Competition, Price Dispersion, and Capacity Constraints:

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

Cornelia Ilin, Ph.D.[†], Guanming Shi, Ph.D.[‡]

Abstract: This paper examines the effect of competition on price dispersion and argues that the effect is contingent on the ability of firms to meet market demand. 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.

[*] 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 and USDA Hatch grant.
[†] Faculty Associate, Department of Agricultural and Applied Economics, Univ. of Wisconsin-Madison, Email: cilin@wisc.edu
[‡] Professor, Department of Agricultural and Applied Economics, Univ. of Wisconsin-Madison, Email: gshi@wisc.edu

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 models (e.g., Stigler 1961, Rothschild 1973, Reinganum 1979, Macminn 1980) and clearinghouse models (e.g., 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 consumers pay to obtain an additional price quotation (e.g. Stigler 1961, Rothschild 1973, Reinganum 1979, Macminn 1980). In clearinghouse models, an information clearinghouse provides price information, thus consumer 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 these models almost always assume that firms have unlimited capacity to supply a homogenous product. However, many markets contain *capacity-constrained* firms. For example, airline companies have a fixed number of seats for sale for any given flight, and can become capacity-constrained during peak travel demand. Agribusiness companies marketing to farmers may 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 reflected these real-world complexities.

This paper contributes to price dispersion literature by, first, presenting a clearinghouse model of price dispersion when: (1) firms have asymmetric capacity-constraints to supply a homogenous product and (2) consumers are heterogeneous in preference (loyal vs. price

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

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 different times, 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.

Second, we 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. The corn seed industry has experienced considerable structural changes since the 1990s, following biotechnological breakthroughs aimed at improving agricultural productivity *via* seed genetic modification. Five large biotechnology firms[2] dominate the corn seed market. This provides an opportunity to empirically test our theory and document the effect of industry consolidation.

Our empirical results confirm the predictions of our theoretical clearinghouse model. An increase in competition among symmetrically capacity-unconstrained seed firms leads to price increases 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 for product availability, allowing capacity-unconstrained firms to charge a price premium at each quantile of the distribution function.

---

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

The remainder of the paper is organized as follows: Section 2 characterizes the equilibrium in the two-stage clearinghouse model and comparative statics predictions. Section 3 introduces data relating to the U.S. corn seed industry and descriptive statistics. The econometric model of price dispersion and estimation method are presented in Section 4. We discuss empirical findings in Section 5 and Section 6. Section 7 is the conclusion.

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. Subgame-perfect equilibria are found by backward induction: In stage one, firms choose capacities simultaneously and independently following a Nash Equilibrium given the corresponding equilibrium prices in the second stage. In stage two, firms choose prices independently and simultaneously following a Nash equilibrium given different capacity choices in stage one.

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 product and a maximum willingness to pay, $r > 0$. The market is equipped with a clearinghouse that provides price information. We assume that firms and consumers can list or access price information at minimal or no cost (e.g., *via* newspaper or internet search engine). There are two consumer types: (1) *price-sensitive shoppers* who access the clearinghouse for information about prevailing market prices. They buy product with the lowest listed price, and if no product is listed they will visit a firm randomly; and (2) *loyal consumers* who always purchase a particular brand regardless of price if less than the reservation value. They do not access the clearinghouse, and they stay uninformed about other firms' pricing practices. Each firm has its own loyal customer base, and we assume a loyal customer will be loyal to 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 $K_i, i = 1,2, \dots N$. We assume that each firm will be able to serve 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 are 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.

We examine how total market demand is allocated among firms. We assume that each firm first 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

[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 $q_i > 0$.
[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.

lowest price in the market, the probability of not being served by firm j is:

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

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

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

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

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

Finally, each firm's strategy space is continuous, ranging from the firm's corresponding average cost, denoted as p_i^* as it is also the firm's reservation selling price, and the 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: $p_i^* = \frac{c(\min[K_i, L_i + D_s(p_i)])}{\min[K_i, L_i + D_s(p_i)]}$.

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 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 $D(p)$: $\mathbb{R}_{++} \to \mathbb{R}_{++}$ 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, $p * D(p)$: $\mathbb{R}_{++} \to \mathbb{R}_{++}$ 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 a quantity q^* such that 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]

There are also 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 is 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.
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.

---

[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.

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. In 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:

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

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 sales attracted 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, which is continuous on $[p^*, r]$ Then, for p_i, the **expected profit** of firm i is given by:

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

[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.

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: $\mathrm{f}(p_i) \geq 0$ *and* $\int_{p^*}^{r} f(p_i)\, dp_i = 1$, given the strategies of other firms and consumer behavior. A mixed pricing strategy is a Nash Equilibrium if and only if all 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 we obtain $[\Pi_l(p_i) - \Pi_w(p_i)]\{\min[K_i, L_i + D_s(p_i) \cdot x_i]\} + [\Pi_l(p_i) - \Pi_l(r)]\{\min[K_i, L_i + D_s(p_i)] - \min[K_i, L_i + D_s(p_i) \cdot x_i]\} < 0$, when $[\Pi_l(p_i) - \Pi_w(p_i)] < 0$, and $[\Pi_l(p_i) - \Pi_l(r)] < 0$. 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.

