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From: GUANMING SHI [mailto:gshi@wisc.edu]
Sent: Monday, October 19, 2009 2:30 PM
To: ATR-Agricultural Workshops
Subject: Paper submission

Dear Sir/Madam,

Please see the attached for three papers on pricing and competition in the U.S. seed industries (including corn, soybean, and cotton) for your consideration of inclusion in the public workshops on agriculture industry competition. Per your request, we will send two paper copies of each to the Legal Policy Section through overnight service.

If you need any information, feel free to contact me via email or phone. Your consideration is highly appreciated!

Sincerely,

Guanming

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Guanming Shi, Ph.D.
Assistant Professor
Agricultural & Applied Economics
University of Wisconsin-Madison
Madison, WI 53706
(Tel)1-608-263-6250
(Fax)1-608-262-4376

An Analysis of the Pricing of Traits in the U.S. Corn Seed Market

by

Guanming Shi

Jean-Paul Chavas

and

Kyle Stiegert[1]

Abstract: This paper investigates the pricing of patented traits in the U.S. hybrid corn seed market under imperfect competition. In a multiproduct context, we first examine how substitution/complementarity relationships among products can affect pricing. This is used to motivate multi-product generalizations of the Herfindahl-Hirschman index (GHHI) capturing cross-market effects of imperfect competition on bundle pricing. The GHHI model is applied to pricing of conventional and patented biotech seeds in the US from 2000-2007. One major finding is that standard component pricing in biotech traits is soundly rejected in favor of subadditive bundle pricing. The econometric estimates show how changes in market structures (as measured by both own- and cross-Herfindahl indexes) affect U.S. corn seed prices.

Key Words: Component pricing, imperfect competition, seed, biotechnology

JEL Code: L13, L4, L65

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[1] Respectively Assistant Professor, Professor and Associate Professor, Department of Agricultural and Applied Economies, University of Wisconsin, Madison, WI. This research was funded in part by USDA-NRI grant #144-QS50.

The U.S. agricultural biotechnology and seed industries have experienced many changes over the last few decades. On the one hand, new seeds including biotech patented traits offer new prospects for increasing agricultural productivity. This has stimulated a rapid adoption of biotech seeds in the U.S. for corn, soybean and cotton. On the other hand, mergers and acquisitions in the seed industry have resulted in concentrated seed markets dominated by a few large biotech firms. This has raised some concern that market power and imperfect competition could lead biotech firms to charge high prices for the biotech seeds, with potential adverse effects on farmers' welfare. Biotechnology and genetic modifications have also stimulated product differentiation with patented traits being bundled with basic seed germplasm. Evaluating the pricing of such products under imperfect competition presents several challenges. One challenge is to evaluate the cross-markets impacts of market power under product differentiation. Another challenge is the empirical assessment of the pricing of bundled traits in biotech seed. A lack of available data has severely limited such investigations in previous research.[1]

This paper addresses these challenges with a focus on the analysis of the pricing of patented traits in the U.S. corn seed market. It makes three important contributions. First, we develop a pricing model of differentiated products under a quantity-setting game. In a multiproduct context, we show the linkages between pricing and substitution/complementarity relationships among products with different bundled characteristics. This is used to motivate multi-product generalizations of the Herfindahl-Hirschman index (hereafter GHHI), which capture cross-market effects of imperfect competition on bundle pricing. Second, the GHHIs are introduced in an econometric analysis of the determinants of bundle pricing. To our knowledge, this is the first econometric investigation using GHHI to estimate the linkages between imperfect

[1] In contrast, there is a rich body of analytical literature on bundle theory (e.g., Adams and Yellen 1976, McAfee et al. 1989, Fang and Norman 2006).

competition and multiproduct pricing. The model also allows for a test of standard component pricing (where the price of bundle is the sum of the prices of each individual component within the bundle). Third, we present an empirical application to the U.S. hybrid corn seed market using extensive survey data. The econometric estimates provide useful information on interactions between bundling and the exercise of market power.

Genetically modified (GM) corn acres account for about 80 percent of the total U.S. corn acreage in 2007. GM corn seed includes patented genetic traits (such as insect resistance and/or herbicide tolerance) patented by biotech firms. These traits can be introduced into the seed either separately, or bundled together when multiple genetic traits are "stacked". The proportion of U.S. corn acres planted with stacked seeds has gone from 2.1 percent in 2000 to 56.2 percent in 2007. Also, there has been a sharp increase in the number of traits being bundled. Single-trait GM corn seed was first commercialized in 1996. Two years later the double-stacked corn seed (i.e., the bundling of two traits) was introduced, followed by the introduction of the triple-stacked system, and then the quadruple-stacked system in around 2006. Moreover, corn seed with eight traits is expected to be released by Monsanto and Dow AgroScience by 2010.

The increased use of GM corn seeds has been associated with changing structure in the U.S. seed markets. After a flurry of horizontal and vertical mergers in the 1990s, the corn seed industry is now dominated by a few large biotech firms (Fernandez-Cornejo 2004). According to Graff, Rausser and Small (2003), these mergers have been motivated in part by the complementarities of assets within and between the agricultural biotechnology and seed industries. This indicates that trait bundling can be associated with cost reductions obtained from capturing economies of scope in the production of genetic traits. But bundling can also be part of a product differentiation strategy and price discrimination scheme intended to extract more profit from farmers facing varying agro-climatic conditions. In this context, increased market concentration has raised concerns about adverse effects of imperfectly competitive pricing and the strategic use of bundling (Fulton and Giannakas 2001; Fernandez-Cornejo 2004). These issues suggest a need to investigate empirically the economics of pricing of hybrid corn seeds.

Our econometric analysis quantifies the linkages between different combinations of traits, changes in market concentrations, and hybrid corn seed pricing. For bundled biotech traits, we reject standard component pricing of biotech traits. We find strong evidence of subadditive bundle pricing, which is consistent with price discrimination strategies and scope economies in the production of bundle-traited seeds. The analysis evaluates the interactive role of market concentrations and complementarity/substitution in demand. We document the linkages between traditional and cross-market concentrations and seed prices. This is done by estimating Lerner indexes, which provide useful information on departures from marginal cost pricing. Our analysis also illustrates how changing market structures (e.g., from mergers) relate to seed prices.

The paper is organized as follows. The model section presents a conceptual framework of multiproduct pricing under imperfect competition. We then provide an overview of the U.S. corn seed market, followed by an econometric model of seed pricing, where the GHHIs reflect the exercise of market power. The estimation method and econometric results are then discussed and the empirical findings and their implications are reported. The conclusion section is at the last.

The Model

Consider a market involving a set $\mathbf{N} = \{1, ..., N\}$ of N firms producing a set $\mathbf{T} = \{1, ..., T\}$ of T outputs. Denote by $y^n \equiv (y_1^n, ..., y_m^n, ..., y_T^n) \in \Re_+^T$ the vector of outputs produced by the n-th firm, y_m^n being the m-th output produced by the n-th firm, $m \in \mathbf{T}$, $n \in \mathbf{N}$. The price-dependent demand for the m-th output is $p_m(\sum_{n\in\mathbf{N}} y^n)$. The profit of the n-th firm is:

$\sum_{m\in\mathbf{T}}[p_m(\sum_{n\in\mathbf{N}} y^n)y_m^n] - C_n(y^n)$, where $C_n(y^n)$ denotes the n-th firm's cost of producing y^n .

Assuming a Cournot game and under differentiability, the profit maximizing decision of the n-th firm for the m-th output y_m^n satisfies

$$p_m + \sum_{k\in\mathbf{T}} \tfrac{\partial p_k}{\partial y_m^n} y_k^n - \tfrac{\partial C_n}{\partial y_m^n} \leq 0, \tag{1a}$$

$$y_m^n \geq 0, \tag{1b}$$

$$\left(p_m + \sum_{k\in\mathbf{T}} \tfrac{\partial p_k}{\partial y_m^n} y_k^n - \tfrac{\partial C_n}{\partial y_m^n}\right) y_m^n = 0. \tag{1c}$$

Equation (1c) is the complementary slackness condition. It applies whether the m-th output is produced by the n-th firm ($y_m^n > 0$) or not ($y_m^n = 0$). This is important for our analysis: (1c) remains valid irrespective of the firm entry/exit decision in the industry; and for an active firm, (1c) holds no matter how many of the T products the firm chooses to sell.

Below, we consider the case of linear demands where $p_k = \alpha_k + \sum_{m\in\mathbf{T}}(\alpha_{km}\sum_{n\in\mathbf{N}} y_m^n)$, with $\frac{\partial p_k}{\partial y_m^n} = \alpha_{km}$ and $\alpha_{mm} < 0$. We also assume that the cost function takes the form $C_n(y^n)$ = $F_n(S^n) + \sum_{m\in\mathbf{T}} c_m y_m^n$, where $S^n = \{j \in \mathbf{T} : y_j^n > 0\}$ is the set of positive outputs produced by the n-th firm. Here, $F_n(S^n) \geq 0$ denotes fixed cost that satisfies $F_n(\varnothing)$ = 0. And $\sum_{m\in\mathbf{T}} c_m y_m^n$ denotes variable cost, with constant marginal cost $\frac{\partial C_n(y^n)}{\partial y_m^n} = c_m$, $m \in \mathbf{T}$ for all $n \in \mathbf{N}$. Note that the presence of fixed cost (where $F_n(S^n) > 0$ for $S^n \neq \varnothing$) implies increasing returns to scale. In this situation, marginal cost pricing would imply negative profit and any sustainable equilibrium must be associated with departures from marginal cost pricing. Fixed cost can also capture the presence of economies of scope. This would occur when $F_n(\mathbf{T}_a) + F_n(\mathbf{T}_b) > F_n(\mathbf{T}_a \cup \mathbf{T}_b)$ for some

$\mathbf{T}_a \subset \mathbf{T}$ and $\mathbf{T}_b \subset \mathbf{T}$, i.e. when the joint production of outputs $y_a^n = \{y_j^n : j \in \mathbf{T}_a\}$ and $y_b^n = \{y_j^n : j \in \mathbf{T}_b\}$ reduces fixed cost (Baumol et al., 1982, p. 75). A relevant example is the case of an R&D investment contributing to the joint production of y_a^n and y_b^n.

Assuming that the aggregate output of the m-th product is positive, $Y_m = \sum_{n \in \mathbf{N}} y_m^n > 0$, define $s_m^n = \frac{y_m^n}{Y_m} \in [0,1]$ as the market share of the n-th firm for the m-th product. Dividing equation (1c) by Y_m and summing across all $n \in \mathbf{N}$ yield

$$p_m = c_m - \sum_{k \in \mathbf{T}} (\alpha_{km} \sum_{n \in \mathbf{N}} s_k^n s_m^n Y_k), \tag{2}$$

which can be alternatively written as

$$p_m = c_m - \sum_{k \in \mathbf{T}} \alpha_{km} H_{km} Y_k , \tag{3}$$

where Y_k is the aggregate output of the k-th product, and $H_{km} \equiv \sum_{n \in \mathbf{N}} s_k^n s_m^n$, with $m, k \in \mathbf{T}$.

Equation (3) is a pricing equation for the m-th product. It is a structural equation in the sense that both price p_m and the market shares in the H_{km}'s are endogenous (as they are both influenced by firms' strategies). Yet, equation (3) provides useful linkages between price and market structure. It shows that the exercise of market power in (3) is given by

$$M_m = -\sum_{k \in \mathbf{T}} \alpha_{km} H_{km} Y_k , \tag{4}$$

which reflects departures from marginal cost pricing. A simple way to characterize this departure is through the Lerner index: $L_m = \frac{p_m - c_m}{p_m}$, where c_m is marginal cost. The Lerner index L_m measures the proportion by which the m-th output price exceeds marginal cost. It is zero under marginal cost pricing, but positive when price exceeds marginal cost. The Lerner index provides a simple characterization of the strength of imperfect competition (where the firm has market power and its decisions affect market prices). From equations (3) and (4), the Lerner index can be written as $L_m = \frac{M_m}{p_m}$. This makes it clear that M_m in (4) gives a per-unit measure of price enhancement beyond marginal cost. Equation (4) also provides useful information on the structural determinants of M_m. Indeed, while $H_{km} \in [0, 1]$, note that $H_{km} \to 0$ under perfect competition (where the number of active firms is large) and $H_{km} = 1$ under monopoly (where there is single active firm). In other words, the term M_m in (4) captures the effects of imperfect competition and the exercise of market power on prices.

When $k = m$, note that H_{mm} is the traditional Herfindahl-Hirschman index (HHI) providing a measure of market concentration. The HHI is commonly used in the analysis of the exercise of market power (e.g., Whinston 2008). Given $\alpha_{mm} < 0,$ equation (3) indicates that an increase in the HHI H_{mm} (simulating an increase in market power) is associated with an increase in the Lerner index L_m and in price p_m. As a rule of thumb, regulatory agencies have considered that $H_{mm} > 0.1$ corresponds to concentrated markets where the exercise of market power can potentially raise competitive concerns (e.g., Whinston 2008).[2]

Equation (3) extends the HHI to a multiproduct context. It defines H_{km} as a generalized Herfindahl-Hirschman index (GHHI). When $k \neq m$, it shows that a rise in the "cross-market" GHHI H_{km} would be associated with an increase (a decrease) in the Lerner index L_m and in the price p_m if $\alpha_{km} < 0$ $(> 0).$ This indicates that the signs and magnitudes of cross demand effects $\alpha_{km} = \frac{\partial p_k}{\partial y_m^n}$ affect the nature and magnitude of departure from marginal cost pricing. Following

[2] The markets shares are often expressed in percentage term in the calculation of the Herfindahl-Hirschman index. Then, the rule becomes $H_{mm} > 1000$ (Whinston 2008).

Hicks (1939), note that $\alpha_{km} = \frac{\partial p_k}{\partial y_m^n}$ < 0 (> 0) when products *k* and *m* are substitutes (complements) on the demand side, corresponding to situations where increasing y_m^n tends to decrease (increase) the marginal value of y_k^n. The terms $\{H_{km} : k \neq m\}$ in equation (3) show how the nature of substitution or complementarity among outputs on the demand side (through the terms α_{km}) influences the effects of market concentration on the Lerner index and prices[3]: a rise in H_{km} would be associated with an increase (a decrease) in the Lerner index L_m and in the price p_m when y_k and y_m are substitutes (complements).

Note that equation (3) applies to general multiproduct pricing in a Cournot game under imperfect competition. It includes as a special case the pricing of bundled goods differentiated by their characteristics. In a way consistent with previous research (e.g., Adams and Yellen 1976; Venkatesh and Kamakura 2003; Fang and Norman 2006), it shows that the exercise of market power in bundling and bundle pricing can be complex. This indicates a need to assess empirically how the bundling of product characteristics interacts with market structures to affect pricing. This issue is explored next in the context of the U.S. corn seed market.

The U.S. Corn Seed Market

Our analysis relies on a large, extensive data set providing detailed information on the U.S. corn seed market. The data were collected by **dmr**kynetec [hereafter dmrk]. The dmrk data come from a stratified sample of U.S. corn farmers surveyed annually from 2000 to 2007.[4] The survey

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[3] Our model provides a more general framework in analyzing the role played by substitution/ complementarity in multiproduct pricing under imperfect competition than Venkatesh and Kamakura (2003), who investigate such issues only in a monopolistic setup.

[4] Data prior to 2000 is not available from dmrk. The survey is stratified to over-sample producers with large acreage. The sampling weights are constructed using the farm census data.

provides farm-level information on corn seed purchases, corn acreage, seed types and seed prices. It was collected using computer assisted telephone interviews. On average about 40-50% of the farms surveyed each year remain in the sample for the next year. For 2000-2007, the dmrk data contains 168,862 observations on individual corn seed purchases from 279 USDA crop reporting districts (CRD)[5] in 48 states. A total of 38,617 farms were surveyed during 2000-2007, with each farm on average purchasing four to five different corn seed each year.

Since farmers typically buy their seeds locally, our analysis defines the "local market" at the CRD level. On average each farm purchased four to five different seeds each year[6]. To guarantee reliable measurement of market concentrations, we focus our analysis on those CRDs in the slightly expanded Corn Belt regions with more than ten farms sampled every year between 2000 and 2007. In total, our data contain 139,410 observations from 80 CRDs in 12 states.[7]

Starting in the 1930s, the development and diffusion of hybrid corn transformed the U.S. seed industry and contributed to the dominant role played by private seed companies. The dmrk data show that about 300 seed companies operate in the current U.S. corn seed market. However, only six biotech firms are involved,[8] four of which own subsidiary corn seed companies.[9]

Currently there are two major groups of genes/traits in the GM seed market: insecticide resistance designed to reduce yield damages caused by insects; and herbicide tolerance designed to reduce yield reductions from competing plants (weeds). For corn, the insect resistance traits

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[5] A crop-reporting district (CRD) is defined by the U.S. Department of Agriculture to reflect local agro-climatic conditions. In general, a CRD is larger than a county but smaller than a state.

[6] Due to the fast turnover in the seed market, farmers may try new hybrid seeds every year, thus would purchase more than one hybrid seed type for their field. In addition, the U.S. EPA requires that farmers maintain at least 20 percent of their cropland for "non-insect resistant" hybrid seeds.

[7] They are: IL, IN, IA, KS, KY, MI, MN, MO, NE, OH, SD, and WI.

[8] They are: Monsanto, Syngenta, Dow AgroSciences, DuPont, Bayer CropScience, and BASF.

[9] While one of the rest two firms has already entered the cotton seed market, the dmrk data show that it has not entered (yet) the U.S. corn seed market.

focus on controlling damages caused by two insects: the European corn borer (*ECB*),[10] and rootworms (*RW*).[11] The herbicide tolerance (*HT*) traits work with corresponding herbicides. After adopting the *HT* traited seed technology, farmers can apply the relevant herbicide to the field, which kills the weeds without damaging the traited crop. Some biotech seeds contain only one of these traits, while the bundled seeds contain multiple traits from some combination of the two groups of traits.

Figure 1 shows the evolution of corn acreage shares reflecting adoption rates in the US from 2000 to 2007, for conventional seed, single-trait biotech seed, double-stacking biotech seed, triple-stacking biotech seed, and quadruple-stacking biotech seed. The conventional seed's acreage share has decreased rapidly over the past eight years: from 67.5% in 2000 to 20.6% in 2007. Table 1 illustrates the average price of different hybrid corn seeds ($ per bag) from 2000 to 2007. It indicates that biotech traits tend to add value to the conventional germplasm, and that multiple stacking/bundling is worth more than single stacking. The information presented in figure 1 and table 1 is at the national level, which masks important spatial market differences. For example, while single-trait biotech seeds had a U.S. market share of 30% in 2000, the dmrk data show that conventional seeds still dominated many local markets. And while the U.S. conventional seed's market share was 20.6% in 2007, some local markets were completely dominated by biotech seeds. This indicates the presence of spatial heterogeneity in the U.S. corn seed market. As shown below, such heterogeneity also applies to seed prices.

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[10] The European corn borer is a major pest of corn in North America and Europe. Yield loss due to *ECB* has been estimated to average about five percent, although damages can vary widely both over time and over space.

[11] Yield loss due to corn rootworms damages average around five percent in the US, amounting to about $800 million of reduced income for U.S. corn growers.

Figure 1. Percentage of U.S. Acreage Planted in Conventional and GM corn seed , 2000 – 2007.

