 ***	-0.029 ***	-0.096 ***	-0.034 ***
	(0.048)	(0.062)	(0.062)	(0.014)	(0.006)	(0.003)	(0.012)	(0.003)
COMPANY ATTRIBUTES								
Biotech company	0.118 *	0.095	0.025	0.109 ***	0.126 ***	0.080 ***	0.003	0.098 ***
	(0.064)	(0.066)	(0.050)	(0.023)	(0.037)	(0.028)	(0.028)	(0.018)
Unconstrained company	0.093 **	0.046	0.014	0.068 ***	0.069 ***	0.042 ***	0.003	0.044 ***
	(0.044)	(0.034)	(0.027)	(0.016)	(0.015)	(0.012)	(0.015)	(0.009)
Unconstrained firm is	-0.088	-0.057	0.011	-0.074 **	-0.096 **	-0.056 **	0.033	-0.076 ***
Biotech	(0.061)	(0.060)	(0.045)	(0.023)	(0.038)	(0.029)	(0.029)	(0.019)
FARMER ATTRIBUTES								
Loyal farmer	0.029 *	0.012	-0.004	0.008	0.0001	0.012 **	-0.008	0.005
	(0.016)	(0.016)	(0.015)	(0.007)	(0.010)	(0.006)	(0.007)	(0.005)
Share of loyal farmers in	0.006	0.003	0.002	0.0005	-0.007 ***	-0.012 ***	-0.014 ***	-0.011 ***
a CRD	(0.005)	(0.005)	(0.003)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Number of loyal farmers	0.002 ***	0.001 ***	0.001 **	0.001 ***	0.001 ***	0.001 ***	0.001 ***	0.0009 ***
in a CRD at the firm level	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
SEED ATTRIBUTES								
Seed is conventional	-0.336 ***	-0.302 ***	-0.283 ***	-0.329 ***	-0.312 ***	-0.295 ***	0.287 ***	-0.318 ***
	(0.019)	(0.017)	(0.016)	(0.008)	(0.009)	(0.005)	(0.007)	(0.005)
Seed has special feature	0.062 ***	0.024 ***	-0.005	0.03 ***	0.004	-0.011 ***	-0.015 ***	0.013 **
for ethanol production	(0.012)	(0.012)	(0.010)	(0.005)	(0.008)	(0.004)	(0.005)	(0.004)
Seed output is intended	0.105 ***	0.083 *	0.063	0.068 ***	0.024 ***	0.018 ***	0.025 ***	0.024 ***
for ethanol production	(0.041)	(0.047)	(0.030)	(0.010)	(0.009)	(0.006)	(0.007)	(0.005)
New seed	0.011	-0.006	-0.004	-0.002	0.008	0.011 ***	0.006	0.004
	(0.015)	(0.015)	(0.011)	(0.005)	(0.006)	(0.004)	(0.005)	(0.004)
New seed is conventional	-0.034	-0.044 **	-0.04 **	-0.032 ***	-0.033 ***	-0.034 ***	-0.026 ***	-0.032 ***
	(0.022)	(0.020)	(0.016)	(0.009)	(0.013)	(0.008)	(0.009)	(0.007)
Constant	9.287 ***	8.876 ***	7.796 ***	6.818 ***	4.938 ***	5.887 ***	7.868 ***	6.010 ***
	(3.262)	(2.438)	(3.220)	(515.000)	(0.200)	(0.103)	(0.311)	(0.141)
CRD Dummies	YES	YES	YES	YES	YES	YES	YES	YES
# of Observations	**17,028**				**21,657**			

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 not reported here but discussed in the text include: the difference between order time and payment time, different types of GM seeds (IR single-stacked, IR double-stacked, IR & HT multi-stacked), temporal pricing (prior or after January), purchase source effects, and a time trend.

Table 6: Wald test for equality of slope parameters in FEIVQR[21]

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

	$\beta_{0.1}-\beta_{0.5}$		$\beta_{0.5}-\beta_{0.9}$		$\beta_{0.1}-\beta_{0.9}$	
	Wald_test	p_val	Wald_test	p_val	Wald_test	p_val
UNCONSTR_SAMPLE						
Fringe region						
(-) HHI * 100	30.784	0.000	9.468	0.002	3.453	0.063
Core region						
(-) HHI * 100	2.004	0.157	2.269	0.132	3.509	0.061
ASYMM_SAMPLE						
Fringe region						
(-) HHI * 100	0.211	0.646	1.854	0.173	2.129	0.145
Unconstrained firm	1.510	0.219	1.219	0.270	3.463	0.063
Unconstrained firm is biotech	0.361	0.548	2.099	0.147	3.154	0.076
Core region						
(-) HHI * 100	10.285	0.001	30.558	0.000	40.957	0.000
Unconstrained firm	2.838	0.092	5.365	0.021	9.645	0.002
Unconstrained firm is biotech	1.027	0.311	6.985	0.008	8.071	0.004

7. 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 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. Our empirical results in the Core and Fringe region confirm these predictions. 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 regions. These results suggest that farmers in our samples are willing to pay a price premium to buy from a seed company that can guarantee seed availability later in the season. 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. 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 and 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 anticompetitive mergers and 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 $\mathrm{K_i} + \sum_{-\mathrm{i}} \mathrm{K_{-i}} > \mathrm{D(p^*)}$ with $K_i \geq D(p^*)$ and $\mathrm{K_{-i}} < \mathrm{D(p^*)}$ 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 $\mathrm{K_i} + \sum_{-i} \mathrm{K_{-i}} > \mathrm{D(p^*)}$ with $K_i < D(p^*)$ and $\mathrm{K_{-i}} \geq \mathrm{D(p^*)}$ for all $-i$ firms, 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.