The comparative static results

Equation (3) can be used to derive predictions about distributional effects of competition (via *N*) on price, and about relationships 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 relative size of loyal customer base would affect competition effects.

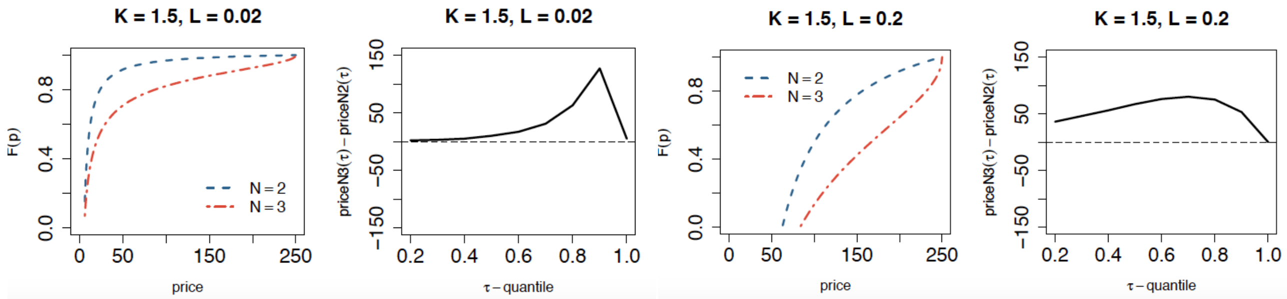
In particular, we focus on the following two scenarios: [1] all firms are capacity-unconstrained with similar loyal customer base ($K_i = K_{-i} > 1,\ L_i = L_{-i}$), and [2] incumbent firms ($i1, i2$) can be capacity constrained or unconstrained ($K_{i1} < 1, K_{i2} \geq 1$) with different loyal customer 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 price-sensitive consumers, not from loyal customers of 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 some price-sensitive consumers convert to the loyal customer base of the entrant firm. Therefore, the incentive to price low to attract the price-sensitive shoppers decreases. Instead, firms focus on extracting surplus from their loyal customer bases. Comparing panel (b) to panel (a), we see that the size of the loyal customer base 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)

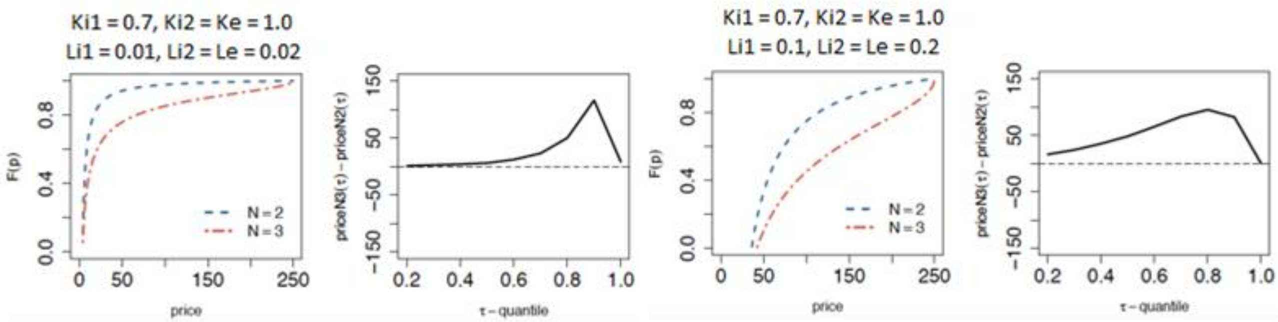
Figure 1: Effect of competition and loyalty for capacity-unconstrained firms. Panel (a)-(b): Cumulative distribution function (left) and its corresponding quantile function (right), c = 0, r = 250. The results are robust to changing from 1.5 to 1.

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): Increased competition from capacity-unconstrained firms leads to an overall price increase in all quantiles.

2. Response of the capacity-unconstrained incumbent firm (i2): Increased competition from capacity-unconstrained firms leads to an overall price increase in all quantiles when firm capacity (i1) and loyal consumer base 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 price-sensitive shoppers. When varying the loyal customer base, we found qualitatively consistent results, yet the magnitude of the competition effect will be greater when the loyal consumer base is larger. Panel (b) vs. (a) also show similar patterns as in result 1: the price increase effect is larger in the lower tail of the price distribution with a larger loyal consumer base 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 *response of the capacity-unconstrained firm* ($i2$). When incumbent firm $i1$ is small relative to incumbent firm $i2$, the entrant of another capacity-unconstrained firm 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 larger than incumbent firm $i2$, , then effects of the entry of another capacity-unconstrained firm 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 $i2$ charges a higher price in the upper quantiles only (illustrated in panel c). When size of loyal customer base increases, 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 suggests a switch of pricing strategy from competing for price-sensitive shoppers to extracting surplus from loyal customers only.