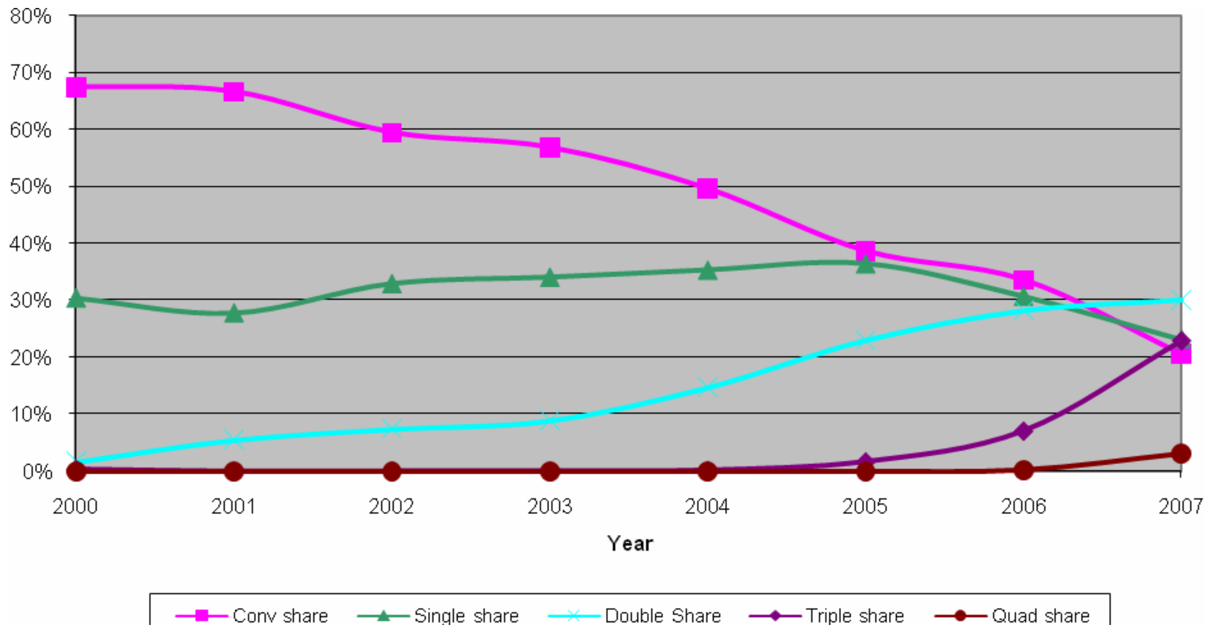

Table 1. Average price for different seeds ($ per bag), 2000 - 2007

Year	Conventional	*ECB Single*	*RW Single*	*HT Single*	*Double*	*Triple*	*Quadruple*
2000	79.37	100.24	n/a	87.34	95.21	100.95	n/a
2001	80.73	103.77	n/a	89.85	100.43	105.29	n/a
2002	81.81	103.91	n/a	89.08	103.19	94.64	n/a
2003	83.79	104.93	114.88	94.73	108.78	82.10	n/a
2004	86.42	108.61	120.49	98.88	113.68	112.21	n/a
2005	86.96	104.46	114.52	101.50	114.49	123.78	n/a
2006	91.36	109.69	116.67	109.93	123.03	139.21	131.29
2007	93.53	111.36	121.07	114.67	124.71	133.02	140.03
Total	84.29	105.37	117.33	101.51	118.25	133.47	139.60

Econometric Specification

Our analysis of the determinants of corn seed prices builds on equation (3). As derived, equation (3) is a structural equation reflecting the determinants of pricing under imperfect competition in a multi-product framework. As discussed in the model section, fixed cost can generate economies of scope. Economies of scope are relevant here as R&D investment likely generates synergies in the production of bundled/stacked seeds. This would in turn affect bundle pricing. Also, the effects of imperfect competition on price can be expected to depend on the nature of substitution/complementarity across bundles. Below, we specify a modified version of (3) that reflects the effects of both bundling and market power on corn seed price.

Consider for the case of seeds exhibiting different genetic characteristics. Partition the set of seeds into mutually exclusive types. Let $K_i \in \{0, 1\}$ be a dummy variable for a seed of the *i*-th type, $i = 1, \ldots J$. Let $i = 1$ characterize conventional seed, and let $\mathbf{Q} \equiv \{2, \ldots, J\}$ denote the set of genetic traits associated with biotech seeds. Thus, $K_1 = 1$ for conventional seeds. Each biotech seed includes at least one genetic trait in the set **Q**, with $K_i = 1$ if the seed includes the genetic traits of the *i*-th type either individually or stacked with other traits, $i \in \mathbf{Q}$, and $K_i = 0$ otherwise. In the absence of bundling/stacking (where each seed can be of only one type), the *K*'s would satisfy $\sum_{i=1}^{J} K_i = 1$. However, in the presence of stacking, some biotech seeds may include the genetic traits of more than one type, implying that $\sum_{i=1}^{J} K_i \geq 1$. Therefore, evaluating the effects of the genetic characteristics on seed prices requires a flexible specification that can capture bundling/stacking effects.

We start with a standard model in which each purchase observation is at the farm-level and the price of a seed varies with its characteristics (e.g., following Rosen 1974). The price *p* represents the net seed price paid by farmers (in $ per bag).[12] Consider the hedonic equation representing the determinants of the price *p* for a seed of characteristics $\{K_1, K_2, \ldots, K_J\}$:

$$p = \beta + \sum_{i \in \{1,\ldots,J\}} \delta_i K_i + \sum_{\substack{j \in \mathbf{Q} \\ j>i}} \sum_{i \in \mathbf{Q}} \delta_{ij} K_{ij} + \sum_{\substack{z \in \mathbf{Q} \\ z>j}} \sum_{\substack{j \in \mathbf{Q} \\ j>i}} \sum_{i \in \mathbf{Q}} \delta_{ijz} K_{ijz} + \sum_{\substack{r \in \mathbf{Q} \\ r>z}} \sum_{\substack{z \in \mathbf{Q} \\ z>j}} \sum_{\substack{j \in \mathbf{Q} \\ j>i}} \sum_{i \in \mathbf{Q}} \delta_{ijzr} K_{ijzr} + \boldsymbol{\varphi}\mathbf{X} + \varepsilon, \qquad (5a)$$

12 We also estimated a log specification of the price equation. The econometric results were qualitatively similar to the ones reported below.

where **X** is a vector of other relevant covariates, and ε is an error term with mean zero and constant variance. In equation (5a), K_{ij} is a dummy variable for double-stacking the *i*-th and *j*-th genetic type. Similarly, K_{ijz} and K_{ijzr} are dummy variables representing respectively triple-stacking and quadruple-stacking.[13]

For conventional seeds and single-trait seeds, the dummy variables K_{ij}, K_{ijz} and K_{ijzr} are all zero. This implies that the coefficients δ_{ij}, δ_{ijz}, and δ_{ijzr} in (5a) capture the effects of bundling on seed price. The dmrk data reveal that trait bundling is common, which allows us to test for its price impacts. One important special case occurs when $\delta_{ij} = \delta_{ijz} = \delta_{ijzr} = 0$, which corresponds to standard component pricing. Here, the price of seed is just the sum of the value of its genetic components (as captured by $\sum_i \delta_i K_i$, with δ_i measuring the unit value of the *i*-th genetic material). When the parameters δ_{ij}, δ_{ijz}, and δ_{ijzr} are not all zero, equation (5a) allows for non-linear pricing associated with bundled goods under stacking.

In general, the parameters δ_{ij}, δ_{ijz}, and δ_{ijzr} can be either positive or negative. When positive, these parameters would reflect super-additive bundle pricing. This could occur when component demands are complementary, i.e., when adding a trait to an existing trait system increases consumer's valuation for the stacked system more than the marginal value of the additional trait. Alternatively, negative parameters would correspond to sub-additive bundle pricing. The price of bundled goods would then be "discounted" compared to component pricing.

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[13] Note that the *K*'s in (5a) satisfy $\sum_{i\in\{1,\ldots,J\}} K_i - \sum_{\substack{j\in\mathbf{Q}\\ j>i}}\sum_{i\in\mathbf{Q}} K_{ij} - 2\sum_{\substack{z\in\mathbf{Q}\\ z>j}}\sum_{\substack{j\in\mathbf{Q}\\ j>i}}\sum_{i\in\mathbf{Q}} K_{ijz} - 3\sum_{\substack{r\in\mathbf{Q}\\ r>z}}\sum_{\substack{z\in\mathbf{Q}\\ z>j}}\sum_{\substack{j\in\mathbf{Q}\\ j>i}}\sum_{i\in\mathbf{Q}} K_{ijzr} = 1$, implying that they are perfectly collinear with the intercept. To deal with this issue below, we set $\delta_1 = 0$ in (5a), meaning that the intercept reflects the price of conventional seeds and that the other δ parameters measure price differences relative to conventional seeds.

This could happen under two scenarios. First, this could be associated with economies of scope on the production side, if the joint production of bundled goods leads to a cost reduction that gets translated into lower bundle price. Second, this could be associated with price discrimination on the demand side, if discounting the price of a bundled good can help increase firm profit. In general, equation (5a) provides a framework to analyze the nature of bundle pricing.

Next, as shown in equation (3), we introduce market power effects in (5a) by specifying

$$\delta_i = \delta_{0i} + \delta_{ii} H_{ii}, \tag{5b}$$

where $H_{ii} \equiv \sum_{n \in \mathbf{N}} s_i^n s_i^n$ is the HHI (s_i^n being the market share of the *n*-th firm in the market for the *i*-th seed type) measuring market concentration in the *i*-th market. We further specify

$$\beta = \beta_0 + \sum_{\substack{j \in \mathbf{Q} \\ j>i}} \sum_{i \in \mathbf{Q}} \beta_{ij} H_{ij} K_i + \sum_{\substack{j \in \mathbf{Q} \\ j>i}} \sum_{i \in \mathbf{Q}} \beta_{ji} H_{ji} K_j, \tag{5c}$$

where $H_{ij} \equiv H_{ji} \equiv \sum_{n \in \mathbf{N}} s_i^n s_j^n$ being the cross-market GHHI discussed in the model section and measuring concentration for firms operating in the market for both *i*-th and *j*-th characteristics. With this specification, the coefficient of the traditional HHI, $\delta_{ii} \neq 0$, would reflect market power related to the *i*-th characteristic, while the coefficient of the GHHI, $\beta_{ij} \neq 0$ or $\beta_{ji} \neq 0$, would reflect the exercise of market power across characteristics.

Since the HHI and the GHHI's are zero under competitive conditions, it follows from equations (4) and (5a)-(5c) that the effect of market power on price is given by

$$M = \sum_{i \in \{1,\dots,J\}} \delta_{1i} H_{ii} K_i + \sum_{\substack{j \in \mathbf{Q} \\ j>i}} \sum_{i \in \mathbf{Q}} \beta_{ij} H_{ij} K_i + \sum_{\substack{j \in \mathbf{Q} \\ j>i}} \sum_{i \in \mathbf{Q}} \beta_{ji} H_{ji} K_j. \tag{6}$$

In a way similar to equation (4), equation (6) provides a representation of the linkages between imperfect competition and pricing. As noted in the model section, the term *M* in (6) measures the difference between price and marginal cost. It can be used to obtain the associated

Lerner index $L = \frac{M}{p}$. When positive, M reflects the price enhancement associated with imperfect competition.

Our analysis is based on five seed characteristics (J = 5): Conventional $(K_1 = 1)$; insect resistance trait *ECB* $(K_2 = 1)$; insect resistance trait *RW* $(K_3 = 1)$; herbicide tolerance trait *HT*1 $(K_4 = 1)$; and herbicide tolerance trait *HT*2 $(K_5 = 1)$. Note that this distinguishes between two types of herbicide tolerance: *HT*1 and *HT*2. The reason is that, in our sample, *HT*1 and *HT*2 are sometimes stacked/bundled together. This implies that farmers see *HT*1 and *HT*2 as being different (otherwise, no farmer would pay extra for a second herbicide tolerant technology).

Our model specification allows us to estimate the pricing of each seed type along with stacking/bundling effects. To illustrate, from (5a)-(5c), the price equation for conventional seed $(K_1 = 1)$ is

$$p_1 = \beta_0 + \delta_{01} + \delta_{11} H_{11} + \sum_{j=2}^{5} \beta_{1j} H_{1j} + \boldsymbol{\varphi}\mathbf{X} + \varepsilon. \tag{7a}$$

For a seed marketed with a single *ECB* trait ($K_2 = 1$), the price equation becomes

$$p_2 = \beta_0 + \delta_{02} + \delta_{22} H_{22} + \beta_{21} H_{21} + \sum_{j=3}^{5} \beta_{2j} H_{2j} + \boldsymbol{\varphi} \cdot \mathbf{X} + \varepsilon. \tag{7b}$$

And for a double-stacking seed with an insect resistance trait (*ECB*) and our first herbicide tolerance trait (*HT*1) $(K_2 = 1, K_4 = 1, \text{ and } K_{24} = 1)$, the price equation is

$$p_{24} = \beta_0 + \delta_{02} + \delta_{04} + \delta_{24} + \delta_{22} H_{22} + \delta_{44} H_{44} + \beta_{21} H_{21} + \sum_{i=1}^{3} \beta_{4i} H_{4i} + \sum_{j=3}^{5} \beta_{2j} H_{2j} + \beta_{45} H_{45} + \boldsymbol{\varphi}\mathbf{X} + \varepsilon\,. \tag{7c}$$

Comparing equations (7b)-(7c) reveals how our model captures price differences between single-trait seed and bundled/stacked seeds. It shows how both stacking and market concentration affect pricing. Equation (7c) contains all the dummy variables reflecting stacking/bundling of traits along with their interaction effects with the traditional HHI's: H_{ii}. It also contains the parameters linking price to the generalized cross market GHHI's: H_{ij}, $i \neq j$. Note that market share information is contained in both the traditional and cross Herfindahl indexes. This means that the effects of market concentration and imperfect competition on prices are complex. Evaluating these effects will be addressed in the implications section.

The relevant covariates in **X** include location, a time trend, each farm's total corn acreage, and binary terms covering the range of how each purchase was sourced. Location is represented by state dummy variables, along with the longitude and latitude of the county where the farm is located. These variables capture spatial heterogeneity in farming systems and agro-climatic conditions (including the length of the growing season). The latitude and longitude variables are specified in both linear and quadratic forms, reflecting possible non-linearity in their effects. For example, according to Griliches (1960), the corn seed industry first developed new hybrids that were best adapted to land in the center of the Corn Belt due to profitability consideration. It is likely that the same path is followed in the biotech seed development, which may result in a significant difference in seed prices between the center and fringe regions. The time trend is included to capture the advances in hybrid and genetic technology through the years of the study. Farm acreage captures possible price discrimination effects related to farm size. While there are a total of 16 different purchasing sources, most seeds are purchased through "Farmer who is a dealer or agent" (33.1%), followed by "Direct from seed company or their representatives" (29%), and "Myself, I am a dealer for that company" (16.1%). Note that a farmer may choose multiple sources to buy his seeds. Including source of purchase as an explanatory variable in (5a) captures possible price discrimination schemes affecting the seed price paid by farmers.

The market share of biotech seeds has increased significantly during the years of our study (see figure 1). In many cases, we found “entry” and “exit” of traited seeds in some local markets. In order to investigate whether entry/exit may affect seed prices beyond the *H* effects, we also introduce entry/exit variables in the specification (5a). In our data, we observe local exits in the conventional seed (K_1) markets. We also observe local entry in the *HT*1 trait (K_4) markets, the *ECB* trait (K_2) markets and the *RW* trait (K_3) markets. To capture entry-exit effects on seed price, the following binary terms are included: *Post-exit*1 = 1, when $H_{11} = 0$; *Pre-entry*2 = 1 when $H_{22} = 0$; *Pre-entry*3 = 1 when $H_{33} = 0$; and *Pre-entry*4 = 1 when $H_{44} = 0$.[14]

Estimation

Table 2 reports summary statistics of key variables used in the analysis. The mean values of H_{ii}'s show that the conventional seed markets are quite concentrated, but are considerably less concentrated than the biotech trait markets. Each CRD is presumed to represent the relevant market area for each transaction; thus, all *H* terms are calculated at that level. Conducting market concentration analysis at the CRD level allows us to evaluate the possibility that seed companies recognize localized market power for seeds with favorable performance parameters under various agro-climatic conditions. For the 80 CRDs covering the eight years of our data, the average conventional seed HHI is 0.242, which is well above the Department of Justice's threshold of 0.18 for identifying "significant market power". The average HHI for the three biotech seeds markets is over 0.80.

[14] Note that we do not construct an event dummy for K_5, as we do not observe any pattern of entry or exit for this trait.

One econometric issue in the specification (5a)-(5c) is the endogeneity of the *H*'s. Both market concentrations (as measured by the *H*'s) and seed pricing can be expected to be jointly determined as they both depend on firm strategies in the seed market. To the extent that parts of the determinants of these strategies are unobserved by the econometrician, this would imply that the *H*'s are correlated with the error term in equation (5a). In such situations, least-squares estimation of (5a)-(5c) would yield biased and inconsistent parameter estimates (due to endogeneity bias). The solution is to consider estimating equation (5a)-(5c) using an instrumental variable (IV) estimation method that corrects for endogeneity bias. To address this issue, we first test for possible endogeneity of the *H*'s using a *C* statistic calculated as the difference of two Sargan statistics (Hayashi 2000, p. 232). Under the null hypothesis of exogeneity of the *H*'s, the *C* statistic is distributed as Chi-square with degrees of freedom equal to the number of variables tested. The test is robust to violations of the conditional homoscedasticity assumption (Hayashi 2000, p. 232).[15] In our case, the *C* statistic is 200.16, showing strong statistical evidence against the null hypothesis of exogeneity of the *H*'s.

The presence of endogeneity motivates the use of an instrumental variable (IV) estimator. We used the lagged value of each *H* and the lagged value of the market size for each trait (including the conventional seed) as instruments. The use of lagged values reflects the time required to grow the seeds, as seed companies typically make production decisions a year ahead of the marketing decisions. Indeed these lag values are part of the information set available to the seed companies at the time of their production decisions. The Hansen over-identification test is not statistically significant, indicating that our instruments appear to satisfy the required

[15] Under conditional homoskedasticity, the *C* statistic is numerically equivalent to a Hausman test statistic.

orthogonality conditions. On that basis, equation (5a)-(5c) was estimated by two-stage-least-square (2SLS). Further evaluation of these instruments is presented below.

Table 2. Summary statistics

Variable	Number of observations[a,b]	Mean	Standard Deviation	Minimum	Maximum
Price ($)	139410	99.61	23.61	3	230
Farm size (acre)	30273	489.48	587.87	5	15500
Longitude	30273	91.59	4.783	80.75	103.76
Latitude	30273	41.71	2.010	36.71	46.98
H_{11}	639	0.242	0.152	0.067	1
H_{22}	639	0.769	0.188	0.337	1
H_{33}	313	0.907	0.150	0.430	1
H_{44}	639	0.772	0.175	0.434	1
H_{12}	601	0.085	0.070	0.99E-04	0.518
H_{13}	291	0.108	0.088	1.10E-03	0.632
H_{14}	580	0.075	0.079	9.58E-05	0.526
H_{23}	312	0.761	0.169	0.172	1
H_{24}	617	0.577	0.261	0.010	1
H_{34}	311	0.785	0.198	0.056	1

[a]/ The data contain 139410 observations from CRDs spanning 8 years (2000-2007). Each farm purchases multiple seeds, therefore the number of observations for farm size is the total count of farms per year. The longitude and latitude information is based on the county level measurement for each farm.

[b]/ For the market concentration measurements *H*'s, we only report the summary statistics of those non zeros at the CRD level, therefore the number of observations is at most $80\times 8 = 640$.

A second pretest was to evaluate the model for the effects on prices from unobserved heterogeneity across farms (e.g., unobserved pest populations). A Pagan-Hall test[16] found strong evidence against homoscedasticity of the error term in (5a). As reported earlier, each farm purchases on average four to five different seeds. Some large farms actually purchase up to 30 different hybrid seeds in a single year. Unobserved farm-specific factors affecting seed prices are expected to be similar within a farm (although they may differ across farms). This suggests that

[16] Compared to the Breusch-Pagan test, the Pagan-Hall test is a more general test for heteroscedasticity in an IV regression, which remains valid in the presence of heteroscedasticity (Pagan and Hall 1983).

the variance of the error term in (5a) would exhibit heteroscedasticity, with clustering at the farm level. On that basis, we relied on heteroscedastic-robust standard errors under clustering at the farm level in estimating equation (5a)-(5c).

Additional tests of the validity of the instruments were conducted. In the presence of heteroscedastic errors, we used the Bound et al. (1995) measures and the Shea (1997) partial R^2 statistic to examine the possible presence of weak instruments. The F-statistics testing for weak instruments were large (i.e., much above 10). Following Staiger and Stock (1997), this means that there is no statistical evidence that our instruments are weak. Finally, The Kleibergen-Paap weak instrument test was conducted (Kleibergen and Paap, 2006),[17] yielding a test statistic of 5.81. Using the critical values presented in Stock and Yogo (2005), this indicated again that our analysis does not suffer from weak instruments.