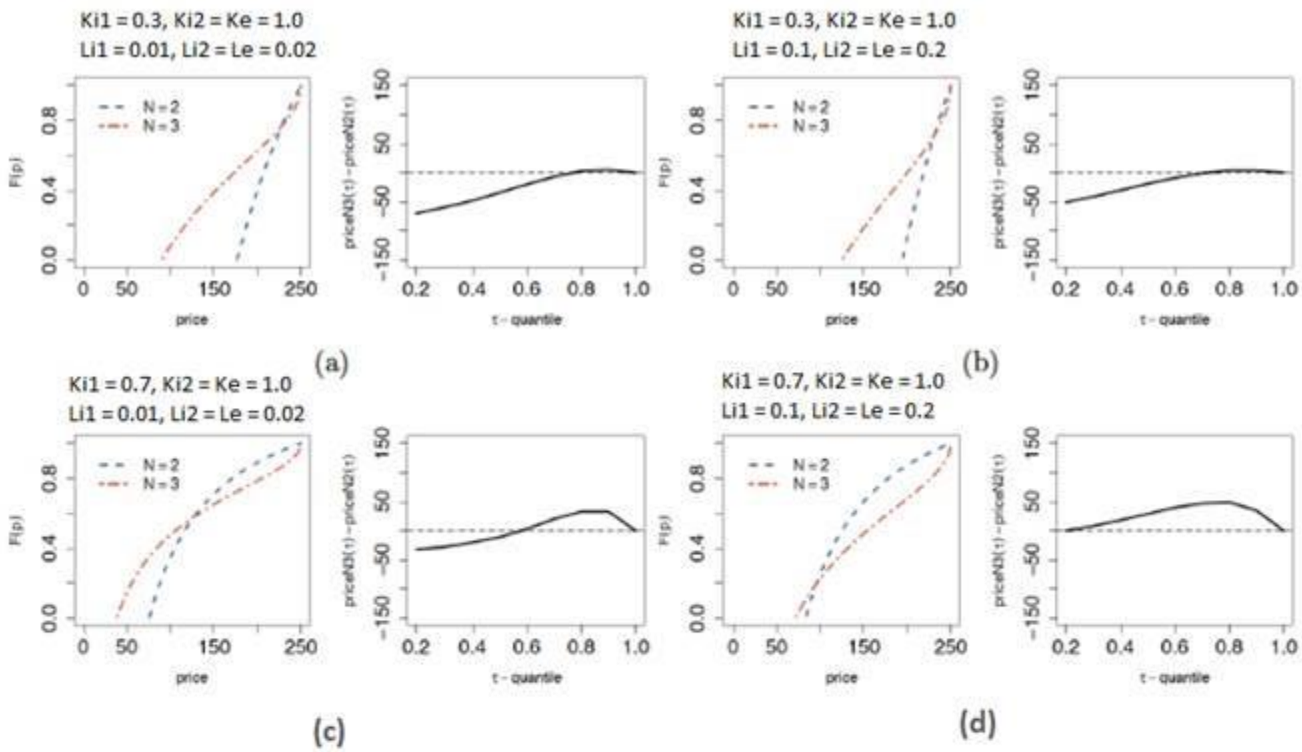


Figure 3: Effect of competition and loyalty: Response of the capacity-unconstrained firm ($i2$). Panel (a)-(d): Cumulative distribution function (left) and its corresponding quantile function (right).

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. 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 (panel a and panel b), although the magnitude of the price difference will be smaller when the loyal consumer base in the market is larger.

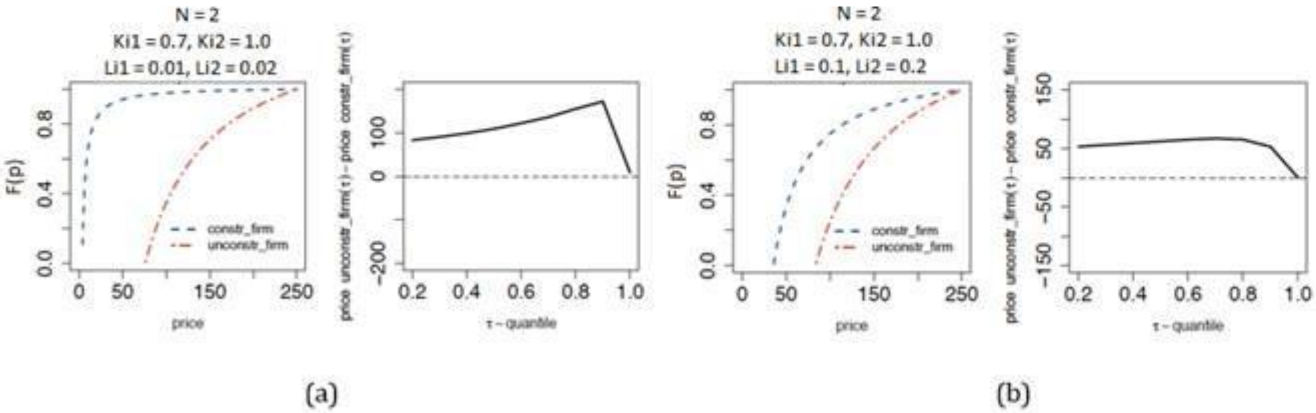


Figure 4: Relationship between product availability and pricing. Panel (a)-(b): Cumulative distribution function (left) and its corresponding quantile function (right).

3. The U.S. Corn Seed industry

Our analysis in Section 2 posits several hypotheses that can be empirically tested. Empirical studies documenting the effect of competition on price dispersion, or on the relationship between product availability and pricing are rare, likely due to lack of data. However, in this study, we use ample data from the U.S. corn seed industry to test our hypotheses. Also, the seed industry is an excellent case study for three reasons. First, seed companies engage in both temporal and spatial price discrimination; that is, they charge different prices for the same seed product over time and across regions. Second, seed firms differ in their abilities to meet market demand for their products; thus, they can be either capacity-constrained or capacity-unconstrained. Third, the industry is characterized by a mix of brand loyal farmers and price-sensitive farmers. [9]

U.S. corn growers plan year $t + 1$ production in year t, usually from August$_t$ to April$_{t+1}$, and start planting seed 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 harvest fields between October$_{t+1}$ and November$_{t+1}$. The planning process is complicated, as corn growers must choose the right corn seed for their land, with this decision affected by farm location, seed pricing, seed performance, growers' relations to seed companies, and expected seed availability at different times (due to capacity constraints, seeds may not be available throughout the planning period).

In this study, we rely on data collected by GfK Kynetec (hereafter dmrk), St. Louis, MO, which provide information on farm- and firm-level seed purchase for the U.S. corn seed industry between 2004 – 2009. Data are collected annually in June using computer-assisted telephone interviews. Data include: seed company identity, seed type (conventional or various genetically modification technology), special seed features, intended end use, net price, seed quantity per transaction, time of order and time of payment, and purchase source.

This study focuses 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, and are likely targeted by similar seed varieties. To account for regional differences, we divide data into *Corn Belt Fringe* (where farmers are likely to alternate between different crops), and *Corn Belt Core* (where corn dominates, and crop substitution is less likely). This distinction allows us to assess spatial differences relating to effects of competition on price dispersion and to examine the relationship between product availability and pricing.

For statistical validity, data are screened to only include 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. Also excluded are transactions with intended use as "corn for seed"[10] and purchase source as "seed left over from last year". Our analysis for the *Fringe Corn*

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

Belt includes 53,413 farm-firm-level sales observations for 55 CRDs out of 13 states. For the *Core Corn Belt*, it includes 61,835 farm-firm-level sales observations from 26 CRDs in six states.[11]

Currently, at least 100 seed companies operate in U.S. market, although numbers of seed companies serving the Corn Belt in general are decreasing (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 of its sales occur between August$_t$ – December$_t$, and capacity-unconstrained otherwise. Table 1 suggests that throughout the study period, over a quarter of total firms are capacity constrained. However, they supply only between 1.5 – 2.7 percent of corn acreage in the Core region, and between 1.7 — 2.3 percent of corn acreage in the Fringe region. Capacity constrained firms seem small in size as compared to capacity unconstrained firms.

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

Year	Fringe			Core		
	# 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 must be recognized that heterogeneity among seed products might account for price dispersion. Seeds sold in the market differ primarily by whether they incorporate Genetic modification (GM) technology. First introduced to the U.S. corn field in 1995, GM seeds soon

[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.

gained farmer acceptance, especially after 2004. GM corn seeds fall into two major categories: (1) genes/traits for insect resistance and (2) genes/traits for herbicide tolerance. Insect resistance (IR) traits are designed to control for damages caused by the European corn borer (ECB) and rootworms (RW). Herbicide tolerant (HT) traits are designed for tolerance to nonselective post-emergence herbicides such as glyphosate, glufosinate, and other herbicides. GM traits were initially introduced as single traits but then were stacked together.

To account for product heterogeneity, our analysis groups seeds into four types: (1) conventional (non-GM); (2) GM IR single-stacked (ECB, RW); (3) GM IR double-stacked (ECB + RW); and (4) GM IR & HT multi-stacked[12]. IR traited GM seeds are treated differently from IR & HT stacked seeds to further capture price differences inherently implied by GM technology.