Empirical Results

Equation 5(a)-(5c) is estimated using 2SLS, with heteroscedastic-robust standard errors under clustering. We first tested whether the cross-market GHHI impact is symmetric: $H_0\colon \beta_{ij} = \beta_{ji}$, where the β's are the coefficients of the corresponding GHHI's. Using a Wald test, we fail to reject the null hypothesis for H_{13}. On that basis, we imposed the symmetry restriction for H_{13} in the analysis presented below.

Table 3 reports the results. For comparison purpose, the ordinary least square (OLS) estimation results are also reported. The OLS estimates of the market concentration parameters differ substantially from the 2SLS results. This reflects the endogeneity of our market concentration measures (and its associated bias). Our discussion below focuses on the 2SLS

[17] Note that the Kleibergen-Paap test is a better choice compared to the Cragg-Donald test for weak instruments: the former remains valid under heteroscedasticity (while the latter one does not).

estimates as IV/2SLS estimation corrects for endogeneity bias. We first discuss the price impacts associated with introducing single biotech traits. This builds toward a broader assessment of the more complex issues related to the marginal price impacts derived from the stacking of traits and from the role that market power has shifting rent between farmers and the seed industry. In the implications section, simulations of the Illinois corn seed market provides additional insights about the interactive forces that derive from biotechnology.

Characteristics effects: Compared to conventional seeds, the results show that the insertion of single biotech traits led to sizeable seed price premiums in three of the four traits considered. The coefficients of the terms K_2 (*ECB*), K_3 (*RW*) and K_5 (*HT*2) are each positive and statistically significant. They are respectively $25.64, $46.06, and $9.63 per bag, suggesting the presence of significant premiums for these biotech traits. The coefficients of K_4 (*HT*1) and K_5 (*HT*2) differ, providing evidence of differences between the two herbicide-tolerant traits *HT*1 and *HT*2. The coefficient of K_4 (*HT*1) is negative but not statistically significant. However, note that the *K*'s also appear in interaction with the *H*'s in (5a)-(5c). This means that coefficients of the *K's* alone provide only partial information on how prices vary across seed types. The magnitude of the price premium across seed types will be analyzed in more detail later.

The coefficients of the terms K_{ij}, K_{ijz}, and K_{ijzr} provide useful information on the effects of trait bundling on seed price. All of the stacking coefficients except for K_{35} are negative and statistically significant. The coefficient for K_{35} is positive but not statistically significant. As discussed in the econometric specifications section, component pricing is associated with the null hypothesis that all stacking coefficients are zero. Using a Wald test, the null hypothesis that the coefficients of stacking effects are all zero is strongly rejected. This provides convincing evidence against component pricing of biotech traits in the corn seed market. The negative and significant stacking effects also indicate the prevalence of subadditive pricing of corn seed in their individual components. Subadditive pricing may be driven by price discrimination associated with demand heterogeneity (higher prices being associated with more inelastic demands). But the fact that all of the stacking coefficients are negative indicates the likely presence of economies of scope in the production of bundled/stacked seeds. This would be consistent with synergies in R&D investment (treated as fixed cost) across stacked seeds. For example, a given R&D investment can contribute to the production of multiple seed types, meaning that bundling can help reduce the overall cost of producing seeds. In this context, the subadditivity of prices would reflect the fact that seed companies share with farmers at least some of the benefits of scope economies.

Market concentration effects: The model incorporates market share information about each of the trait using the traditional Herfindahl indexes H_{ii} along with generalized cross-Herfindahl indexes H_{ij} as given in equations (5a)-(5c). Here, we discuss the partial effects of concentration and withhold a global assessment of market concentration until the implications section.[18] The partial effects of changes to the traditional Herfindahl indexes for each trait are presented in the first four rows of the "Market concentration effects". In this context, our estimates indicate that an increase in market concentration for conventional seeds (as measured by H_{11}) has a positive and statistically significant association with the price of conventional seeds. More specifically, a one-point increase in H_{11} is associated with a \$14.81 per bag increase in the price of conventional seeds. The partial effect of concentration in the RW trait market

[18] We do not observe non-zero H_{15} because no firm that operates in $HT2$ market sells a conventional seed. Similar situations arise for H_{25}, H_{35} and H_{45}. When present, H_{55} =1 because only one firm operates in this trait market.

(H_{33}) and the *HT*1 trait market (H_{44}), were also positive and statistically significant: A one-point increase in H_{33} (H_{44}) is associated with a $32 ($14.92) per bag increase in the price of *RW* (*HT*1) seeds. Finally, the concentration effect in the *ECB* trait market is negative but not statistically significant.

We have shown in the model section that the effects of cross-market concentration H_{ij}, $i \neq j$, depend on the substitutability/complementarity relationship between traits *i* and *j*. We expect that an increase in the cross-market concentration H_{ij} will be associated with a rise (decrease) in the price if the two components are substitutes (complements).

Of the five cross GHHI's that involves conventional seed ($H_{12}, H_{21}, H_{13}, H_{14}, H_{41}$), only the coefficients on H_{12} (conventional market share crossed with *ECB* market share) and H_{41} (conventional market share crossed with *HT*1 market share) are statistically significant. The positive effect of both coefficients suggests that the *ECB* trait is viewed as a substitute for the conventional seed from the perspective of non-GM farmers; and the conventional seed is viewed as a substitute for the *HT*1 trait for the *HT*1 traited seed adopters. This is plausibly explained by the presence of a "yield drag" associated with adding a trait into a seed (Avise 2004, p. 41), which would induce some substitution in demand between this trait and conventional seed.

All the cross-market concentration effects involving biotech traits are statistically significant. This stresses the importance of a cross-market evaluation of market power. The *ECB* and *RW* cross-market effects (H_{23} and H_{32}) are both negative. This suggests that these two *IR* traits are complements to each other. Since these two traits are targeting the control of different insects, this could reflect the fact that crop damages caused by one insect infestation are larger in the presence of damages from another insect infestation. The *ECB* and *HT*1 effects (H_{24} and

H_{42}) are both positive, suggesting that the *ECB* and *HT*1 traits are substitutes. The *RW* and *HT*1 effects (H_{34} and H_{43}) are statistically significant but with opposite sign, suggesting that the *RW* trait and *HT*1 trait may have asymmetric effects on each other: *HT*1 trait is viewed as complement to *RW* trait by *RW* traited seed adopters; and *RW* trait is viewed as substitute for *HT*1 trait by *HT*1 traited seed adopters. This indicates that the effects of insect infestation on corn yield differ significantly from those for weed infestation.

Location effects: Corn seed prices are found to vary significantly across states. Compared to Illinois, the price difference is statistically significant for Iowa ($1.53), Indiana (-$1.13), Ohio (-$2.16), Wisconsin (-$2.34), and Kentucky (-$3.22). This suggests that seed companies do price discriminate across regions, reflecting spatial differences in elasticities of demand for seeds. The longitude variables are not statistically significant. But the latitude variables have significant effects on corn seed price: the linear term is positive while the quadratic term is negative. This suggests that seed price rises from south to north, reaches a peak near the center of the Corn Belt[19] and then declines when moving further north. This confirms significant differences in seed prices between the center of the Corn Belt and fringe regions.

Purchase source effects: Recall that most farmers purchase seed from “Farmer dealer or agent”, followed by “Direct from seed company” , and “Myself, I am a dealer for that company” . Compared to purchasing from “Farmer dealer or agent”, “buying directly from a seed company” costs about $4.57 less, while purchasing from “myself” costs about $4.40 less. These results may reflect the effect of farmer’s bargaining position, but also possibly the presence of price discrimination across different modes of purchase.

[19] For the latitude, the peak is reached at 40.54, which is close to the center of our study region (mean latitude at 41.71)

Table 3. OLS and 2SLS regression with robust standard errors,[a, b, c, d]

Dependant Var: Price ($/bag)	OLS		2SLS	
	Coefficient	t-statistics	Coefficient	Robust z statistics
Characteristic effects, benchmark is K_1: Conventional seed				
K_2 (*ECB*)	24.31***	46.93	25.64***	12.65
K_3 (*RW*)	31.89***	23.82	46.06***	5.09
K_4 (*HT*1)	1.93***	2.97	-3.78	-1.16
K_5 (*HT*2)	6.92***	18.68	9.63***	10.28
K_{23}	-9.49***	-11.20	-11.20***	-7.06
K_{24}	-10.06***	-30.10	-13.83***	-13.75
K_{25}	-3.44***	-7.96	-5.82***	-6.00
K_{34}	-11.03***	-12.74	-14.35***	-10.13
K_{35}	0.39	0.33	-1.27	-0.67
K_{45}	-19.70**	-2.25	-21.95***	-2.92
K_{234}	-24.52***	-28.17	-30.62***	-11.82
K_{235}	-13.63***	-12.26	-18.71***	-6.47
K_{245}	-16.51***	-24.34	-22.92***	-11.84
K_{345}	-12.26***	-6.17	-17.36**	-5.98
K_{2345}	-28.85***	-24.78	-37.88***	-10.05
Market concentration effects				
H_{11} (conventional seed)	11.71***	15.83	14.81***	6.47
H_{22} (*ECB*)	1.45**	2.41	-0.57	-0.27
H_{33} (*RW*)	4.82**	2.04	32.00***	2.93
H_{44} (*HT*1)	11.25***	12.70	14.92***	2.91
H_{12} on conventional seed	28.06***	11.72	36.07***	3.10
H_{21} on *ECB* trait	-7.22***	-4.73	-7.29	-0.95
H_{13} on conventional seed/*RW* trait	-1.74	-1.00	2.78	0.21
H_{14} on conventional seed	-24.19***	-9.93	-14.58	-1.04
H_{41} on *HT*1 trait	9.22***	6.49	22.42*	1.78
H_{23} on *ECB* trait	-2.10***	-6.14	-3.42**	-2.38
H_{32} on *RW* trait	1.79	0.74	-28.87***	-3.45
H_{24} on *ECB* trait	-2.58***	-5.10	3.00*	1.66

H_{42} on *HT*1 trait	6.53***	9.59	10.07***	4.17
H_{34} on *RW* trait	-8.41***	-4.54	-24.98***	-2.98
H_{43} on *HT*1 trait	3.99***	9.35	7.77***	4.15
Other variables				
Post-exit1	-4.36*	-1.58	-2.77	-0.59
Pre-entry2	-5.50**	-2.21	-4.52	-1.21
Pre-entry3	-0.30	-1.34	0.12	-0.11
Pre-entry4	-7.75***	-3.64	-6.57**	-2.02
Total farm corn acreage (1000 acre)	0.75***	9.61	0.72***	4.68
Longitude	0.33***	2.90	0.37	1.49
Longitude squared	-0.01	-1.52	-0.01	-1.00
Latitude	0.97***	5.59	1.18***	3.30
Latitude squared	-0.11***	-6.93	-0.13***	-4.20
Year	2.30***	47.42	1.95***	13.95
Constant	71.01***	71.41	70.36***	29.39
Number of observations	123861			

[a] Statistical significance is noted by * at the 10 percent level, ** at the 5 percent level, ** at the 1 percent level.
[b] The R^2 is 0.54 for the OLS estimation. For the 2SLS estimation, the centered R^2 is 0.53, and un-centered R^2 is 0.98.
[c] Results for the location effects and purchase source effects are not reported here but are discussed in the text.
[d] The longitude and latitude measures are normalized by subtracting the lower bound (80 for longitude and 36 for the latitude) from the true value.

Other variables: Most exit and entry dummies are not statistically significant. The only exception is *Pre-entry4*, which is negative and statistically significant at the 5 percent level. The introduction of *HT*1 traited biotech seed may raise the price for all seeds, including the conventional ones. This result is consistent with the finding in Shi (2009), where she argues that the introduction of biotech seed can raise the conventional seed price. The farm size effect is statistically significant: large farms within each state pay more for corn seed. This result may be due to the fact that large farms are more productive (compared to smaller farms) and located in areas where corn hybrids are better tailored to local growing conditions. The time trend effect is positive and statistically significant, reflecting technological improvements in the seed industry.

Implications

In this section, our empirical estimates are used to generate insights on bundle pricing, and the interactive role of market power within and across markets on seed pricing. For illustration purpose, our analysis focuses on Illinois in 2004. Illinois is one of the largest corn-producing states in the US, and it has the largest number of farms in our sample. The year 2004 is chosen as it is in the middle of our sample period; and it avoids entry/exit events for traits.

Three sets of results are presented. First, we evaluate the effects of bundling/stacking by simulating how stacking influences seed prices. Second, we simulate the Lerner indexes applied to the pricing of different seed types. This provides useful information on the extent of departure from marginal cost pricing. Third, in a further evaluation of market power effects, we simulate the potential impact of merger activities.

Simulation of bundling effects

The bundling literature has identified situations where component pricing may not apply (e.g., when the demands for different components are correlated, or when consumers are heterogeneous in at least a subset of the component markets). As discussed above, our econometric results strongly reject component pricing (i.e., seeds being priced as the sum of their component values). This raises the question: how do prices vary across bundles? To address this question, we simulate the effects of bundling/stacking on seed prices using mean values of relevant variables for Illinois in 2004 (including farm size, the traditional HHIs (H_{ii}) and the cross market GHHIs (H_{ij})).[20]

[20] The purchase source is set to be from "Farmer who is a dealer or agent".

Table 4 contains the simulation results.[21] The simulated mean conventional seed price is $90.86/bag, which is presented as the base case (case 1). Cases 2-16 involve biotech seeds, including stacked/bundled seeds. The last column of table 4 reports price premiums measured as price differences of each seed type compared to conventional seed. Except for the seed with two herbicide tolerant traits (case 11: K_{45}), all biotech seed price premiums are statistically different from the mean conventional seed at the 1 percent level or higher. Thus, seed companies are able to generate price premiums linked to specific biotech traits.

Cases 2-5 reflect the premium attached to seeds sold with a single biotech trait. Adding the *ECB* trait (K_2) alone raises the seed price by a premium of $17.96. The corresponding price premium is $29.91 for RW (K_3), $13.03 for $HT1$ (K_4), and $4.51 for $HT2$ (K_5).

Double, triple, and quadruple-stacked seed prices and premiums are presented in cases 6-15. Note first the $41.74 premium for stacking *ECB* and *RW* traits (K_{23}). While this is greater than the price premium farmers pay for unstacked versions of these seeds (i.e., *K2* or *K3*), it is less than the sum of them (17.96 + 29.91 = $47.87). A similar pattern is evident in all the double stacked seed prices except for case 10: K_{35} and case 11: K_{45}. The triple stacking of *ECB*, *RW* and $HT1$ traits (K_{234}) has a price premium of $40.49. This is greater than the value of any individual trait component or any relevant double stacked seed price (except for K_{23} where the price difference is insignificant). But this is less than the sum of the individual premiums ($65.41). Note also that adding the third trait to any of the K_{23}, K_{24}, or K_{34} seeds produces a marginal contribution of the third trait that is smaller than the contribution of the trait being added into a

[21] Note that we did not simulate the case for $HT1$ trait stacked with $HT2$ trait (K_{45}) because we have very few observations on the K_{45} stacking system. The same applies for K_{245}.

single traited system (to form a double stacking system) or alone (to form a single traited system). Other triple stacking systems follow a similar pattern. Finally, the price premium for quadruple stacking (K_{2345}) is $42.85, which is (weakly) greater than all other scenarios (including K_{235} and K_{345}). As before, the marginal contribution of each individual trait is again lower than in a triple system.

Table 4. Effects of Bundling/Stacking on Seed Prices, $/bag.[a]

Case	Traits	Expected Seed Price	Standard Error	Price difference from K_1 (Conventional)	Standard Error
1	K_1 (Conventional)	90.86***	0.46	0.00	
2	K_2 (*ECB*)	108.82***	0.49	17.96***	0.65
3	K_3 (*RW*)	120.78***	1.28	29.91***	1.16
4	K_4 (*HT*1)	103.89***	0.67	13.03***	0.79
5	K_5 (*HT*2)	95.38***	0.67	4.51***	0.80
6	K_{23}	132.60***	1.41	41.74***	1.34
7	K_{24}	113.13***	0.75	22.26***	0.88
8	K_{25}	112.62***	0.59	21.76***	0.72
9	K_{34}	124.54***	1.43	33.68***	1.33
10	K_{35}	129.11***	1.43	38.25***	1.56
11	K_{45}	91.40***	7.49	0.54	7.53
12	K_{234}	131.35***	1.42	40.49***	1.41
13	K_{235}	134.80***	1.64	43.94***	1.64
14	K_{245}	113.67***	0.90	22.81***	1.02
15	K_{345}	131.20***	2.19	40.34***	2.16
16	K_{2345}	133.72***	1.69	42.85***	1.74

[a] Statistical significance is noted by * at the 10 percent level, ** at the 5 percent level, and *** at the 1 percent level.

Overall, these results document significant departures from component pricing (where seeds are priced as the sum of their component values). The evidence supports sub-additive pricing. It shows that the marginal contribution of each component to the seed price declines with the number of components. Note that such a finding is consistent with the presence of economies of scope in seed production. Indeed, synergies in R&D investment (treated as fixed cost) across seed types can contribute to reducing total cost. This cost reduction can then be (at least partially) shared with farmers in the form of lower seed prices. Our empirical evidence against component pricing and in support of sub-additive pricing could then be interpreted as indirect evidence of scope economies in seed production.

Estimated Lerner indexes

As discussed earlier, the Lerner index provides a simple characterization of the strength of imperfect competition: it is zero under marginal cost pricing, but positive when price exceeds marginal cost. The market power component M in equation (6) gives a per-unit measure of the price enhancement beyond marginal cost. And the associated Lerner index is $L = \frac{M}{p}$. Evaluated at sample means for Illinois in 2004, the Lerner indexes ($100 \times L$) are reported in Table 5 for selected seed types.

The Lerner indexes are statistically significant at the 10 percent level in four cases (out of eight cases).[22] When significant, the Lerner indexes are positive in three cases (conventional seed K_1, $HT1$ traited seed K_4, and double stacked seed of ECB and $HT1$ K_{24}) but negative in the case of K_{23} (double stacked seed of ECB and RW), with estimates of ($100 \times L$) varying from 5.92 percent for conventional seeds (K_1) to 20.87 percent for $HT1$ (K_4) for the positive cases and -10.11 percent for ECB and RW (K_{23}). This provides empirical evidence that market power affects seed prices. The effect of market power on price is found to be moderate in the conventional seed market K_1, but larger in the $HT1$ market. Finally, the Lerner indexes are not statistically different from zero for K_2 (ECB) and K_3 (RW), but is negative and statistically significant in the stacked market K_{23}. Thus, our analysis suggests empirical evidence of

[22] Cases involving the K_5 trait are dropped due to lack of variation in the K_5 market concentration.

complementarity interacting with market power: an increased market concentration in these two sub-market is associated with a price reduction in the relevant stacked seed market.

Table 5. Simulated Lerner Indexes[a]

	Lerner Index (100 × *L*)	Standard Error	t-ratio
K_1 (Conventional)	5.92***	1.51	3.91
K_2 (*ECB*)	-2.44	2.05	-1.19
K_3 (*RW*)	-8.99	6.31	-1.43
K_4 (*HT*1)	20.87***	2.79	7.47
K_{23}	-10.11**	5.02	-2.01
K_{24}	15.90***	2.89	5.50
K_{34}	8.47	6.72	1.26
K_{234}	6.00	5.64	1.06

[a] Lerner indexes are calculated from prices at the mean GHHI levels compared to the case of competition (GHHI=0)
[b] Statistical significance is noted by * at the 10 percent level, ** at the 5 percent level, and *** at the 1 percent level.

Effects of changing market structure

In equation (3), we defined the GHHI's $H_{ij} \equiv \sum_{n \in \mathbf{N}} s_i^n s_j^n$ for sub-markets *i* and *j*. As discussed above, the *H's* are endogenous variables measuring market concentrations. They provide useful information linking market structure with pricing. The assessment of changing market structures is complex in the presence of bundling when the same firms sell different bundled goods, as all the H_{ij}'s typically change in response to any change in industry structure. The changes in the H_{ij}'s depend on the nature of changes in firms' concentration in all relevant markets. This indicates that changes in market structure can have complex effects on prices.