3.1. Scenario Samples

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

We define a CRD as symmetrically unconstrained if market share of unconstrained seed companies in a year equals or exceeds 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 Fringe and Core regions, respectively. We denote this sample as **unconstr_sample**. The asymmetrically constrained sample is also an unbalanced panel sample,

[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.

with 17,028 and 21,657 observations in 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, by region, and by scenario samples; thus, price dispersion is generally present in the market. 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 products in a given sample. Moreover, GM seeds are on average priced at a premium over conventional seeds, and GM seeds with multiple trait-stacking systems are generally priced more than single-trait GM seeds.

[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 2suggests distributional effects to competition, which may interact with product availability and loyal customer base. The empirical estimation builds on the equilibrium distribution function derived in equation (4). We use quantile regression analysis, which allows for variables of interest (firm-specific and market-level factors) to have heterogeneous effects at different points in the distribution function of price.

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

$$\ln\big(P(k)\big)_{ict} = \beta_{0(k)} - \beta_{1(k)}\ HHI_{ct} \times 100 + \Upsilon^1{}_{(k)}\ \boldsymbol{M} + \Upsilon^2{}_{(k)}\boldsymbol{F} + \Upsilon^3{}_{(k)}\ \boldsymbol{C}$$

$$+ \Upsilon^4{}_{(k)}\ \boldsymbol{S} + \Upsilon^5{}_{(k)}\ \boldsymbol{X} + \alpha_{c(k)} + \epsilon_{ict} \qquad (5)$$

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 covariates related to discriminatory pricing, grouped into market attributes (**M**), farmer attributes (**F**), company attributes (**C**), seed attributes (**S**), and other variables (**X**); Alpha's ($\alpha_{c(k)}$) capture the CRD fixed effect accounting for regional heterogeneity, beta and gammas 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 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
HLFS and/or HLES feature								
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 output 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 market concentration computed at the CRD level: HHI $= \sum_{i=1}^{N} s_i^2$, where N is number of firms in a CRD, and s_i is market share of firm i computed as firm-specific seed acreage divided by total seed acreage in a CRD. On average, the market in the Core region is more competitive than that in the Fringe region, with HHI at 0.16 vs. 0.21 for the unconstrained sample, and at 0.14 vs. 0.17 for the asymm_sample. Variation in individual CRDs is larger, with HHI ranging from 0.06 to 0.81 across samples and regions.

Another market attribute is crowdedness of seed-product varieties. When farmers can choose among many seed products with similar technologies, there is high substitutability in demand for seed products. This affects firms' seed pricing. We construct a product density variable to measure such market crowdedness, calculated as the percentage of number of seed hybrid varieties in a given CRD market relative to total number of seed hybrids present in all CRD markets in Fringe or Core regions. A higher product density measure suggests more intensive product competition in a market. Similar to the HHI, the market in the Core region is more competitive than that in the Fringe region in terms of crowdedness, with an almost doubling crowded product space: 11 percent vs. 6 percent for 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 order early in the season (August$_t$ – December$_t$), whereas price-sensitive farmers shop around for the entire season (from August$_t$ to April$_{t+1}$) and tend to order later 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 between August – December. Otherwise, seed was ordered 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 size of the loyal customer base in any local market. One relates to share of loyal farmers in a CRD defined as percentage of transactions in each CRD occurring between $August_t$ to $December_t$ over those during the entire season; the other one relates to the number of firm-specific loyal farmers in a CRD, defined as total number of transactions per company occurring between $August_t$ to $December_t$ at the CRD level. On average, loyal farmers in the unconstrained sample place more firm-specific orders than those in the asymm-sample: 40 loyal farmers vs. 27 price-sensitive farmers in the Fringe region and 64 loyal farmers vs. 50 price-sensitive in the Core region.

Also, , some seed companies, as price discrimination schemes, offer cash discounts for farmers paying in advance.[17] We capture this effect by counting timing difference between date orders are placed and date payments are made. Table 3 suggests that, on average, it takes farmers longer to pay in the Fringe region (about 2 months) than farmers in the Core region (about one and a half months). However, at the individual farmer level, time variance is greater, ranging from on-site payment (no time difference) to 11 months.

Company attributes: Seed companies are differentiated by vertical structure affiliation. A firm is either independent (e.g., Beck's Hybrids, Unity Seeds), or belongs 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% in the unconstr_sample and 73-4% in the asymm_sample. However, at local market levels, 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 unconstrained 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 may use a different pricing strategy by introducing the corresponding interaction terms.

Seed attributes: Seeds differ by technology (conventional vs. various GM) and whether seed hybrid has higher levels of fermentable starch (HLFS) and/or extractable starch (HLES)—special features widely recognized as suitable for ethanol production. Farmers also reported 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. Conventional seed share decreases quickly over time, reflecting general adoption of GM seeds by U.S. corn farmers. Seeds with special features (HLFS and/or HLES) have a larger share in the unconstr_sample than that in the asymm_sample for both Core and Fringe regions: 25% vs. 19% and 24% vs. 17%, respectively. However, farmers have indicated intended output use in ethanol production for less than half of these seeds.