We evaluated such effects by simulating the effects of changing market structures associated with alternative merger scenarios. Several simulations are presented to evaluate the potential effects of increased market concentrations on seed prices. Each simulation considers a hypothetical merger in a given market, merger leading to a monopoly in that market (where the post-merger market share becomes equal to 1).[23] While these are rather extreme scenarios, the simulated effects can be interpreted as upper bound estimates of the potential impact of market power. Three sets of (hypothetical) mergers are simulated: 1/ mergers between biotech companies within each genetic trait market (*biotech/biotech within trait*); 2/ mergers between biotech companies producing different genetic traits (*biotech/biotech across traits*); and 3/ mergers between biotech companies and seed companies (*biotech/seed merger*). Again, such merger scenarios are counterfactual. They are presented to illustrate how our analysis can be used to evaluate the price implications of changing market structures.

The price effects of three sets of merger scenarios are reported in Table 6. The first set (scenarios 1-3) considers mergers between biotech companies within a given genetic trait market (*biotech/biotech within trait*). This covers mergers of biotech firms within the *ECB* market (scenario 1), within the *RW* market (scenario 2), and within the *HT*1 market (scenario 3). In scenarios 1-3, Table 6 shows that the effect of such mergers on seed price would not be statistically significant for *ECB* and *RW*. However, the effect is statistically significant for *HT*1. Our simulation results show that mergers of biotech firms in the *HT*1 markets could potentially induce a price increase of up to $19.08/bag of *HT*1 seed.

The second set (scenarios 4-6) considers mergers between biotech companies producing different genetic traits (*biotech/biotech across traits*). This covers mergers of biotech firms involved in *ECB* and *RW* markets (scenario 4), in *ECB* and *HT*1 markets (scenario 5), in *RW* and *HT*1 markets (scenario 6). In each case, the simulations again assume that the merger leads to a monopoly in the corresponding market (with a market share equal to 1). Table 6 shows that the mergers across *ECB* and *RW* markets are associated with a price reduction of $5.99/bag for *ECB*

[23] In situations where the mergers lead to increased market concentration but without full monopolization, note that our simulations present upper-bound estimates of the corresponding price effect.

seeds (scenario 4a), a price reduction of $25.10/bag for *RW* seeds (scenario 4b), and a price reduction of $31.09/bag for *ECB/RW* stacking seeds (scenario 4c). The results for scenario 4 underscore the importance of possible efficiency gains that might emerge from mergers. Mergers involving *ECB* and *HT*1 could potentially induce a price increase of up to $22.22/bag of *HT*1 seed (scenario 5b) and $22.55/bag of *ECB*/*HT*1 stacking seeds (scenario 5c), but not on the *ECB* trait market. And mergers involving *RW* and *HT*1 could be associated with a price reduction of up to $21.34/bag of *RW* seed (scenario 6a) and a price increase of up to $19.91/bag of *HT*1 seed (scenario 6b). However, the price effects on *RW*/*HT*1 stacking seeds (scenario 6c) are not statistically significant.

Finally, the third set (scenarios 7-9) considers mergers involving biotech companies and seed companies (*biotech/seed merger*). The simulations assume that the mergers lead to the monopolization in the corresponding biotech trait market. However, since the monopolization of seed companies is unlikely (there are too many seed companies), the mergers in scenarios 7-9 are assumed to increase market concentrations for conventional seed (as measured by the H_{ii}'s and H_{ij}'s) only to the maximum observed in our sample. How are mergers involving both seed companies and biotech firms associated with changes in conventional seed prices? The simulated price change can be up to +$32.37/bag when mergers involve *ECB* biotech firms (scenario 7). However, our simulations indicate that the effects of such mergers would not be statistically significant when it involves *RW* biotech firms (scenario 8) or when the mergers involve *HT*1 firms (scenario 9). Importantly, note that these simulation results capture cross-market effects contributing to the exercise of market power in the conventional seed market. These cross-market effects play a significant role in the evaluation of the exercise of market power.

Table 6. Simulated Merger Effects[a]

Sector affected by mergers	Scenarios	Market/Price Affected	Induced price change ($/bag)	Standard Error	t-ratio
ECB (K_2)	1	*ECB* (K_2)	-1.88	2.82	-0.67
RW (K_3)	2	*RW* (K_3)	-3.37	3.21	-1.05
*HT*1 (K_4)	3	*HT*1 (K_4)	19.08***	3.74	5.10
ECB and *RW* (K_2, K_3)	4a	*ECB* (K_2)	-5.99**	3.01	-1.99
	4b	*RW* (K_3)	-25.10***	9.35	-2.68
	4c	*ECB/RW* (K_{23})	-31.09***	10.45	-2.97
ECB and *HT*1 (K_2, K_4)	5a	*ECB* (K_2)	0.33	3.33	0.10
	5b	*HT*1 (K_4)	22.22***	4.52	4.92
	5c	*ECB*/*HT*1(K_{24})	22.55***	6.20	3.64
RW and *HT*1 (K_3, K_4)	6a	*RW* (K_3)	-21.34***	6.30	-3.39
	6b	*HT*1 (K_4)	19.91***	3.62	5.50
	6c	*RW*/*HT*1 (K_{34})	-1.43	6.14	-0.23
Conv. and *ECB* (K_1, K_2)	7	Conventional (K_1)	32.37***	8.93	3.62
Conv. and *RW* (K_1, K_3)	8	Conventional (K_1)	7.87	10.09	0.78
Conv. and *HT*1 (K_1, K_4)	9	Conventional (K_1)	-5.99	10.16	-0.59

[a] Statistical significance is noted by * at the 10 percent level, ** at the 5 percent level, and *** at the 1 percent level.

The simulations in Table 6 illustrate the potential usefulness of the model in studying the effects of changing market concentrations. For example, in a pre-merger analysis, this would involve evaluating the HHIs and GHHIs in all relevant markets before and after a proposed merger with a quantitative assessment of the price effects. Alternatively, the model could be used to estimate the effects of spin-offs by evaluating their anticipated effects on HHIs and GHHIs and by simulating the associated price changes.

Concluding remarks

This paper has presented an analysis of bundle pricing under imperfect competition. A multiproduct Cournot model identifies the role of substitution/ complementarity in bundle pricing. It explains how oligopoly pricing manifests itself, and motivates generalized HHI measures of market concentration. The model is applied to the U.S. corn seed market and estimated using farm-level data from 2000-2007. The U.S. corn seed market represents a unique opportunity to evaluate the pricing of bundled goods, where patented genetic traits are inserted into conventionally bred corn seed either bundled or independently. These GM seeds compete alongside conventional seeds in a spatially diverse farm sector. There is considerable variation in the spatial concentration of conventional seeds and seeds with various patented genetic traits. Through the years of this study, GM seeds have been adopted quickly among U.S. farmers and are part of a broader wave of technological progress impacting the agriculture sector.

The econometric investigation documents the determinants of seed prices, including the effects of bundling and the pricing component associated with imperfect competition. Several major conclusions follow the research findings. First, we find extensive evidence of spatial price discrimination. We observe, *ceteris paribus*, that seed prices vary by state and in a south to north pricing pattern that peaks in the central part of the Corn Belt. This would be consistent with a type of price discrimination pattern that recognizes the inherent productivity of land in the Corn Belt. Second, we find strong evidence of subadditive bundle pricing, thus rejecting standard component pricing. This is consistent with the presence of economies of scope in seed production and/or demand complementarities. Third, we investigated the interactive role of market concentrations with complementarity/substitution effects in the pricing of seeds. Using generalized HHI's, this helps to document how traditional and cross-market effects of imperfect competition can contribute to higher (or lower) seed prices. Our results indicate that Lerner indices for three seed types are positive and statistically significant while prices for one market indicate a pro-competitive environment. Fourth, our simulation of hypothetical mergers produced numerous interesting results. Perhaps most striking is a simulation involving a merger of conventional seed firm with a biotech firm selling seeds traited for ECB. Conventional seed prices provide an important competitive benchmark by which farmers can use to weigh the decision to purchase biotech seed. The simulated merger indicates that the conventional seed price would rise significantly. Such a price increase may be of great concern to policymakers because the impact would contribute to raising the price of the entire corn seed complex.

Our analysis could be extended in several directions. First, it would be useful to explore the implications of bundle pricing and imperfect competition in vertical markets. Second, there is a need for empirical investigations of bundle pricing analyzed jointly with bundling decisions. Third, it would be useful to estimate the separate effects of supply versus demand factors in bundle pricing. But this would require better data (especially on the supply side) to identify these effects separately. Finally, there is a need to explore empirically the economics of bundling applied to other sectors. These appear to be good topic for further research.

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On Pricing and Vertical Organization of Differentiated Products

by

Guanming Shi

and

Jean-Paul Chavas[1]

Abstract: This paper investigates the pricing and vertical organization of differentiated products under imperfect competition. In a multiproduct context, we examine how substitution/complementarity relationships among products and vertical structures relate to the exercise of market power. The analysis is applied to pricing of U.S. soybean seeds from 2000-2007. We consider two vertical structures: vertical integration and licensing. We find evidence that vertical organization has significant effects on prices. These effects vary depending on the institutional setup and the bundling of genetic material. Our analysis indicates that market concentration analyses that neglect vertical structures would fail to capture the linkages between market structure and pricing. The empirical evidence shows that complementarity and economies of scope can mitigate the price-enhancement associated with market power in a multi-market context.

Key Words: Vertical structures, pricing, imperfect competition, seed, biotechnology

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[1] Respectively, Assistant Professor and Professor, Taylor Hall, University of Wisconsin, Madison, WI 53706. Email: gshi@wisc.edu and jchavas@wisc.edu. This research was funded in part by NRI grant #144-QS50 and USDA Hatch grant.

On Pricing and Vertical Organization of Differentiated Products

1. Introduction

The role of imperfect competition in horizontal markets is well understood: high market concentration leads oligopolies to exercise market power and increase output price. Yet, production processes often involve multiple stages, raising the issue of how firms get organized in and across those stages. A large body of literature has developed on the exercise of market power in vertical structures (e.g., Spengler 1950; Hart and Tirole 1990; Ordover, Saloner and Salop 1990; O'Brien and Shaffer 1992; McAfee and Schwartz 1994; De Fontenay and Gans 2005; Lafontaine and Slade 2007; Gans 2007; Rey and Tirole 2008). However, the implications of vertical control have remained a difficult and controversial topic in industrial organization (e.g., Tirole 1992; Whinston 2006). One school of thought (often associated with the University of Chicago) has stressed that greater vertical control can generate efficiency gains. Another school of thought has examined the impact on foreclosure, where reduced competition can induce efficiency losses (e.g., Whinston 2006; Rey and Tirole 2008).

Difficulties in evaluating these effects become even more severe when considering differentiated products. Previous work has circumvented this complication by focusing on monopoly or perfect substitutes in the upstream and/or downstream markets (e.g. Hart and Tirole 1990; Ordover, Saloner and Salop 1990; O'Brien and Shaffer 1992). However, product differentiation is commonly found across vertical channels. This creates two significant challenges. First, there is need to refine our conceptual approach to the economics of vertical structures under imperfect competition and differentiated products. Second, to be useful, the analysis should be empirically tractable.

This paper addresses both challenges. First, it develops a Cournot model of pricing of differentiated products under imperfect competition and different vertical organizations. The analysis shows how substitution/complementarity relationships across vertical channels relate to the price-enhancement associated with market power. It provides a structural representation of price determination with an explicit characterization of the market power component. The Herfindahl-Hirschman index (HHI) has been commonly used to assess horizontal market concentration (e.g., Whinston 2006). We propose a vertical HHI (termed VHHI) that captures how market concentration and vertical organization interact with each other in influencing the market power component in differentiated products pricing. The concept of VHHI was firstly introduced in Gans (2007). Our approach extends Gans (2007) by allowing for both horizontal and vertical product differentiation in final goods. In addition, in contrast with Gans (2007), we do not impose restrictions on the production technology or on trading patterns between upstream and downstream firms. As such, our approach applies under more general conditions.

Second, the usefulness of the approach is illustrated in an econometric application. While the theoretical model motivates the VHHI measures, our econometric analysis involves the empirical estimation of a hedonic linear pricing equation where our VHHI's capture imperfect competition across both horizontal and vertical markets. The empirical analysis focuses on the U.S. soybean seed industry. In this application, the upstream firm develops the seed production technology (e.g., a biotech firm developing patented biotech seeds by inserting genetic material in the basic seed germplasm), and the downstream firm uses the upstream technology to produce and sell the seeds to farmers. The recent biotechnology revolution has contributed to both a rise in market concentration and a rapid increase in patenting of genetic material. Seed patenting by biotech firms has created new opportunities for product differentiation and price discrimination under alternative vertical structures.

The advances in agricultural biotechnology have also led to the bundling of patented genetic traits, where multiple traits are stacked within a seed. Our analysis investigates the nature of bundle pricing in the U.S. soybean biotech seed industry.[2] To our knowledge, previous literature has not studied how bundling behavior and pricing can vary under alternative vertical structures. Our empirical investigation provides new and useful insights into the interactions between bundle pricing and vertical organization.

The soybean seed market makes an excellent case study for three reasons. First, a flurry of mergers since the 1980s led a few large biotech firms to dominate the U.S. soybean seed industry (Fernandez-Cornejo 2004). The top four largest firms accounted for 40% of the soybean seed market in the late 1980s, a substantial rise from 5.2% in 1980 (Fernandaz-Cornejo 2004). Our data show that this percentage further increased to 55% in 2007, and all are vertically integrated biotech/seed companies. As noted by Graff, Rausser and Small (2003), these mergers have been motivated in part by the complementarities of assets within and between the agricultural biotechnology and seed industries. This means that seed markets may be highly concentrated due to the efficiency gains obtained from vertical and horizontal integration (e.g., due to economies of scope in the production of genetic traits). But market power by biotech firms can also be used to increase seed prices, leading to adverse effects on economic efficiency and farmers' profits (e.g., Fulton and Giannakas 2001; Fernandez-Cornejo 2004).

[2] The economic literature has analyzed three types of bundle pricing: component pricing where the price of a product is set equal to the sum of the value of its components; pure bundling where consumers are restricted to choose between either a fixed bundle of components or nothing at all; and mixed bundling where products are offered both bundled and unbundled, each being priced separately (e.g., Adams and Yellen 1976; McAfee et al. 1989; Whinston 1990).

Second, vertical structures in the U.S. soybean seed industry have been changing due to firm's merger/acquisition behavior. While the licensing of biotech seeds remains dominant, biotech firms have increased their use of vertical control through integration. Our data show that, in the US single-trait soybean seed market, vertical integration has increased from 13% of the market in 2000 to 26% in 2007. This raises the questions: Are these changes motivated by efficiency gains? Or are they reflecting attempts to increase market power? These questions suggest a need to investigate empirically the economics of pricing of differentiated products under alternative vertical structures.

Finally, the biotechnology revolution has stimulated the development of product differentiation involving patented genetic material. Our analysis of the soybean seed market helps assess the pricing implications of alternative forms of product differentiation. In addition, the seeds can differ by the institutional setup of providers. The U.S. soybean seed industry has experienced a rapid shift from public sector breeding to private sector breeding since the 1970s. The acreage share of publicly developed varieties decreased from over 70% in 1980 to 10% in the mid-1990s (Fernandez-Cornejo 2004), and is 0.5% in 2007 according to our data.[3] Such changes were caused in large part by advances in breeding technology (including biotechnology) and changes in the intellectual property protection of life forms since the 1980s. At this point, the implications of such institutional changes for pricing are not well understood. Our study provides new and useful information of these effects.

Our econometric analysis examines the nature of product differentiation and pricing. The empirical evidence shows how the interaction of market concentration and vertical organization relate to the market power component associated with soybean seed prices. It finds that such

[3] However, within the conventional seed market, public sourced soybean seed varieties still account for around 10% of the acreage in 2007.

relationships vary with the vertical organization and the institutional setup of the seed providers. As expected, we find that publicly sourced seeds are priced significantly lower than privately sourced seeds. We uncover evidence that complementarity and economies of scope can mitigate the price-enhancement of market power in the privately sourced seed market. Our empirical analysis indicates that market concentration analyses that neglect vertical structures (e.g., using a traditional HHI) would fail to capture the linkages between market structure and pricing. We find that seeds sold through vertically integrated structure are priced higher than those through licensing. In addition, we fail to reject component pricing under licensing. But we strongly reject component pricing under vertical integration, where the evidence points to sub-additive pricing.

The paper is organized as follows. Section 2 presents a conceptual framework of multiproduct pricing under imperfect competition. It develops a Cournot model that motinvates the VHHIs capturing imperfect competition in both vertical and horizontal markets. Sections 3 and 4 present an econometric application to the U.S. soybean seed market, where the relationship between VHHIs and the market power component is empirically investigated. The estimation method and econometric results are discussed in section 5. Sections 6 and 7 report the empirical findings and evaluate their implications. Finally, section 8 concludes.

2. The Model

Consider a market involving a set $\mathbf{N} = \{1, \ldots, N\}$ of N firms producing a set $\mathbf{K} = \{1, \ldots, K\}$ of K outputs. The production and marketing of outputs involve upstream technology/input markets under V alternative vertical structures (e.g., vertical contract, ownership). Denote by $\mathbf{y}^n = (y_{11}^n, \ldots, y_{k\tau}^n, \ldots, y_{KV}^n\} \in \Re_+^{KV}$ the vector of outputs produced by the n-th firm, $y_{k\tau}^n$ being the k-th output produced by the n-th firm under the τ-th vertical structure, $k \in \mathbf{K}$, $n \in \mathbf{N}$, $\tau \in \mathbf{V} \equiv \{1, \ldots, V\}$. We assume that the vertical structures can support price discrimination schemes. In other words, through different labeling or packaging, prices for a given product are allowed to vary across vertical structures. In this context, the price-dependent demand for the *k*-th output under the *τ*-th vertical structure is $p_{k\tau}(\sum_{n\in\mathbf{N}}\mathbf{y}^n)$.

Each firm maximizes profit across all marketing channels. We assume the existence of contracts (implicit or explicit) between the upstream technology provider and the downstream firm. Such contracts mean that production and marketing decisions are made efficiently so as to maximize firm profit in the vertical channel.[4] In this context, we want to examine how the exercise of market power can affect both horizontal and vertical markets. The profit of the *n*-th firm is $\sum_{k\in\mathbf{K}}\sum_{\tau\in\mathbf{V}}[p_{k\tau}(\sum_{n\in\mathbf{N}}\mathbf{y}^n)\cdot y_{k\tau}^n]-C_n(\mathbf{y}^n)$, where $C_n(\mathbf{y}^n)$ denotes the *n*-th firm's cost of producing $\mathbf{y}^n$. Assuming a Cournot game and under differentiability, the profit maximizing decision of the *n*-th firm for the *k*-th output in the *τ*-th vertical structure $y_{k\tau}^n$ satisfies

$$p_{k\tau}+\sum_{m\in\mathbf{K}}\sum_{u\in\mathbf{V}}\tfrac{\partial p_{k\tau}}{\partial y_{mu}^n}y_{k\tau}^n-\tfrac{\partial C_n}{\partial y_{k\tau}^n}\leq 0, \tag{1a}$$

$$y_{k\tau}^n\geq 0, \tag{1b}$$

$$[p_{k\tau}+\sum_{m\in\mathbf{K}}\sum_{u\in\mathbf{V}}\tfrac{\partial p_{k\tau}}{\partial y_{mu}^n}y_{k\tau}^n-\tfrac{\partial C_n}{\partial y_{k\tau}^n}]y_{k\tau}^n=0. \tag{1c}$$

Equation (1c) is the complementary slackness condition which applies whether the *k*-th output is produced by the *n*-th firm in the *τ*-th vertical structure ($y_{k\tau}^n > 0$) or not ($y_{k\tau}^n = 0$). Equation (1c) remains valid whether or not the *n*-th firm produces the *k*-th output, i.e. it applies no matter how many of the *K* products the firm chooses to sell. And equation (1c) holds irrespective of the vertical structure chosen by the *n*-th firm in marketing its products. It means that, under imperfect competition, equation (1c) allows for situations where the actions of one firm can restrict the involvement of other firms in given vertical markets. As such, it can

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4 Note that the presence of efficient vertical contracts rules out vertical externalities. Taking into consideration the effects of vertical externalities is briefly discussed in footnote 6.

represent foreclosure strategies that have been the subject of much scrutiny (e.g., Ordover, Saloner, and Salop 1990; Whinston 2006; Rey and Tirole 2008).