We also control for whether seed is new to the market or not (i.e., if it had never presented in the dmrk data since 1994). Seed company pricing strategy and farmer willingness to pay likely differ for seeds new to the market. Around 50 percent of seeds are new in the market across samples and regions, indicating that seed companies continuously develop new seed varieties. We also interact the variables representing "new seed" and "conventional seed" 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". At least 60 percent of transactions were classified into one of the first three categories.

Prices may fluctuate throughout the season, which may depend on probability at time of order that demand will exceed capacity. We construct two time-trend variables to control for such an effect. Using January$_t$ as the benchmark, orders placed prior to or after this month will take the corresponding values that equals to the month's distance to January$_t$. 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 suggest that most orders are placed between 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, inflation, and other potential time consistent structural changes.

5. Econometric Estimation

Our theoretical model allows us to examine the whole distribution function of pricing using a quantile regression approach to accomplish research objectives. One challenge to the identification strategy in the econometric specification (5) is related to the assumption that the error term and explanatory variables are contemporaneously uncorrelated. However, both market concentration, as measured by HHI, and seed prices are likely endogenous as jointly determined in the model.

A firm's decision to enter a 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 understand demand, with knowledge of customer base correlated with the decision to enter the market and affecting pricing strategies; 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 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 estimation of covariate effects at different quantiles while controlling for additive fixed effect as introduced in Koenker (2004) that may affect response and are correlated with independent variables.

The Wu-Hausman test is applied to the econometric specification (5) 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}) to account for lags in the seed production process which takes on average eight months. As a result, firm managers may use previous year information on market concentration to decide seed production quantity for next year's market.

The lagged value HHI_{t-1} is an appropriate instrument if it is correlated with the endogenous regressor HHI_t (not a "weak instrument") and not with the error term (the orthogonality condition). 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, results suggest 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 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 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 the FE IV QR method, with bootstrap robust standard errors. Results will be discussed for each sample scenario and for both regions. We also compare results from 2SLS IV 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 Fringe and Core regions. We report bootstrapped standard errors[18] (FE IV QR) and heteroskedastic-robust standard errors (2SLS IV) in parentheses.

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

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. Statistical evidence shows that firms operating in the unconstrained sample 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 and positive in the Core region. In the Fringe region, estimates suggest that a one-percentage point increase in HHI may lead to a decrease in seed price by 0.9 percent ($0.72 per bag) at the 0.1-quantile, and by 1.9 percent decrease ($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 Wald test statistics. Table 6 reports 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.

The 2SLS IV results find that an increase in competition significantly increases mean price in both Fringe and Core regions.[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 described 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. 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.

[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).

They focus on extracting surplus from the loyal group and avoid competition in the price-sensitive farmer group when facing new market entries.

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. A crowded market leads to price increases in the Fringe regions but to price reductions in Core regions.

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 is not significant in the Fringe region. Additionally, the share of loyal farmers in a CRD 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 and positively affects prices as well; the corresponding coefficient is statistically significant in the Fringe and Core regions but has a small magnitude. These results indicate that an increase in a firm's loyal customer base may raise the price of seeds for farmers in the two regions. Thus, they confirm our theoretical prediction of Case 1b, described 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 between payment time and order time may result in a price increase between 0.3-0.6 percent in the Core region.

***Company attributes*:** We find evidence of distributional price effects associated with 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 variables controlling for various GM technologies show that GM seeds are sold at a price premium over conventional seeds. Additionally, GM seeds with single-stacking IR systems or with multiple technologies are generally more expensive than GM seeds with single-stacking herbicide tolerant systems. We also find that farmers in the Fringe region might be willing to pay a price premium to plant seeds with HLFS and/or HLES features or for seeds intended for ethanol production. Additionally, negative coefficients on "new seed" and "new seed is conventional" indicate that farmers in the two regions associate conventional new seeds with higher performance uncertainty as opposed to GM.

***Other variables*:** Variables corresponding to the top three purchase sources are positive, negative, or change signs across the price distribution in the Fringe region, and positive in the Core region. These results possibly reflect the presence of price discrimination across regions and across purchase sources.

Variables capturing transaction timing (prior or after January) indicate that seed companies may engage in time-based price discrimination. Both loyal and price-sensitive farmers in the Core region can save on input costs if they order seeds early in the season; loyal farmers in the Fringe save if they order earlier and price sensitive farmers save if they order later.

Finally, we find the time trend effect is positive and significant across regions, with a greater magnitude in the Core. This indicates that technology advancement, inflation, and other potential time consistent structural changes contribute to part of the observed price increase.

Table 4: FEIVQR and 2SLS IV Regression Results for selective variables – 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)
HLFS and/or HLES feature	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 both Fringe and Core regions. 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*:**

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. 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 0.1-quantile and 8.3 percent ($13.48 per bag) at the 0.9-quantile in the Core region. Wald test statistics reported in Table 6 suggest that 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 are rejected in favor of the alternative in the Core region. It is not rejected in the Fringe region. Thus, competition effects in the lower and the upper tail of the price distribution differ only in the Core region.