We assume that the cost function takes the form $C_n(\mathbf{y}^n) = F_n(\mathbf{R}_n) + \sum_{k\in\mathbf{K}}\sum_{\tau\in\mathbf{V}} c_{k\tau} y_{k\tau}^n + 0.5\sum_{k,m\in\mathbf{K}}\sum_{\tau,u\in\mathbf{V}} c_{mk,u\tau} y_{mu}^n y_{k\tau}^n$, where $\mathbf{R}_n = \{(j,\tau)\text{: } y_{j\tau}^n > 0, j\in\mathbf{K}, \tau\in\mathbf{V}\}$ is the set of positive outputs produced by the n-th firm. Here, $F_n(\mathbf{R}_n) \geq 0$ denotes fixed cost that satisfies $F_n(\varnothing) = 0$, and $\sum_{k\in\mathbf{K}}\sum_{\tau\in\mathbf{V}} c_{k\tau} y_{k\tau}^n + 0.5\sum_{k,m\in\mathbf{K}}\sum_{\tau,u\in\mathbf{V}} c_{mk,u\tau} y_{mu}^n y_{k\tau}^n$ denotes variable cost. Note that the presence of fixed costs (where $F_n(\mathbf{R}_n) > 0$ for $\mathbf{R}_n \neq \varnothing$) can imply increasing returns to scale. Then, marginal cost pricing would imply negative profit and any sustainable equilibrium must be associated with departures from marginal cost pricing. Note that the fixed cost $F_n(\mathbf{R}_n)$ can have two sources: the fixed cost associated with the upstream technology (e.g., the R&D cost of developing new products in the upstream technology); and the fixed cost associated with the downstream firm (e.g., the setup cost of establishing a vertical structure).

In addition, the cost $C_n(\mathbf{y}^n)$ can represent economies of scope. This can come from both the variable cost as well as the fixed cost. Indeed, economies of scope can arise in the presence of complementarity among outputs, i.e., when $\frac{\partial^2 C_n(y^n)}{\partial y_{ju}^n \, \partial y_{k\tau}^n} < 0$ and output y_{ju}^n reduces the marginal cost of $y_{k\tau}^n$ for $j \neq k$ and $u \neq \tau$ (Baumol et al. 1982, p. 75). And it can arise when fixed cost $F_n(\mathbf{R}_n)$ satisfies $F_n(\mathbf{R}^a) + F_n(\mathbf{R}^b) > F_n(\mathbf{R}^a \cup \mathbf{R}^b)$ for some $\mathbf{R}^a \subset \mathbf{K}\cup\mathbf{V}$ and $\mathbf{R}^b \subset \mathbf{K}\cup\mathbf{V}$, i.e. when the joint provision of $\mathbf{y}^a = \{y_{ju}^n : (j,u) \in \mathbf{R}^a\}$ and $\mathbf{y}^b = \{y_{ju}^n : (j,u) \in \mathbf{R}^b\}$ reduces fixed cost (Baumol et al., 1982, p. 75). This can apply to the upstream technology (e.g., R&D investment contributing to the joint production of $\mathbf{y}^a$ and $\mathbf{y}^b$) as well as the downstream technology (e.g., the cost of establishing alternative vertical structures). In the first case, efficiency gains would be obtained from the joint development of technology used to produce outputs $\mathbf{y}^a$ and $\mathbf{y}^b$. In the second case, efficiency gains could be generated from producing and selling multiple products in multiple vertical structures.

While these arguments make it clear that our approach can capture efficiency gains, how does it represent the exercise of market power? Let $\frac{\partial p_{mu}}{\partial y_{k\tau}} = \alpha_{mk,u\tau}$ with $\alpha_{mm,uu} < 0$. The marginal cost of $y^n_{k\tau}$ is $\frac{\partial C_n(\mathbf{y}^n)}{\partial y^n_{k\tau}} = c_{k\tau} + \sum_{m\in\mathbf{K}}\sum_{u\in\mathbf{V}} c_{mk,u\tau} y^n_{mu}$, with $c_{mm,uu} \geq 0$ and $c_{mk,u\tau} = c_{km,\tau u}$. Let $Y_{m\tau} = \sum_{n\in N} y^n_{m\tau}$ be the aggregate output of the m-th product in the τ-th vertical structure, $m\in\mathbf{K}$, $\tau\in\mathbf{V}$. Assuming that $Y_{k\tau} > 0$, define $S^n_{k\tau} = \frac{y^n_{k\tau}}{Y_{k\tau}} \in [0, 1]$ as the market share of the n-th firm for the k-th product in the τ-th vertical structure. Dividing equation (1c) by $Y_{k\tau}$ and summing across all $n \in \mathbf{N}$ yield

$$p_{k\tau} = c_{k\tau} + \sum_{m\in\mathbf{K}}\sum_{u\in\mathbf{V}} (c_{mk,u\tau} - \alpha_{mk,u\tau}) \sum_{n\in\mathbf{N}} s^n_{mu} s^n_{k\tau} Y_{mu}\,, \tag{2}$$

which can be alternatively written as

$$p_{k\tau} = c_{k\tau} + \sum_{m\in\mathbf{K}}\sum_{u\in\mathbf{V}} (c_{mk,u\tau} - \alpha_{mk,u\tau}) H_{mk,u\tau} Y_{mu}\,, \tag{3}$$

where $H_{mk,u\tau} = \sum_{n\in\mathbf{N}} s^n_{mu} s^n_{k\tau}$, with $m, k \in \mathbf{K}$ and $u, \tau \in \mathbf{V}$.

Equation (3) is a pricing equation for the k-th product in the τ-th vertical structure. It includes the term

$$M_{k\tau} = \sum_{m\in\mathbf{K}}\sum_{u\in\mathbf{V}} (c_{mk,u\tau} - \alpha_{mk,u\tau}) H_{mk,u\tau} Y_{mu}\,. \tag{4}$$

$M_{k\tau}$ in (4) is associated with the exercise of market power. To see that, note that $H_{mk,u\tau} \in [0, 1]$, and that $H_{mk,u\tau} \to 0$ under perfect competition (when the number of active firms is large). It follows that $M_{k\tau} \to 0$ under perfect competition. At the other extreme, $H_{mk,u\tau} = 1$ under monopoly (when there is a single active firm). In general, $H_{mk,u\tau}$ increases with market concentration. This means that the term $M_{k\tau}$ in (4) is the component of the pricing equation (3) which captures the effects of imperfect competition. As such, $M_{k\tau}$ provides a convenient measure of the market power component of price. We will make extensive use of equations (3) and (4) in our analysis below.

Equation (4) provides useful information on the structural determinants of $M_{k\tau}$. When there is a single product (K = 1) and a single vertical structure (V = 1), note that $H_{11,11}$ is the traditional Herfindahl-Hirschman index (HHI) providing a measure of market concentration. The HHI is commonly used in the analysis of the exercise of market power (e.g., Whinston 2006). Given positive marginal cost ($c_{11,11} \geq 0$) and negative demand slope ($\alpha_{11,11} < 0$), equations (3)-(4) indicate that an increase in the HHI, $H_{11,11}$, (simulating an increase in market power) is associated with an increase in M_{11}, and thus an increase in price, p_{11}. As a rule of thumb, regulatory agencies have considered that $H_{11,11} > 0.1$ corresponds to concentrated markets where the exercise of market power can potentially raise competitive concerns (e.g., Whinston 2006).

Equations (2)-(4) extend the HHI to a multi-product context (when $K > 1$) and under various vertical structures (when $V > 1$). They define $H_{mk,u\tau}$ as a vertical Herfindahl-Hirschman index (VHHI). When $m \neq k$ and $u = \tau$, it shows that a rise in the "cross-market" VHHI $H_{mk,\tau\tau}$ would be associated with an increase (a decrease) in price if $[c_{mk,\tau\tau} - \alpha_{mk,\tau\tau}] > 0$ (< 0). Since $\alpha_{mk,\tau\tau} = \frac{\partial p_{m\tau}}{\partial y^n_{k\tau}}$ and following Hicks (1939), note that $\alpha_{mk,\tau\tau} < 0$ (> 0) when products m and k are substitutes (complements) on the demand side, corresponding to situations where increasing $y^n_{k\tau}$ tends to decrease (increase) the marginal value of $y^n_{m\tau}$. Similarly, $c_{mk,\tau\tau} = \frac{\partial^2 C_n(y^n)}{\partial y^n_{m\tau} \partial y^n_{k\tau}} > 0$ (< 0) when products m and k are substitutes (complements) on the supply side, corresponding to situations where increasing $y^n_{k\tau}$ tends to increase (decrease) the marginal cost of $y^n_{m\tau}$. Note that the complementary case (where $c_{mk,\tau\tau} < 0$) generates economies of scope (Baumol et al. 1982, p. 75), where multi-output production contributes to reducing cost. It follows that the term $[c_{mk,\tau\tau} - \alpha_{mk,\tau\tau}]$ would be positive when $y^n_{m\tau}$ and $y^n_{k\tau}$ behave as substitutes on both the supply and demand side. And it would be negative when $y^n_{m\tau}$ and $y^n_{k\tau}$ behave as complements on both the supply and demand side. From equations (3) and (4), it follows that the qualitative effects of the market concentration terms $H_{mk,\tau\tau}$ on $M_{k\tau}$ and on price, $p_{k\tau}$, depend on the nature of substitution or complementarity among outputs (through the terms $[c_{mk,\tau\tau} - \alpha_{mk,\tau\tau}]$).[5] A rise in $H_{mk,\tau\tau}$ would contribute to an increase (a decrease) in $M_{k\tau}$ when two products within a vertical channel ($y_{k\tau}$ and $y_{m\tau}$) are substitutes (complements).

Of special interest here are the effects of vertical structures on pricing. Consider the case where $u \neq \tau$ and $k = m$. Then, equations (3) and (4) also show how vertical structures influence prices. They show that a rise in VHHI $H_{kk,u\tau}$ would be associated with an increase (a decrease) in $M_{k\tau}$ if $[c_{kk,u\tau} - \alpha_{kk,u\tau}] > 0$ (< 0).[6] This indicates that, for a given product *k*, the sign of $[c_{kk,u\tau} - \alpha_{kk,u\tau}]$ affects the nature and magnitude of departure from competitive pricing. As just discussed, we expect $[c_{kk,u\tau} - \alpha_{kk,u\tau}] > 0$ (< 0) when product *k* exhibits substitution (complementarity) across vertical structures *u* and *τ*. Thus the terms $H_{kk,u\tau}$'s in equations (3)-(4) show how the nature of substitution or complementarity across vertical structures influences the

[5] Note that identifying the role of substitution/complementarity in the exercise of market power is not new (e.g., Tirole 1992; Venkatesh and Kamakura 2003; Whinston 2006; Rey and Tirole 2008). What is new here is the explicit linkage of substitution/complementarity with our VHHI's measures.

[6] This is an extension of the analysis presented by Gans (2007) to cover differentiated products.

effects of market concentration on prices. It indicates that a rise in $H_{kk,u\tau}$ would contribute to an increase (a decrease) in $M_{k\tau}$ when the *k*-th product across two vertical channels (y_{ku} and $y_{k\tau}$) are substitutes (complements).[7]

Are there conditions under which vertical structures would have no effect on prices? As shown below, this would occur if products were perfect substitutes across vertical structures on the demand side as well as on the supply side. Perfect substitution on the supply side corresponds to situations where the cost function takes the form $C_n(\mathbf{y}^n) = C_n(\sum_{\tau\in\mathbf{V}} y^n_{1\tau},\ldots,\sum_{\tau\in\mathbf{V}} y^n_{K\tau})$, implying that $c_{k\tau} = c_k$ and $c_{mk,u\tau} = c_{mk}$ for $k \in \mathbf{K}$ and τ and $u \in \mathbf{V}$. Similarly, perfect substitution on the demand side corresponds to situations where $\frac{\partial p_{mu}}{\partial y_{k\tau}} \equiv \alpha_{mk,u\tau} = \alpha_{mk}$ for $k, m \in \mathbf{K}$ and all $u, \tau \in \mathbf{V}$. These restrictions are testable hypotheses that can be used to evaluate the effects of vertical structures on pricing. We will investigate these hypotheses in our empirical analysis presented in sections 4 and 5.

Denote the aggregate market share of the *n*-th firm for the *k*-th product by $S^n_k = \frac{\sum_{\tau\in\mathbf{V}} y^n_{k\tau}}{Y_k} \in [0, 1]$, where $Y_k \equiv \sum_{\tau\in\mathbf{V}}\sum_{n\in\mathbf{N}} y^n_{k\tau} > 0$. Under conditions of perfect substitution across vertical structures (where $c_{k\tau} = c_k$, $c_{mk,u\tau} = c_{mk}$ and $\alpha_{mk,u\tau} = \alpha_{mk}$), the law of one price would apply across vertical organizations, with $p_{k\tau} = p_k$ for all $\tau \in \mathbf{V}$. Multiplying equation (2) or (3) by $\frac{Y_{m\tau}}{Y_m}$ and summing across τ gives

$$p_k = c_k + \sum_{m\in\mathbf{K}} [c_{km} - \alpha_{km}] \cdot H_{mk} \cdot Y_m\,, \tag{3'}$$

[7] Our analysis implicitly assumes that vertical contracts are efficient. Possible inefficiencies in vertical contracts have been discussed (e.g., Spengler 1950; Tirole 1992). They include situations of "double marginalization" where a failure to deal with vertical externalities can induce a reduction in perceived demand and inefficient price enhancements. Note that, in our case, such reductions in perceived demand could be captured by changes in the demand slope parameters α's.

for $k \in \mathbf{K}$, where $H_{mk} = \sum_{n\in\mathbf{N}} S_m^n \cdot S_k^n$. Under equation (3'), the market power component of price given in equation (4) would become

$$M_k = \sum_{m\in\mathbf{K}} (c_{km} - \alpha_{km}) \cdot H_{mk} \cdot Y_m \,. \tag{4'}$$

Comparing (4) and (4'), there exists a close relationships between $H_{mk} \equiv \sum_{n\in\mathbf{N}} S_m^n S_k^n$ and our VHHI's $H_{mk,u\tau} = \sum_{n\in\mathbf{N}} s_{mu}^n s_{k\tau}^n$. The general relationship is: $H_{mk} = \sum_{u\in\mathbf{V}} \sum_{\tau\in\mathbf{V}} H_{mk,u\tau} \frac{Y_{mu}}{Y_m} \frac{Y_{k\tau}}{Y_k}$, showing that H_{mk} is a weighted average of our VHHI's $H_{mk,u\tau}$, with market shares as weights.

Taking the analysis one step further, what would happen to equation (3) or (3') if horizontal products were also perfect substitutes? Following the same arguments, this would imply that $c_k = c_0$, $c_{km} = c$ and $\alpha_{km} = \alpha$. Then, under perfect substitution across all products, the law of one price would apply, with $p_{k\tau} = p$ for all $k \in \mathbf{K}$ and all $\tau \in \mathbf{V}$. Then, letting $Y = \sum_{m\in\mathbf{K}} Y_m$, multiplying the right-hand side of (3') by $\frac{Y_m}{Y}$ and summing over $m \in \mathbf{K}$ would give

$$p = c_0 + [c - \alpha] \cdot H \cdot Y \,, \tag{3''}$$

where $H \equiv \sum_{n\in\mathbf{N}} (w^n)^2$, $w^n = \frac{\sum_{m\in\mathbf{K}} \sum_{u\in\mathbf{V}} y_{mu}^n}{Y}$ being the n-th firm overall market share. Under equation (3''), the market power component of price given in equation (4) or (4') would become

$$M = [c - \alpha] \cdot H \cdot Y \,, \tag{4''}$$

In this case, note that H is the standard HHI providing a measure of overall market concentration. And it satisfies $H = \sum_{m\in\mathbf{K}} \sum_{k\in\mathbf{K}} H_{km} \frac{Y_k}{Y} \frac{Y_m}{Y} = \sum_{m\in\mathbf{K}} \sum_{k\in\mathbf{K}} \sum_{u\in\mathbf{V}} \sum_{\tau\in\mathbf{V}} H_{km,u\tau} \frac{Y_{ku}}{Y} \frac{Y_{m\tau}}{Y}$, i.e. it is a weighted average of our VHHI's $H_{mk,u\tau}$. This makes it clear that when all products are perfect substitutes, our approach reduces to a single market analysis and to the HHI approach commonly found in the literature (e.g., Whinston 2006). It also shows how our VHHI generalizes previous analyses in the presence of product differentiation (when products are not perfect substitutes). It identifies the role of substitution/complementarity among products and their effects on pricing under imperfect competition. Importantly, our generalization allows for product differentiation both in horizontal and vertical organizations.

Besides being consistent with Cournot-imperfect competition, equation (3) provides a convenient basis for supporting an empirical analysis of how market power gets exercised in vertical channels involving differentiated products. Below, this is used to analyze the pricing implications of product differentiation, bundling and vertical structures in the U.S. soybean seed industry.

3. Data

Our analysis relies on an extensive data set providing detailed information on the U.S. soybean seed market. The data were collected by **dmr**kynetec [hereafter dmrk]. The dmrk data come from a stratified sample of U.S. soybean farmers surveyed annually from 2000 to 2007.[8] The survey provides farm-level information on seed purchases, acreage, seed types, and seed prices. It was collected using computer assisted telephone interviews.

Since farmers typically buy their seeds locally, and seeds suitable for planting in the local market are often different across regions, our analysis defines the "local market" at the Crop Reporting District (CRD)[9] level. To guarantee reliable measurement of market concentrations, our analysis focuses on those CRDs with more than ten farms sampled every year between 2000 and 2007. The data contain 76,308 observations from 76 CRDs in 18 different states.[10] On

8 The survey is stratified to over-sample producers with large acreage.

9 A crop-reporting district (CRD) is defined by the U.S. Department of Agriculture to reflect local agro-climatic conditions. In general, a CRD is larger than a county but smaller than a state.

10 They are: AR, IL, IN, IA, KS, KY, LA, MI, MN, MS, MO, NE, NC, ND, OH, SD, TN, and WI.

average, around 3000 farmers are included in the sample every year, of which between 30-50% remain in the sample for the next year.[11]

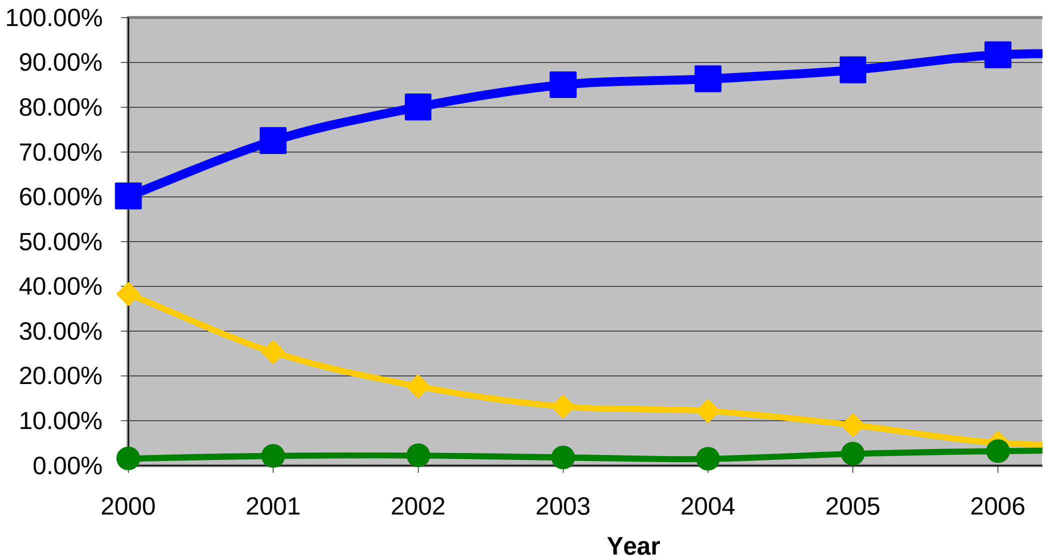
Currently the only available gene/trait technology in the biotech soybean seed market is the herbicide tolerance (*HT*) trait designed to reduce yield loss from competing plants (weeds). There are two major *HT* traits, labeled here as *HT*1 and *HT*2. These traits are owned by different biotech companies, which also own subsidiary seed companies. Some biotech seeds contain only one of these traits, while some bundle both *HT*1 and *HT*2 traits (also called "double stacking").

Figure 1 shows the evolution of soybean acreage shares reflecting adoption rates in the US from 2000 to 2007, for conventional seed, single-trait biotech seed, and double-stacking biotech seed. The conventional seed's acreage share has decreased rapidly: from 38.3% in 2000 to 4.6% in 2007. The single-trait biotech seeds dominate the market, with over 90% in acreage share since 2006.