The 2SLS IV results find a positive and significant competition effect in both regions.[20] These results confirm that the FEIVQR method is a 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 incumbent firms and number of loyal farmers in the 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 greater at 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).

lower price quantiles, suggesting the presence of a larger number of loyal farmers. This result contrasts with the Core region, where the effect is greater at the upper quantiles.

Similar to the unconstrained sample, the coefficient corresponding to the product density variable is negative and significant in the Core regions. However, the coefficient is either statistically insignificant or marginally significant but negative in the Fringe regions. Price will decrease (weakly) when the market becomes crowded.

Farmer attributes: An increase in firms' loyal customer base may increase the price of seeds paid by price-sensitive farmers in the Fringe region: the coefficient is significant and positive at 0.1-quantiles. The coefficient for company specific total number of transactions purchased by loyal customers (those occurred in August$_t$ to December$_t$) at the CRD level is also positive and significant across the price distribution function in both regions but the magnitude is small.

The coefficient estimates corresponding to the share of loyal customers in a CRD suggest that it 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, described in Section 2.2.2, relating to the positive effect of an increase in the value of the loyal farmer parameter (L). The coefficient measuring the difference between payment time and order time is positive and significant in both regions, ranging between 0.02 – 0.4 percent.

Company attributes: Biotechnology companies charge a price premium at the mean and lower price quantiles in both regions. Evidence also strongly suggests 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.

Wald test statistics reported in Table 6 suggest that the null hypothesis of equality across quantiles for 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, vertically integrated capacity-unconstrained 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.

Table 6 suggests that 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 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 HLFS and/or HLES features 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 it 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. Our estimates also indicate 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 contrasts with the unconstr_sample findings, which predict significant negative price effects across the whole distribution. It may reflect differences in farmer connection with ethanol plants across regions. According to estimates from the U.S. Energy Information Administration (EIA), six states (Iowa, Nebraska, Illinois, Minnesota, Indiana and South Dakota) accounted for 72% of Ethanol production in the US in 2016. Five of these six states are included in our Core region. Therefore, farmers in the Core region may find the production for ethanol plants more profitable than those in the fringe region.

Finally, the coefficient on new conventional seeds is negative along the price distribution, indicating that 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. Compared to other purchasing sources, farmers may pay lower prices for seeds purchased directly from seed companies in both the Fringe and Core regions, or if they are also seed company dealers in the Fringe region. Additionally, our estimates indicate that seed companies competing in a market with firms of asymmetric capacity levels also engage in time-based price discrimination. Fringe and Core farmers may pay lower prices for seed if orders are placed earlier or later than January. Finally, we find the time trend effect $Year$ is positive across the entire distribution of prices, the sign and magnitude of the coefficients comparable with those in 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 biotech	-0.088	-0.057	0.011	-0.074 **	-0.096 **	-0.056 **	0.033	-0.076 ***
	(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 a CRD	0.006	0.003	0.002	0.0005	-0.007 ***	-0.012 ***	-0.014 ***	-0.011 ***
	(0.005)	(0.005)	(0.003)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Number of loyal farmers in a CRD at the firm level	0.002 ***	0.001 ***	0.001 **	0.001 ***	0.001 ***	0.001 ***	0.001 ***	0.0009 ***
	(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)
HLFS and/or HLES feature	0.062 ***	0.024 ***	-0.005	0.03 ***	0.004	-0.011 ***	-0.015 ***	0.013 **
	(0.012)	(0.012)	(0.010)	(0.005)	(0.008)	(0.004)	(0.005)	(0.004)
Seed output is intended for ethanol production	0.105 ***	0.083 *	0.063	0.068 ***	0.024 ***	0.018 ***	0.025 ***	0.024 ***
	(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]

	$\beta_{0.1} - \beta_{0.5}$		$\beta_{0.5} - \beta_{0.9}$		$\beta_{0.1} - \beta_{0.9}$	
	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

This study examines how firms price differently for given products, and contributes to an understanding of the relationship between product availability and pricing. We propose a clearinghouse model of price dispersion to explain the roles that constraints in firm capacity and differences in consumer preferences play in forming temporal price dispersion for a homogenous product. 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.

Our research findings yield several major conclusions. First, our model predicts a positive relationship between competition and pricing. Our empirical results in Core and Fringe regions

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

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. This finding is similar to those in the airline company or hoteling industry, where capacity constraint exists. Reservations with flexibility of changing time of travel will be more expensive than those with fixed dates of travel.

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 time-based 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 developing antitrust and consumer protection laws 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 significant roles. The entry may actually induce implicit collusion with incumbent firms and harm all consumers if incumbent firms charge 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 that the incumbent firm's share of loyal customer base remains unchanged when new entrants in the industry occurs. Finally, there is a need to explore empirically the role of capacity constraints and brand loyalty in other sectors of the economy.