Typically, the biotech seeds can be distributed by seed companies affiliated with the biotech companies who own that trait, and/or by those not affiliated. According to patent law, if a non-affiliated seed company wants to produce a seed with the patented trait, it needs to obtain a license from the patent owner, the related biotech company. This licensing requirement does not apply to the affiliated seed companies. We consider two vertical structures, $\mathbf{V} = \{v, \ell\}$, v corresponding to *vertical integration* (where the seed company is affiliated with the related biotech firm) and ℓ corresponding to *licensing* (where seeds are sold to farmers by a non-affiliated seed company under a license agreement with a biotech firm).

Figure 1. Soybean seed adoption rates in the US, acreage share, 2000 – 2007.

[11] Thus, the dmrk survey is not a true panel as the farm composition of the sample changes over time.



Noting that single-trait seeds dominate the U.S. soybean seed market, figure 2 illustrates the evolving acreage share of *licensing* versus *vertical integration* for single trait seeds from 2000 to 2007. It shows that the proportion of the vertically integrated seed has increased from 13% of the market in 2000 to 26% in 2007. Among farmers who adopted at least some biotech seeds in 2007, 57% purchased the biotech seeds only via the licensed channel, while 16% bought seeds only via the integrated channel, and 27% bought their seeds partly from the licensed channel and partly from the integrated channel. This last category indicates that the two vertical structures are perceived as producing differentiated products.

Figure 2. Vertically integrated vs. licensed single trait seeds, acreage share 2000-2007.

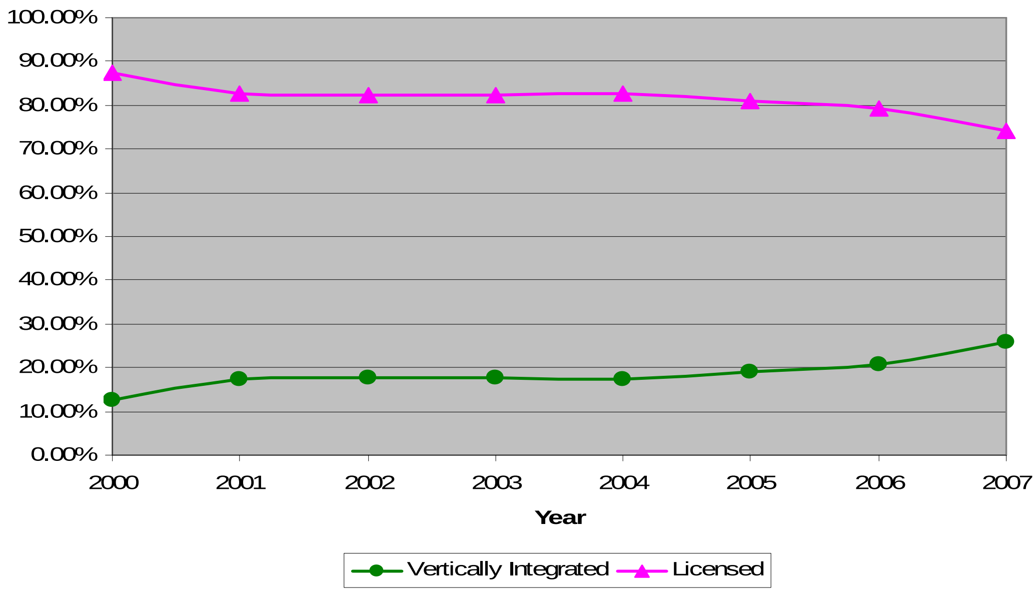
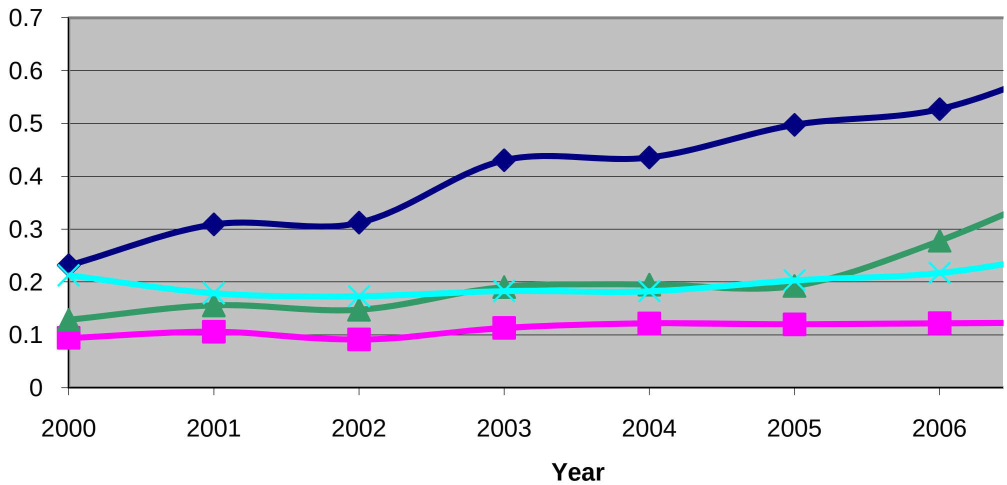


Figure 3 illustrates the time trend in the constructed VHHIs involving the conventional seed market (denoted by subscript 1) and the single trait *HT*1 market (dented by subscript 2). Market concentration in the conventional seed market ($H_{11,\ell\ell}$) increased substantially over the years: from 0.231 in 2000 to 0.623 in 2007. The cross market concentration between vertically integrated *HT*1 market and the conventional seed market ($H_{12,\ell v}$) also increased steadily since 2000 and at a faster rate since 2005: from 0.128 in 2000 to 0.192 in 2005 and then to 0.395 in 2007. The market concentration in licensed *HT*1 market ($H_{22,\ell\ell}$) and the cross market concentration between licensed *HT*1 market and the conventional seed market ($H_{12,\ell\ell}$) do not show dramatic changes over the year.

Figure 3. VHHI's over time, 2000 – 2007



4. Econometric specification

Our analysis of the soybean seed prices builds on equation (3). As derived, equation (3) is a structural equation reflecting the determinants of pricing under imperfect competition of differentiated products under alternative vertical structures. As noted above, we focus our attention on the case of two vertical structures: *vertical integration*, *v*, and *licensing*, ℓ, and four seed types, each with genetic traits that can be present either individually or bundled/stacked together. Let $T_k \in \{0, 1\}$ be dummy variables for seed types, satisfying $T_k = 1$ for the *k*-th seed type and $T_k = 0$ otherwise, $k \in \mathbf{K} = \{1, \ldots, 4\}$, with $\sum_{k=1}^{4} T_k = 1$: conventional ($T_1 = 1$), single trait *HT*1 ($T_2 = 1$), single trait *HT*2 ($T_3 = 1$), and bundling/stacking of *HT*1 and *HT*2 ($T_4 = 1$). Let $D_\tau \in \{0, 1\}$ be dummy variables for vertical structures, satisfying $D_\tau = 1$ for the τ-th vertical structure and $D_\tau = 0$ otherwise, $\tau \in \mathbf{V} = \{\ell, v\}$.

Note that our analysis allows cost (both fixed and variable) to vary across vertical structures. Under vertical integration, R&D fixed cost can be recovered directly by the integrated firm but the biotech firm may possibly face a higher cost of integration. Under licensing, a royalty fee is paid by the seed company to the biotech firm to help it recover its R&D investment. In general, the two vertical structures can vary both in terms of efficiency (e.g., which structure has lower cost?) and in terms of the exercise of market power. Also, both assessments can be affected by the multi-product nature of the market. For example, the presence and magnitude of economies of scope can vary between vertical structures. As discussed above, the presence of complementarity (or substitution) across vertically differentiated products can reduce (enhance) the firms' ability to exercise market power. The empirical analysis presented below will shed some light on these issues.

We start with a standard hedonic pricing model where the price of a good varies with its characteristics (e.g., following Rosen 1974). Consider the hedonic equation representing the determinants of the price p for a seed of type k sold in the τ-th vertical structure

$$\begin{aligned} p_{k\tau} &= \beta_{k\tau} + \sum_{m\in\mathbf{K}} \sum_{u\in\mathbf{V}} \delta_{m\tau} T_m D_u + \boldsymbol{\varphi}\mathbf{X} + \varepsilon_{k\tau} \\ &= \beta_{k\tau} + \delta_{k\tau} + \boldsymbol{\varphi}\mathbf{X} + \varepsilon_{k\tau}, \end{aligned} \tag{5a}$$

where $\mathbf{X}$ is a vector of other relevant covariates, and $\varepsilon_{\kappa\tau}$ is an error term with mean zero and finite variance. The specification (5a) allows prices to vary across seed types as well as across vertical structures.

As shown in equation (3), we introduce market power effects in (5a) by specifying

$$\beta_{k\tau} = \beta_0 + \sum_{m\in\mathbf{K}} \sum_{u\in\mathbf{V}} \beta_{mk,u\tau} H_{mk,u\tau} Y_{mu} T_k D_\tau , \tag{5b}$$

where $\beta_{mk,u\tau} = [\, c_{mk,u\tau} - \alpha_{mk,u\tau} \,]$ and $H_{mk,u\tau} = \sum_{n\in\mathbf{N}} s_{mu}^n s_{k\tau}^n$ is the VHHI, s_{mu}^n being the market share of the n-th firm in the market for the m-th seed type under the u-th vertical structure. Since $H_{mk,u\tau} = 0$ under competitive conditions, it follows from (5b) that that the exercise of market power in (5a)-(5b) is given by

$$M_{k\tau} = \sum_{m\in\mathbf{K}} \sum_{u\in\mathbf{V}} \beta_{mk,u\tau} H_{mk,u\tau} Y_{mu} T_k D_\tau , \tag{6}$$

where $M_{k\tau} = 0$ under perfect competition. Equation (6) provides a convenient measure of the effect of imperfect competition under various vertical structures.

Since the conventional seed does not need to add any additional biotech trait, we assume, for convenience, that the vertical structure for the conventional seed is "un-integrated" only (ℓ).

To illustrate, from (5a)-(5b), the equation estimated for conventional seeds ($T_1 = 1$) is

$$p_{1\ell} = \beta_0 + \sum\nolimits_{m\in\mathbf{K}} (\beta_{m1,\ell\ell} H_{m1,\ell\ell} Y_{m\ell} + \beta_{m1,v\ell} H_{m1,v\ell} Y_{mv}) T_1 D_\ell + \delta_{1\ell} + \boldsymbol{\varphi}\mathbf{X} + \varepsilon_{1\ell} ,$$

And for *HT*1 seed ($T_2 = 1$), the price equations for licensed and integrated seeds are

$$p_{2\ell} = \beta_0 + \sum\nolimits_{m\in\mathbf{K}} (\beta_{m2,\ell\ell} H_{m2,\ell\ell} Y_{m\ell} + \beta_{m2,v\ell} H_{m2,v\ell} Y_{mv}) T_2 D_\ell + \delta_{2\ell} + \boldsymbol{\varphi}\mathbf{X} + \varepsilon_{2\ell} ,$$

$$p_{2v} = \beta_0 + \sum\nolimits_{m\in\mathbf{K}} (\beta_{m2,\ell v} H_{m2,\ell v} Y_{m\ell} + \beta_{m2,vv} H_{m2,vv} Y_{mv}) T_2 D_v + \delta_{2v} + \boldsymbol{\varphi}\mathbf{X} + \varepsilon_{2v} .$$

Similar equations can be written for *HT*2 seed ($T_3 = 1$) and for the bundled/stacked seed ($T_4 = 1$). However, the numbers of observations of T_3 and T_4 seed types are not sufficient in our sample for obtaining reliable measures of the VHHIs. Given these data limitations, for these two seed types, we examine only how prices vary across characteristics and vertical structures.

Each CRD is assumed to represent the relevant market area for each transaction; thus, all VHHI terms are calculated at that level. Each purchase observation is at the farm-variety level. The price p in equation (5a) is the net seed price paid by farmers (in $ per 50lb bag).

The relevant covariates **X** include location, year dummies, each farm's total corn acreage, and binary terms capturing alternative purchase sources. Farmers can choose different sources for different seed varieties. Including source of purchase as an explanatory variable in (4a) captures possible price discrimination schemes affecting the seed price paid by farmers. The location variables are defined as state dummy variables, reflecting spatial heterogeneity in cropping systems, weather patterns, and yield potentials. Year dummies are included to capture advances in genetic technology, changes in agricultural markets and other structural changes over time. Farm acreage catches possible price discrimination related to bulk purchase.

We also include entry and exit dummies for a seed if it is the first year it is observed in the market (*Entry* = 1), or if it is the last year it remains in the market (*Exit* = 1). This captures potential strategic pricing where firms may lower the price of a seed to speed up its adoption (for a new seed), and to slow down the disadoption of obsolete seed (for an old seed that is about to be withdrawn from the market).

Finally, as mentioned in section 3, the soybean industry has experienced a transition from publicly bred varieties to privately bred varieties since the 1980s. Our model is based on profit maximizing multi-product firms. This may not be appropriate for analyzing the behavior of public breeders. In our data, almost all observations of public-sourced seeds are conventional seeds. The nature of pricing in the public sector is expected to differ from the private sector. On that basis, we introduce a dummy variable capturing the role of the institutional structure: *Pub* = 1 for public sector, and *Pub* = 0 for private sector. We include the dummy variable *Pub* as both an intercept shifter and a slope shifter in equation (5b).

5. Econometric estimation

Table 1 reports summary statistics of key variables used in the analysis. As discussed above, the VHHIs are evaluated at the CRD level. The mean value of conventional seed HHI, $H_{11,\ell\ell}$, is 0.412, more than twice the Department of Justice's threshold of 0.18 for identifying "significant market power". Biotech seeds in the licensed channel exhibit greater competition than the conventional seed, with a mean value of $H_{22,\ell\ell}$ at 0.201. We observe significant changes in the VHHIs both across regions and over time (see figure 3). This reflects the fact that the soybean seed market has undergone dramatic structural changes over the last decade. Our analysis of the determinants of seed prices both over time and across space provides useful information on the effects of these changes.

Table 1. Summary statistics

Variable[c]	Number of observations[a,b]	Mean	Standard Deviation	Minimum	Maximum
Net Price ($/bag)	75560	23.05	5.04	2.46	43
Farm size (acre)	75562	619.02	656.51	4	24000
$H_{11,\ell\ell}$	564	0.412	0.280	0.063	1
$H_{12,\ell\ell}$	520	0.110	0.093	6.04E-05	0.606
$H_{12,\ell v}$	308	0.180	0.180	0.001	1
$H_{22,\ell\ell}$	608	0.201	0.094	0.065	0.805
$H_{22,vv}$	601	1	0	1	1

[a]/ The data contain 75562 observations from 76 CRDs spanning 8 years (2000-2007). For the net price, two observations have missing value, thus the total number of observation becomes 75560.
[b]/ For the market concentration measurements *H*'s, we only report the summary statistics of those non zeros at the CRD level, therefore the number of observations is at most 76× 8 = 608.
[c]/ Two VHHI's are not reported in the table: $H_{22,\ell v} = H_{22,v\ell} = 0$, as in the soybean market, we do not observe companies both vertically integrated and licensed in the same market. This is not a general case; for example, these measures are nonzero in the cotton seed market. Moreover, $H_{12,\ell\ell} = H_{21,\ell\ell}$ and $H_{12,\ell v} = H_{21,v\ell}$ by symmetry in construction.

One econometric issue in the specification (5a)-(5b) is the endogeneity of the VHHIs. Both market concentrations (as measured by *H*), quantity sold (*Y*) and seed pricing are expected to be jointly determined as they both depend on firm strategies in the seed market. To the extent that some of the determinants of these strategies are unobserved by the econometrician, this would imply that the interaction terms, $H{\cdot}Y$, are correlated with the error term in equation (5a). In such situations, least-squares estimation of (5a)-(5b) would yield biased and inconsistent parameter estimates. The solution is to consider estimating equation (5a)-(5b) using an instrumental variable (IV) estimation method that corrects for endogeneity bias. To address this issue, we first test for possible endogeneity of the *H*'s and *Y*'s using a *C* statistic calculated as the difference of two Sargan statistics (Hayashi 2000, p. 232). Under the null hypothesis of exogeneity of *H* and *Y*, the *C* statistic is distributed as Chi-square with degrees of freedom equal to the number of variables tested. The test is robust to violations of the conditional homoscedasticity assumption (Hayashi 2000, p. 232).[12] In our case, the *C* statistic is 33.93, showing strong statistical evidence against the null hypothesis of exogeneity.

The presence of endogeneity motivates the use of an IV estimator. We rely on the lagged *Y* alone and the interaction of the lagged value of each *H* and the lagged value of *Y* as instruments. The use of lagged values reflects the time required to grow the seeds, as seed companies make production decisions at least a year ahead of the marketing decisions. Indeed these lag values are part of the information set available to the seed companies at the time of their production decisions. A series of tests was conducted to support this choice (see below). On that basis, equation (5a)-(5c) was estimated by two-stage-least-squares (2SLS).

We evaluated the effects on prices from unobserved heterogeneity across farms (e.g., unobserved pest populations). A Pagan-Hall test[13] found strong evidence against homoscedasticity of the error term in (5a). On average each farm purchases three different seed varieties. Some large farms purchase up to 27 different varieties in a single year. Unobserved farm-specific factors affecting seed prices are expected to be similar within a farm (although they may differ across farms). This suggests that the variance of the error term in (5a) would exhibit heteroscedasticity, with clustering at the farm level. On that basis, we relied on heteroscedastic-robust standard errors under clustering at the farm level in estimating equation (5a)-(5b).

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[12] Under conditional homoskedasticity, the *C* statistic is numerically equivalent to a Hausman test statistic.

[13] Compared to the conventional Breusch-Pagan test, the Pagan-Hall test is a more general test for heteroscedasticity in an IV regression, which remains valid in the presence of heteroscedasticity (Pagan and Hall 1983).

The Hansen over-identification test is not statistically significant, indicating that our instruments appear to satisfy the required orthogonality conditions. Good instruments should also provide information identifying the parameters, i.e. they should not be "weak instruments". In the presence of heteroscedastic errors, we used the Bound et al. (1995) measures and the Shea (1997) partial R^2 statistic to test for weak instruments. Following Staiger and Stock (1997), the test results did not provide any evidence that our instruments are weak. Finally, The Kleibergen-Paap weak instrument test was conducted (Kleibergen and Paap, 2006),[14] yielding a test statistic of 21.89. Using the critical values presented in Stock and Yogo (2005), this indicated again that our analysis does not suffer from weak instruments.

6. Results

Table 2 reports the IV estimation of equations (5a)-(5b) using 2SLS, with heteroscedastic-robust standard errors under clustering. For comparison purpose, the ordinary least square (OLS) estimation results are also reported. The OLS estimates of the market concentration parameters differ from the 2SLS results substantially. This suggests the presence of endogeneity. As IV estimation corrects for endogeneity bias, our discussion below focuses on the 2SLS estimates.

We first discuss the estimates of how prices vary across seed types and vertical structures, followed by a discussion of the estimated effects of market power.

Characteristics effects

From table 2, publicly bred conventional seeds are priced significantly lower than the privately bred ones, at a discount of $5.05 per bag. This is consistent with our expectation that publicly-sourced seed companies and private companies use different pricing rules. Compared to

[14] Note that the Kleibergen-Paap test is a better choice compared to the Cragg-Donald test for weak instruments: the former remains valid under heteroscedasticity (while the latter does not).

private conventional seeds, the results show that all biotech seeds receive a price premium, but this price premium varies with the vertical structure. The coefficients of the T_iD_v's (i-th seed under integrated vertical structure) and T_iD_ℓ's (except for T_3D_ℓ) (i-th seed under licensing vertical structure), i = 2, 3, 4, are each positive and statistically significant. Being in the range from \$2.18 to \$7.76, they show evidence of significant premiums for these biotech traits. The coefficient of T_3D_ℓ (type 3 biotech seed under licensing) is not statistically different from zero. For all three biotech seeds, the coefficients show that seeds sold under vertical integration are priced higher than those produced and marketed under licensing.

Market concentration and vertical structures

The model incorporates market share information about each seed type in different vertical structures using the VHHI. We have shown in section 2 that the impacts of VHHI $H_{mk,u\tau}$, $k \neq m$, depend on the substitutability/complementarity relationship between the type-m seed in u-th market structure and the type-k seed in τ -th market structure. We expect that an increase in the VHHI will be associated with a rise (decrease) in the price if the two types of seed are substitutes (complements).

For the three VHHIs that may relate to the conventional seed price ($H_{11,\ell\ell}$, $H_{21,\ell\ell}$, $H_{21,v\ell}$), the public sector effect is separated from the private sector effect through the interaction between the public dummy and the VHHIs. Again, table 2 shows strong statistical evidence that the public sector follows different pricing rules (compared to the private sector). For the private sector, the coefficient of the traditional HHI ($H_{11,\ell\ell}$) is positive and statistically significant at the 5 percent level. However, this positive effect disappears for the public sector. The coefficient of the VHHI between licensed HT1 seed and the conventional seed ($H_{21,\ell\ell}$) is negative for the private sector but positive for the public sector. The negative sign of $H_{21,\ell\ell}$ in the private sector suggests that the two products are complements either in supply or in demand or both. If complementarity exists in the demand side, it should affect the seed pricing in the public sector in a similar way, as farmers' demand complementarity should not be affected by the source of seeds. However, the coefficient of $H_{21,\ell\ell}$ is positive for public sourced conventional seed, which would offset the complementarity effects between the two seed types in the private sales. We thus infer that the complementarity between conventional and licensed $HT1$ seeds may come from the supply side, where the private sector differs from the public sector in significant ways. The coefficients of the VHHI between integrated $HT1$ seed and the conventional seed ($H_{21,v\ell}$) for the private and public sectors are not statistically significant.

Of the four coefficients on VHHIs that may affect the $HT1$ biotech seed, two are statistically significant: between licensed $HT1$ seed and the conventional seed ($H_{12,\ell\ell}$) and the traditional HHI in vertically integrated $HT1$ seed market ($H_{12,vv}$). The coefficient of $H_{12,\ell\ell}$ affecting the licensed $HT1$ seed is again negative, consistent with its effects in the conventional seed market. This suggests strong and symmetric complementarity between conventional and $HT1$ seeds on the supply side. Since complementarity contributes to economies of scope (as discussed in section 2), this provides indirect evidence that seed companies experience economies of scope in the production and marketing of both conventional seed and the licensed $HT1$ seeds. Note that the coefficient of the VHHI between integrated $HT1$ seed and the conventional seed ($H_{12,\ell v}$) is also negative, but not statistically significant. This may possibly reflect the presence of transaction costs in vertical integration (such as negotiation and re-organization) that may offset some of the efficiency gains from economy of scope.

Both $H_{22,\ell\ell}$ and $H_{22,vv}$, are standard Herfindahl indexes measuring market concentration in the $HT1$ seed market, licensed and integrated, respectively. Although the impact is positive for the licensed seed market (consistent with *a priori* expectation), it does not have a statistically significant effect. The coefficient of $H_{22,vv}$ term is negative and statistically significant, contrary to *a priori* expectation. However, note that in this market, the market concentration measure $H_{22,vv}$ is 1 throughout the study period, meaning there is only one monopoly in that market. The variation in the $H_{22,vv}$ term is due to change in market size Y, which has been expanding over the years. The negative sign of this term may be related to the monopolistic firm's strategic low ball pricing for market expansion.

Does vertical organization affect pricing? To investigate this issue, we examine whether market concentrations relate to seed prices in similar ways under alternative vertical structures. This generates the following hypotheses. For a given seed type,

(I) H_0: $\beta_{21,\ell\ell} = \beta_{21,v\ell}$,

(II) H_0: $\beta_{12,\ell\ell} = \beta_{12,\ell v}$,

(III) H_0: $\beta_{22,\ell\ell} = \beta_{22,vv}$,

where the β's are the coefficients of the corresponding VHHI's.

The test results reject the null hypothesis for (I) and (II) at 5% significance level but fail to reject the null hypothesis for (III) at 10% significance level. It suggests that the conventional and $HT1$ cross-market concentration effects on the conventional seed are different with different vertical structures in the $HT1$ seed market (hypothesis I). Moreover, the cross-market concentration between the $HT1$ seed and the conventional seed affect the licensed $HT1$ differently from the vertically integrated $HT1$ seed (hypotheses II). As discussed in section 2, this provides statistical evidence that vertical organization matters. It indicates that vertical structures interact with the exercise of market power as they relate to pricing. In particular, it means that market concentration analyses that neglect vertical structures (e.g., using a traditional HHI) would fail to capture the linkages between market structure and pricing. These effects are further discussed below.[15]

Other factors

Table 2 shows how prices vary over time. The year dummy effects show a strong rising trend in and after 2004. In 2007, seed price is \$6.49 per bag higher than in 2001. Given that the mean price is about \$23.05 per bag, this gives an annual growth rate higher than the inflation rate over the same time period.[16] Our estimates show that soybean seeds are sold at a discount price in the Corn Belt compared to the non-Corn Belt states. They also indicate how the method of purchase affects prices. Compared to purchasing from "farmer who is a dealer or agent", seeds bought "directly from a seed company or their representative" cost \$0.12 less per bag, and those purchased from cooperatives cost \$0.27 more per bag.

Table 2. OLS and IV (2SLS) regression with robust standard errors.[a, b, c]

Dependent Variable: Net Price (\$/bag)	OLS		2SLS	
	Coefficient	t-statistics	Coefficient	Robust z statistics
Characteristics effects, benchmark is private T_1: Conventional seed				
T_1 public (conventional seed via public source)	-4.35***	-19.03	-5.05***	-10.71
T_2D_ℓ (*HT1* under licensing)	7.51***	101.65	7.38***	29.70
T_2D_v (*HT1* under vertical integration)	7.89***	96.60	7.76***	30.33
T_3D_ℓ (*HT2* under licensing)	0.44***	3.94	0.00	0.00
T_3D_v (*HT2* under vertical integration)	2.02***	9.48	2.18***	5.23

[15] Since the demand for seed is a derived demand from farmers' profit maximization, the willingness to pay for a seed can be interpreted in terms of marginal profit and the demand slope is the second derivative of farmers' profit. By Young's theorem, this would imply the symmetry restrictions $\frac{\partial p_{mu}}{\partial y_{k\tau}} = \frac{\partial p_{k\tau}}{\partial y_{mu}}$. Given that $\frac{\partial p_{mu}}{\partial y_{k\tau}} = \alpha_{mk,u\tau}$, $c_{mk,u\tau} = c_{km,\tau u}$, and $\beta_{mk,u\tau} = [c_{mk,u\tau} - \alpha_{mk,u\tau}]$, this generates the following hypotheses for the relevant cross markets:

(IV) H_0: $\beta_{21,\ell\ell} = \beta_{12,\ell\ell}$,

(V) H_0: $\beta_{12,\ell v} = \beta_{21,v\ell}$.

Using a Wald test, we failed to reject these null hypotheses. While the results presented below do not impose these null hypotheses, note that imposing such symmetry restrictions did not affect our main findings.

[16] According to the Department of Labor statistics, the average inflation rate from 2000 to 2007 is 2.78%.

T_4D_ℓ (stacked under licensing)	7.69***	50.78	7.45***	25.77
T_4D_v (stacked under vertical integration)	8.01***	87.50	7.75***	30.56
Market concentration and vertical structures				
$H_{11,\ell\ell}T_1D_\ell Y_{1\ell}$ (conventional seed)	0.025***	3.26	0.163**	2.58
$H_{11,\ell\ell}T_1D_\ell Y_{1\ell}$*_pub* (public-sourced conventional seed)	-0.071	-0.25	-0.156*	-1.89
$H_{21,\ell\ell}T_1D_\ell Y_{2\ell}$ (conventional seed)	-0.047***	-3.59	-0.261***	-3.85
$H_{21,\ell\ell}T_1D_\ell Y_{2\ell}$*_pub* (public-sourced conventional seed)	0.102*	1.84	0.330***	3.22
$H_{21,v\ell}T_1D_\ell Y_{2v}$ (conventional seed)	-0.055**	-2.15	0.009	0.10
$H_{21,v\ell}T_1D_\ell Y_{2v}$*_pub* (public-sourced conventional seed)	-0.020	-0.25	-0.029	-0.21
$H_{12,\ell\ell}T_2D_\ell Y_{1\ell}$ (*HT1* under licensing)	-0.060***	-6.02	-0.145***	-3.01
$H_{22,\ell\ell}T_2D_\ell Y_{2\ell}$ (*HT1* under licensing)	0.012***	2.99	0.000	0.017
$H_{12,\ell v}T_2D_v Y_{1\ell}$ (*HT1* under vertical integration)	0.041***	4.43	0.075	1.58
$H_{22,vv}T_2D_v Y_{2v}$ (*HT1* under vertical integration)	-0.004	-1.40	-0.021***	-2.62
Other variables				
Exit	-0.35***	-12.36	-0.33***	-8.43
Entry	0.21***	9.92	0.03	0.99
Year 2002	0.14***	4.70	0.33**	6.03
Year 2003	-0.32***	-8.37	-0.09	-1.18
Year 2004	2.28***	60.29	2.48***	34.54
Year 2005	5.17***	138.94	5.39***	60.56
Year 2006	6.06***	131.62	6.29***	56.92
Year 2007	6.27***	165.80	6.49***	65.21
Total soybean acre by each farm (1000 acre)	-0.286***	-13.57	-0.273***	-4.99
Constant	16.65***	175.92	16.98***	64.84
Number of observations	64550			

[a] Statistical significance is noted by * at the 10 percent level, ** at the 5 percent level, ** at the 1 percent level.

[b] The R^2 is 0.77 for the OLS estimation. For the 2SLS estimation, the centered R^2 is 0.74, and un-centered R^2 is 0.99.

[c] Results for the location effects and purchase source effects are not reported here to save space, but are discussed in the text.

The exit dummy is negative and statistically significant. Prior to the year of exit, seed price tends to discount by $0.22 per bag, which may be due to the fact that the exiting seed's performance has deteriorated. The entry dummy has a positive but insignificant coefficient, suggesting that new seeds are not priced differently from other seeds. Finally, table 2 shows that the farm size effect is statistically significant: large farms within each state pay less for seeds.

7. Implications

In this section, our empirical estimates are used to generate insights on pricing within and across markets under different vertical structures. For illustration purpose, our analysis focuses on Illinois in 2004. Illinois is one of the largest soybean-producing states in the US, and it has the largest number of farms in our sample. The year 2004 is a convenient choice for being the middle of the sample period.

Two sets of results are presented. First, we evaluate the characteristics effects within and across different vertical structures by estimating how stacking influences seed prices in the licensed case and the vertically integrated case. Second, in an evaluation of the imperfect competition, we estimate the market power component *M* of price for different seed types under different vertical structure. This provides useful information on the extent of departure from competitive pricing.

Bundling/Stacking effects

The bundling literature has identified situations in which component pricing may not apply (e.g., when demands are heterogeneous). Our analysis provides a basis for testing component pricing (where seeds are priced as the sum of their component values). More generally, it can be used to investigate how prices vary across bundles within and across different vertical structures. Next, these issues are evaluated by simulating our estimated model at sample means of relevant variables for Illinois in 2004 (including farm size and VHHIs).[17]

Table 3 reports the estimated bundling/stacking effects for different markets and vertical structures. The mean conventional seed price is $16.25 per bag. It is used as a "base case" to evaluate both integrated and licensed market structures. The biotech traits add price premiums

[17] The purchase source is set to be from "Farmer who is a dealer or agent". The simulation is conducted by varying the seed type and vertical structure dummies, while keeping the corresponding other variables at the sample mean level for IL. All simulated prices are bootstrapped.

over the conventional varieties. In addition the stacking premium is higher than single trait premium in both market structures. The stacking effect (reflecting the difference between what the price would be under component pricing and the bundled price) is -$2.57 per bag in the integrated market, but not different from zero in the licensed market. These results indicate that component pricing applies under licensing. But they strongly reject component pricing under vertical integration. There, the evidence documents sub-additive pricing, where the price of the bundled good is priced significantly less than the sum of its component values.

Table 3. Effects of Bundling/Stacking in Different Markets on Seed Prices, $/bag.[a]

Seed type	Licensed		Vertically integrated		Difference between vertical structures
	Expected Seed Price	Price difference from T_1	Expected Seed Price	Price difference from T_1	
T_1 (Conventional)	16.25	N/A	N/A	N/A	N/A
T_2 (*HT*1 biotech)	23.88	7.63*** (0.12)	24.38	8.13*** (0.12)	-0.50*** (0.07)
T_3 (*HT*2 biotech)	16.75	0.50** (0.21)	18.94	2.69*** (0.36)	-2.17*** (0.38)
T_4 (stacked biotech)	24.21	7.96*** (0.20)	24.50	8.25*** (0.14)	-0.31* (0.16)
Stacking effect (T_4 vs. T_2+T_3)	-0.17 (0.26)		-2.57*** (0.37)		2.36*** (0.41)

[a] Standard errors are in parentheses. Statistical significance is noted by * at the 10 percent level, ** at the 5 percent level, and *** at the 1 percent level.

Sub-additive pricing in bundling could be driven by price discrimination associated with demand heterogeneity across differentiated commodities (higher prices being associated with more inelastic demands). It could also reflect the presence of economies of scope in the production of bundled/stacked seeds. This would be consistent with synergies in R&D investment across stacked seeds. For example, a given R&D investment can contribute to the production of multiple seed types, meaning that bundling can help reduce the overall cost of producing seeds. In this context, the subadditivity of prices means that seed companies would share with farmers at least some of the benefits of scope economies through a lower price of bundled/stacked seeds.

Estimated Market Power Component

As discussed in sections 2 and 4, the market power component can be measured by the term *M* in equation (4) or (6). Our estimated model allows us to evaluate *M* in equation (6). This provides a simple characterization of the strength of imperfect competition: it is zero under perfect competition, but non-zero under concentrated markets. The term *M* can be interpreted as a per-unit measure of the price enhancement associated with imperfect competition. Evaluated at mean values, table 4 reports the estimated market power component *M* for selected seed types for Illinois in 2004. Table 4 also presents the corresponding relative measures $\frac{M}{p}$.[18]

The market power measures *M* are statistically significant in the conventional seed market and in the licensed *HT*1 seed market. The market power measure for the conventional seed is $0.60 per bag; it is statistically significant at 5% level. The corresponding relative measure $\frac{M}{p}$ is 0.036, indicating that the exercise of market power component amounts to 3.6% of the seed price. For the licensed *HT*1 seed, the market power measure is not statistically different from zero for the own market power increase. But table 4 reports negative and significantly effects (at the 1% level) of changing market concentration in both conventional and licensed *HT*1seed markets on the price of licensed *HT*1 seeds. This provides empirical evidence that market power affects seed prices differently across market structures. It also shows that the cross-market power effect works against and dominates the own market power effect in the

[18] Note that $\frac{M}{p}$ is related to the Lerner index, defined as $L = \frac{p - \partial C/\partial y}{p}$, which provides a relative measure of departure from marginal cost pricing. Using our notation, we have $L_{k\tau} = \frac{-\sum_{m\in\mathbf{K}}\sum_{u\in\mathbf{V}}\alpha_{mk,u\tau}H_{mk,u\tau}Y_{mu}}{p_{k\tau}}$. From equation (4), it follows that $\frac{M_{k\tau}}{p_{k\tau}} = L_{k\tau} + \frac{\sum_{m\in\mathbf{K}}\sum_{u\in\mathbf{V}}c_{mk,u\tau}H_{mk,u\tau}Y_{mu}}{p_{k\tau}}$. This shows that $\frac{M_{k\tau}}{p_{k\tau}} = L_{k\tau}$ when marginal cost is constant.

licensed *HT*1 seed market. These results are due to our estimated complementarity effects that reduce the price enhancement associated with market power. Since complementarity reflects cross-markets effects, this stresses the need to address market power issues in a multi-market framework, involving both horizontal and vertical markets.

Table 4. Estimated Market Power Component *M*.[a]

Seed type	Mean Seed price ($/bag)	Market Power Component[b]					
		T_1		T_2		T_1 & T_2	
		M (*$/bag*)	*M/p*	*M* (*$/bag*)	*M/p*	*M* (*$/bag*)	*M/p*
T_1 (Conventional)	16.47	0.60**	0.036	N/A	N/A	-0.52*	-0.032
Licensed T_2 (*HT*1 biotech)	23.53	N/A	N/A	0.00	0.00	-0.25***	-0.011
Integrated T_2 (*HT*1 biotech)	23.58	N/A	N/A	-0.31***	-0.013	-0.13	-0.006

[a] Statistical significance is noted by * at the 10 percent level, ** at the 5 percent level, and *** at the 1 percent level.
[b] The terms *M* are calculated at the difference between the predicted price when the *VHHI*s are set equal to the mean and the predicted price when the *VHHI*s are set equal to zero (which implies *M* being zero). In scenario "T_1", the market concentration change is set to happen only in the conventional market, i.e. $H_{11,\ell\ell}$ is changed from zero to the sample mean in IL. Similarly, in scenario "T_2", only $H_{22,\ell\ell}$ or $H_{22,vv}$ is set to change for the licensed T_2 or integrated T_2 seeds, correspondingly. And in scenario "T_1& T_2", market concentration is set to change in both the conventional market and the *HT*1 (licensed or integrated) market, implying that all HHIs and VHHIs are set to change.

8. Concluding Remarks

The paper has developed a Cournot model of pricing of differentiated products under imperfect competition and alternative forms of vertical control. It proposes a general approach to evaluate the exercise of market power in vertical structures. This involves a vertical HHI (termed VHHI) that captures how the interaction of market concentration and vertical organization relate to the pricing of differentiated products under general conditions.

The usefulness of the analysis is illustrated in an econometric application involving the estimation of a structural model of pricing where our VHHIs capture the imperfect competition across both horizontal and vertical markets. Applied to the U.S. soybean seeds, the econometric analysis finds evidence that vertical organization has significant effects on seed prices. It means that market concentration analyses that neglect vertical structures (e.g., using a traditional HHI) would fail to capture the linkages between market structure and pricing. However these effects are found to vary with the institutional setup and the bundling of seeds. We find that component pricing applies to privately sourced seeds sold under licensing. But we reject component pricing in favor of sub-additive pricing for privately sourced seeds sold under vertical integration. We uncover evidence that complementarity and economies of scope can reduce the price-enhancement associated with market concentration. Since complementarity reflects cross-markets effects, this stresses the need to address market power issues in a multi-market framework. Additional research is needed to explore whether our empirical findings about the exercise the market power in horizontal and vertical markets would apply to other industries.

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An Analysis of Bundle Pricing in Horizontal and Vertical Markets:
The Case of the U.S. Cottonseed Market

by

Guanming Shi
Kyle Stiegert
and
Jean Paul Chavas[1]

Abstract: In this paper, we investigate substitution/complementarity relationships among products sold with different bundled characteristics and under different vertical arrangements. Our conceptual model demonstrates the interactive price impacts emanating from product differentiation, market concentration and market size. The model is applied to the U.S. cottonseed market using transaction level data from 2002 to 2007. This market has been impacted structurally in numerous ways due to the advances and the rapid adoption of seeds with differing bundles of biotechnology traits and vertical penetration emanating from the biotechnology seed industry. Several interesting findings are reported. The econometric investigation finds evidence of sub-additive pricing in the bundling of patented biotech traits. Vertical organization is found to affect pricing and the exercise of market power. While higher market concentration is associated with higher prices, there is also evidence of cross-product complementarity effects that lead to lower prices. Simulation methods are developed to measure the net price effects. These simulations are applicable for use in pre-merger analysis of industries producing differentiated products and exhibiting similar market complexities.

Key Words: Modal vertical strategy, imperfect competition, cottonseed, biotechnology
JEL Code: L13, L4, L65

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[1] Respectively Assistant Professor, Associate Professor, and Professor, Department of Agricultural and Applied Economics, Taylor Hall, University of Wisconsin, Madison, WI. This research was funded in part by USDA-NRI grant #144-QS50 and a USDA Hatch grant.

1. Introduction

It is common for firms to produce multiple products. Firms that engage in successive stages of production and marketing of these products must choose among alternative forms of vertical organization, including arms-length transactions, contracting, and vertical ownership (i.e. forward or backward vertical integration). At each step along the vertical channel there is the potential for horizontal competition in which firms develop strategies for pricing and product design that can involve bundling or tie-in sales of their various products. Much research has examined the economic incentives underlying these choices (see Lafontaine and Slade, 2007 for an overview of this literature).