References

Arnoldm M. A. & Saliba, C. (2011), "Asymmetric capacity constraints and equilibrium price dispersion", *Economics Letters* 111(2), 158-160.

Barron, J.M., Taylor, B. A. & Umbeck, J.R. (2004), "Number of sellers, average prices, and price dispersion", *International Journal of Industrial Organization* **22**(8), 1041-1066.

Baye, M. R., Morgan, J. & Scholten, P. (2004), "Price dispersion in the small and in the large: Evidence from an internet price comparison site", *The Journal of Industrial Economics* **52**(4), 463-496.

Baye, M.R., Morgan, J. & Scholten, P. (2006), "Information, search and price dispersion", *Handbook on economics and information systems* **1**.

Beckmann, M. (1965), "Efgeworth-Bertrand duopoly revisited", *Operations Research-Verfahren"*, Vol.3, Misenheim am Glan Hain, 55-68.

Borenstein, T.S. & Pagan, A.R. (1979), "A simple test for heteroschedasticity and random coefficient variation", *Econometrica: Journal of the Econometric Society*, 1287-1294.

Cameron, A. C. & Miller, D.L. (2015), "A practitioner's guide to cluster-robust inference", *Journal of Human Resources* **50**(2), 317-372.

Chernozhukov, V. & Hansen, C. (2008), "Instrumental variable quantile regression: A robust inference approach", *Journal of Econometrics* **142**(1), 379-398.

Davidson, C. & Deneckere, R. (1986), "Long-run competition in capacity, short-run competition in price, and the Cournot model", *The Rand Journal of Economics*, 404-415.

Efron, B. & Tibshirani, R. J. (1994), "An introduction to the bootstrap", *CRC press*.

Harding, M. & Lamarche, C. (2009), "A quantile regression approach for estimating panel data models using instrumental variables", *Economics Letters* **104**(3), 133-135.

Haynes, M. & Thompson, S. (2008), "Price, price dispersion and number of sellers at a low cost entry shopbot", *International Journal of Industrial Organization* **26**(2), 459-472.

Janssen, M. C. & Moraga-Gonzalez, J.L. (2004), "Strategic pricing, consumer search and the number of firms", *The Review of Economic Studies* **71**(4), 1089-1118.

Koenker, R. (2004), "Quantile regression for longitudinal data", *Journal of Multivariate Analysis* **91**(1), 74-89.

Koenker, R. & Bassett Jr. G (1978), "Regression quantiles", *Econometrica: Journal of the Econometric Society*, 33-50.

Lester, B. (2011), "Information and prices with capacity constraints", *The American Economic Review* **101**(4), 1591-1600.

MacMinn, R.D. (1980), "Search and Market Equilibrium", *The Journal of Political Economy,* 308-327.

Morgan, J., Orzen, H. & Sefton, M. (2006), "An experimental study of price dispersion", *Games and Economic Behavior* **54**(1), 134-158.

Narasimhan, C. (1988), "Competitive promotional strategies", *Journal of Business,* 427-449.

Reinganum, J. F. (1979), "A simple model of equilibrium price dispersion", *The Journal of Political Economy,* 851-858.

Rosenthal, R. W. (1980), "A model in which an increase in the number of sellers leads to a higher price", *Econometrica: Journal of the Econometric Society,* 1575-1579.

Rothschild, M. (1973), "Models of market organization with imperfect information: A survey", *The Journal of Political Economy,* 1283-1308.

Salop, S. & Stiglitz, J, (1977), "Bargains and ripoffs: A model of monopolistically competitive price dispersion", *The Review of Economic Studies,* 493-510.

Shi. G., Chavas J. -P. & Stiegert, K. (2010), "An analysis of the pricing of traits in the U.S. corn seed market", *American Journal of Agricultural Economics* **92**(5), 1324-1338.

Shilony, Y. (1977), "Mixed pricing in oligopoly", *Journal of Economic Theory* **14**(2), 373-388.

Spulber, D. F. (1995), "Bertrand competition when rivals' costs are unknown", *The Journal of Industrial Economics,* 1-11.

Stiegert, K., Shi. G. & Chavas, J.-P. (2010), "Spatial pricing of genetically modified hybrid corn

Stigler, G. J. (1961), "The economics of information." *The Journal of Political Economy, 213-225*

Stock, J. H. & Watson, M.W. (2003), *Introduction to econometrics*, Vol. 104, Addison Wesley Boston.

Varian, H.R. (1980), "A model of sales", *The American Economic Review,* 651-659.

White, H. (1980), "A heteroskedasticity-consistent covariance matrix estimator and a direct test for heteroskedasticity", *Econometrica: Journal of the Econometric Society,* 817-838.

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 total capacity in the market is at most equal with 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 total capacity in the market exceeds 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 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 .

We 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.

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