Beginning with Williamson (1968), the influence of horizontal and vertical structures on end product pricing has been an area of intense legal and economic debate (e.g., Hart and Tirole 1990; Ordover et al. 1990; O'Brien and Shaffer 1992; McAfee and Schwartz 1994; De Fontenay and Gans 2005; Gans 2007; Rey and Tirole 2008). On the one hand, the exercise of market power associated with tacit collusion, exclusive dealing, vertical foreclosure, and increased concentration through mergers can lead to market inefficiency. This has motivated government actions through antitrust legislation and enforcement. On the other hand, proponents of the "Chicago School" approach have argued that increased horizontal concentration or vertical integration can be motivated by efficiency gains. Firms with superior technologies, human capital, or business models are perceived to expand by purchasing the assets of poor performers or by driving these firms out of business. As a result, increased horizontal concentration or vertical integration may not lead to welfare losses (Bork 1978). This focus on efficiency gains has contributed to reduced antitrust enforcement in the US over the last two decades (Pitofsky 2008).

While previous literature has examined the economics of industry concentration and efficiency gains from horizontal and vertical restructuring,[2] studying the tradeoffs between market power and efficiency remains challenging in markets involving differentiated products (e.g., Spengler 1950; Katz 1989; Hart and Tirole 1990; Whinston 2006; Rey and Tirole 2008). Addressing these challenges is relevant given the prevalence of product differentiation in many industries. And it appears timely given the recent call for more vigorous antitrust enforcement by the U.S. Department of Justice (DOJ) (Varney 2009).

This paper examines end product pricing in horizontal and vertical markets both conceptually and empirically. We develop a Cournot model of pricing of differentiated products under imperfect competition in different vertical organizations. The model demonstrates how substitution/complementarity relationships between products and across vertical channels relate to the exercise of market power. It also provides a structural representation of pricing with an explicit characterization of the role of market power. The Herfindahl-Hirschman index (HHI) has been commonly used to assess horizontal market concentration (e.g., Whinston 2006). Our analysis relies on a vertical HHI (termed VHHI) that captures how market concentration and vertical organization relate to the pricing of differentiated products.

The approach is then applied to an analysis of pricing in the U.S. cottonseed industry. The cottonseed market makes an excellent case study for at least three reasons. First, the cottonseed industry is highly concentrated and now dominated by a few large seed firms (Fernandez-Cornejo 2004). Second, the recent biotechnology revolution has stimulated the

[2] For example, Azzam (1997) tested for efficiency gains and market power losses in the horizontal market for processed beef. He found that efficiency gains outweighed the market power welfare losses. More recently, Hortaçsu and Syverson (2007) found no evidence that vertical organization negatively impacted prices in the U.S. cement-concrete market. Gugler and Siebert (2007) studied the impacts of mergers and joint research ventures for the computer microcomponents and memory markets. Their counterfactual experiments found that research joint ventures achieve efficiency gains similar to what mergers could do.

development of patented genetic material by biotech firms, which has been used as upstream inputs in the downstream cottonseed production industry. This has created new opportunities for product differentiation and price discrimination under alternative vertical structures. Third, the role of both horizontal and vertical organization in biotechnology and seed markets has been of interest to economists and anti-trust policy makers because of the surge of mergers and acquisitions in these industries since the 1990s (e.g., Graff et al. 2003; Fernandez-Cornejo 2004; Moss 2009; Shi 2009). Graff et al. (2003) suggest that vertical integration may be motivated by efficiency gains obtained from the complementarity of assets in agricultural biotechnology and seed industries. Others have raised questions about whether market power may have adverse effects on efficiency (e.g., Fernandez-Cornejo 2004). These concerns have motivated the involvement of the U.S. DOJ in a recent vertical merger in the cottonseed industry: the acquisition of Delta and Pine Land Company (DPL), the largest cottonseed company in the US, by Monsanto, one of the largest agricultural biotech companies in the world.[3]

Our econometric analysis evaluates the pricing of cottonseeds in the major cotton-producing region of Texas and Oklahoma. We develop a structural estimation of a pricing equation in the first part of the paper. The model motivates the use of the VHHI as a measure of concentration in both horizontal and vertical markets. We consider the case of multi-seed-product markets, including "stacked seeds" where patented biotech traits are bundled in given cottonseed types. We also consider two vertical structures: vertical integration and licensing.

[3] In 2007, the DOJ gave approval to the merger under the condition that Monsanto divests of some of its assets in markets where it is a dominant player. See the DOJ website: http://www.usdoj.gov/opa/pr/2007/May/07_at_391.html.

Our empirical analysis covers the period 2002-2007. It documents that the market share of conventionally bred cottonseeds has been declining. The market for biotech seeds (i.e., seeds with patented traits) shows patterns that vary for different firms and different seed types. Bayer CropScience, also a large agricultural biotech company, entered the cottonseed market in 1999, and has exhibited a major growth in sales since 2002 (Shi 2009). Monsanto purchased a major seed-breeding firm in 2005 and expanded on its vertical integration afterwards. Our econometric analysis provides useful information on the implications of these trends and their linkages with the pricing of cottonseed.

Our investigation examines the differential pricing of conventional seeds and of patented biotech seeds. The biotech cottonseeds include two types of patented traits: herbicide tolerance (HT) and insect resistance (IR), either present independently or stacked (when HT and IR traits are bundled together). Our empirical analysis of stacked seeds finds strong evidence against component pricing and in favor of sub-additive pricing of patented traits. We also document how changing market concentration and vertical organization relate to cottonseed prices. We find that vertical organization affects pricing and the exercise of market power. Our analysis documents that seeds sold under vertical integration are priced higher than those sold through licensing. While we find that increased market concentration is associated with a higher price in the corresponding market, our results also show evidence of cross-market complementarities that mitigate the price-enhancement associated with market power. By identifying the role of cross-market concentrations, this stresses the need to conduct the analysis of market structure in a multi-market context.

The remainder of the paper is organized as follows. The conceptual model is presented in section 2. The data and empirical specification are discussed in section 3. Section 4 reports the econometric results. Section 5 discusses the economic implications of our findings. Finally, section 6 presents conclusions.

2. Conceptual Approach

Consider markets serviced by N firms producing up to Q outputs, $\mathbf{N} = \{1, \ldots, N\}$ denoting the set of firms and $\mathbf{Q} = \{1, \ldots, Q\}$ being the set of outputs. The production and marketing of these outputs engages an upstream technology that can involve V alternative vertical organizations. Let $\mathbf{V} \equiv \{1, \ldots, V\}$ denote the set of possible vertical structures (including vertical contract and vertical integration). The output vector produced by the n-th firm is denoted by $y^n = (y_{11}^n, \ldots, y_{m\tau}^n, \ldots, y_{QV}^n\} \in \Re_+^{QV}$, $y_{m\tau}^n$ being the quantity of the m-th good produced by the n-th firm under the τ-th vertical structure, $m \in \mathbf{Q}$, $n \in \mathbf{N}$, $\tau \in \mathbf{V}$.

Each firm maximizes profit across marketing channels. With the potential for implicit or explicit contracts between upstream technology provider and the downstream firm, we examine how the exercise of market power in both horizontal and vertical markets is associated with pricing in the end-use market. We allow for vertical as well as horizontal product differentiation. This takes place through quality choices, labels, brands, advertising, etc. Vertical product differentiation means that pricing can vary across vertical structures.

The price-dependent demand for the m-th output under the τ-th vertical structure is denoted by $p_{m\tau}(\sum_{n \in N} y^n)$. Then, profit for the n-th firm is: $\sum_{m \in \mathbf{Q}} \sum_{\tau \in \mathbf{V}} [p_{m\tau}(\sum_{n \in \mathbf{N}} y^n) \cdot y_{m\tau}^n$ - $C_n(y^n)$, where $C_n(y^n)$ represents the n-th firm's total costs of production and marketing. Assuming Cournot behavior, the Kuhn-Tucker conditions for the n-th firm for the m-th output in the τ-th vertical structure $y_{m\tau}^n$ are:

$$p_{m\tau} + \sum_{k \in \mathbf{Q}} \sum_{u \in \mathbf{V}} \frac{\partial p_{m\tau}}{\partial y_{ku}^n} \cdot y_{m\tau}^n - \frac{\partial C_n}{\partial y_{m\tau}^n} \leq 0, \tag{1a}$$

$$y^n_{m\tau} \geq 0, \tag{1b}$$

$$[p_{m\tau} + \sum_{k\in\mathbf{Q}} \sum_{u\in\mathbf{V}} \frac{\partial p_{m\tau}}{\partial y^n_{ku}} \cdot y^n_{m\tau} - \frac{\partial C_n}{\partial y^n_{m\tau}}] \cdot y^n_{m\tau} = 0. \tag{1c}$$

Equation (1c) is the complementary slackness condition which applies whether the m-th output is produced by the n-th firm in the τ-th vertical structure ($y^n_{m\tau} > 0$) or not ($y^n_{m\tau} = 0$). As such, (1c) holds even if the firm does not produce the full array of differentiated products. This allows for foreclosure, where the strategy of one firm may preclude other firms from producing a particular product. And (1c) applies for any vertical organization selected by the firm.

Assume that the cost function of the n-th firm takes the quadratic form $C_n(y^n) = F_n(\mathbf{S}_n) + \sum_{m\in\mathbf{Q}} \sum_{\tau\in\mathbf{V}} c_{m\tau} y^n_{m\tau} + ½ \sum_{k,m\in\mathbf{Q}} \sum_{u,\tau\in\mathbf{V}} c_{km,u\tau} y^n_{ku}\, y^n_{m\tau}$, where $F_n(\mathbf{S}_n)$ denotes fixed cost, $c_{kk,uu} \geq 0$ and $c_{km,u\tau} = c_{mk,\tau u}$. Fixed cost $F_n(\mathbf{S}_n)$ satisfies $F_n(\varnothing) = 0$, where $\mathbf{S}_n = \{(m, \tau)\text{: } y^n_{m\tau} > 0, m\in\mathbf{Q}, \tau\in\mathbf{V}\}$ is the set of positive outputs. While the variable cost enters explicitly in equations (1a)-(1c), the fixed cost $F_n(\mathbf{S}_n)$ can also play a role. Indeed, fixed costs must be recovered to guarantee the sustainability of each firm. This typically implies a departure from marginal cost pricing. Fixed costs can come from two potential sources: the upstream industry (e.g., R&D investment); and the downstream industry (e.g., fixed cost in establishing a vertical organization). Both fixed costs and variable costs are relevant in evaluating the efficiency of a firm. For example, as shown by Baumol et al. (1982), both fixed costs and variable costs can contribute to economies of scope. And economies of scope can generate efficiency gains by reducing the cost of production for multi-output firms.

Let the price-dependent demand for the kth product under the u-th vertical structure be $p_{ku} = b_{ku} + \sum_{m\in\mathbf{Q}} \sum_{\tau\in\mathbf{V}} \sum_{n\in\mathbf{N}} \alpha_{km,u\tau} y^n_{m\tau}$, with $\alpha_{kk,uu} < 0$. Denote by $Y_{m\tau} = \sum_{n\in N} y^n_{m\tau}$ the aggregate output of the m-th product in the τ-th vertical structure. Assuming that $Y_{m\tau} > 0$, define $s^n_{m\tau} = \frac{y^n_{m\tau}}{Y_{m\tau}}$

$\in [0, 1]$ as the corresponding market share for the n-th firm. Dividing equation (1c) by $Y_{m\tau}$ and summing across all n, we obtain the following result.

Proposition 1: The pricing of the m-th product under the τ-th vertical structure satisfies

$$p_{m\tau} = c_{m\tau} + \sum_{k\in\mathbf{Q}} \sum_{u\in\mathbf{V}} [c_{km,u\tau} - \alpha_{km,u\tau}] \cdot H_{km,u\tau} \cdot Y_{ku}, \tag{2}$$

where

$$H_{km,u\tau} \equiv \sum_{n\in\mathbf{N}} s_{ku}^{n} \cdot s_{m\tau}^{n}, \tag{3}$$

with m, $k \in \mathbf{Q}$ and u, $\tau \in \mathbf{V}$.

Following Shi and Chavas (2009), the term defined in (3), $H_{km,u\tau}$, is called the vertical Herfindahl-Hirschman index, or VHHI. Note that $H_{km,u\tau} \in [0, 1]$, and that $H_{km,u\tau} \to 0$ under prefect competition when there are many active firms in all markets. It follows that the part of the price equation (2) that includes the $H_{km,u\tau}$'s reflect departures from competitive conditions and the exercise of market power. It will be useful to identify this part explicitly by defining

$$M_{m\tau} = \sum_{k\in\mathbf{Q}} \sum_{u\in\mathbf{V}} [c_{km,u\tau} - \alpha_{km,u\tau}] \cdot H_{km,u\tau} \cdot Y_{ku} \ . \tag{4}$$

Given that $H_{km,u\tau} \to 0$ under perfect competition and using (2), it follows that $M_{m\tau}$ in (4) provides a measure of the market power component of prices. With $H_{km,u\tau} \in [0, 1]$, note that $H_{km,u\tau}$ increases with market concentration; and it reaches its maximum ($H_{km,u\tau} = 1$) under monopoly. As such, $M_{m\tau}$ in (4) provides a convenient measure of how market concentration is associated with pricing. Equations (2)-(4) are central to our empirical analysis below. Note that the magnitude of $M_{m\tau}$ also depends on Y_{ku}, reflecting the market size of product k under the u-th vertical structure. As market size is affected by entry/exit, this means that the evaluation of market power has to consider both market concentration effects and market size effects. We will discuss these effects in more details in section 5.

Public policy regarding imperfect competition (e.g. merger policy, price fixing, cartels, abuse of dominance) remains principally concerned with the potential negative impacts of concentration on competition (Coates and Ulrich 2009). The most common measure of market concentration is the Herfindahl-Hirschman index (HHI) defined as the sum of squared market shares across all firms in the relevant market.[4] When there is a single product ($Q = 1$) and a single vertical structure ($V = 1$), note that our VHHI measure $H_{11,11}$ is just the classical HHI. Given $c_{11,11} \geq 0$ and $\alpha_{11,11} < 0$, equations (2)-(4) indicate that an increase in the HHI, $H_{11,11}$, (simulating an increase in market power) is associated with an increase in M_{11}, and thus an increase in price p_{11}.

Equations (2)-(4) extend the HHI to a multi-product context (when $Q > 1$) and under various vertical structures (when $V > 1$). When $k \neq m$ and $u = \tau$, it shows that a rise in the "cross-market" VHHI, $H_{km,\tau\tau}$, would be associated with an increase (a decrease) in $M_{m\tau}$ if $[c_{km,\tau\tau} - \alpha_{km,\tau\tau}] > 0$ (< 0). This indicates that, under vertical structure τ, the sign of $[c_{km,\tau\tau} - \alpha_{km,\tau\tau}]$ affects the nature of the departure from competitive conditions. Since $\alpha_{km,\tau\tau} = \frac{\partial p_{k\tau}}{\partial y^n_{m\tau}}$ and following Hicks (1939), note that $\alpha_{km,\tau\tau} < 0$ (> 0) when products k and m are substitutes (complements) on the demand side, corresponding to situations where increasing $y^n_{m\tau}$ tends to decrease (increase) the marginal value of $y^n_{k\tau}$. Similarly, $c_{km,\tau\tau} = \frac{\partial^2 C_n(y^n)}{\partial y^n_{k\tau} \partial y^n_{m\tau}} > 0$ (< 0) when products k and m are substitutes (complements) on the supply side, corresponding to situations where increasing $y^n_{m\tau}$ tends to

[4] As a rule of thumb, HHI > 0.18 has been considered as a threshold that raises concerns about the degree of competition (Whinston 2006). As Coates and Ulrich (2009) report, the decision to challenge mergers by the U.S. Federal Trade Commission typically focused on HHIs mainly in the 0.20 to 0.50 range.

increase (decrease) the marginal cost of $y^n_{k\tau}$. Note that the supply side complementary case (where $c_{km,\tau\tau} < 0$) contributes to economies of scope (Baumol et al. 1982, p. 75), where multi-output production reduces costs. It follows that the term $[c_{km,\tau\tau} - \alpha_{km,\tau\tau}]$ would be positive (negative) when $y^n_{m\tau}$ and $y^n_{k\tau}$ behave as substitutes (complements) on the supply side and demand side. From equations (2)-(4), the qualitative effects of the market concentration terms $\{H_{km,\tau\tau}\}$ on $M_{m\tau}$ depend on the nature of substitution or complementarity among outputs (through the terms $[c_{km,\tau\tau} - \alpha_{km,\tau\tau}]$). It means that a rise in $H_{km,\tau\tau}$ would be associated with an increase (a decrease) in $M_{m\tau}$ when $y_{k\tau}$ and $y_{m\tau}$ are substitutes (complements).

Of special interest here are the effects of vertical structures on pricing. Consider the case where $u \neq \tau$ and $k = m$. Then, equations (3) and (4) also show how vertical organization influences prices. They show that a rise in VHHI $H_{mm,u\tau}$ would be associated with an increase (a decrease) in $M_{m\tau}$ if $[c_{mm,u\tau} - \alpha_{mm,u\tau}] > 0$ (< 0). This indicates that, for a given product m, the sign of $[c_{mm,u\tau} - \alpha_{mm,u\tau}]$ affects the nature of the departure from competitive pricing. As just discussed, we expect $[c_{mm,u\tau} - \alpha_{mm,u\tau}] > 0$ (< 0) when product m exhibits substitution (complementarity) across vertical structures u and τ. Thus the terms $H_{mm,u\tau}$'s in equations (3)-(4) show how the nature of substitution or complementarity across vertical structures influences the correlation of market concentration and prices. It indicates that a rise in $H_{mm,u\tau}$ would be associated with an increase (a decrease) in $M_{m\tau}$ when y_{mu} and $y_{m\tau}$ are substitutes (complements).

Are there conditions under which vertical structures would have no effect on pricing? As shown by Shi and Chavas (2009), this would occur if products were perfect substitutes across vertical structures on the demand side as well as on the supply side. Then, $p_{m\tau} = p_m$, as the law of one price applies to perfect substitutes. Perfect substitution on the supply side corresponds to situations in which the cost function takes the form $C_n(y^n) = C_n(\sum_{\tau\in\mathbf{V}} y^n_{1\tau},\ldots,\sum_{\tau\in\mathbf{V}} y^n_{Q\tau})$, implying that $c_{m\tau} = c_m$ and $c_{km,u\tau} = c_{km}$ for $k, m \in \mathbf{Q}$ and $u, \tau \in \mathbf{V}$. Similarly, perfect substitution on the demand side corresponds to situations in which $\frac{\partial p_{ku}}{\partial y_{m\tau}} \equiv \alpha_{km,u\tau} = \alpha_{km}$ for $k, m \in \mathbf{Q}$ and all $u, \tau \in \mathbf{V}$. These are testable restrictions that will be investigated in our empirical analysis below.

What happens to equation (4) under perfect substitution across vertical markets? Let $Y_m = \sum_{\tau\in\mathbf{V}} Y_{m\tau}$. When $c_{km,u\tau} = c_{km}$ and $\alpha_{km,u\tau} = \alpha_{km}$, multiplying the right-hand side of (4) by $\frac{Y_{m\tau}}{Y_m}$ and summing over τ gives

$$M_m = \sum_{k\in\mathbf{Q}} [c_{km} - \alpha_{km}] \cdot H_{km} \cdot Y_k , \tag{4'}$$

where $H_{km} \equiv \sum_{n\in\mathbf{N}} S^n_k \cdot S^n_m$, $S^n_k = \frac{\sum_{u\in\mathbf{V}} y^n_{ku}}{Y_k}$ is the n-th firm market share for the k-th product. M_m in (4') gives the market power component of the price of the m-th product (p_m). In this case, note that H_{km} is a concentration measure across the k-th and m-th horizontal markets, and it satisfies $H_{km} = \sum_{u\in\mathbf{V}} \sum_{\tau\in\mathbf{V}} H_{km,u\tau} \cdot \frac{Y_{ku}}{Y_k} \cdot \frac{Y_{m\tau}}{Y_m}$, i.e. it is a weighted average of our VHHI's $H_{km,u\tau}$.

Taking the analysis one step further, what would happen to equation (4) or (4') if horizontal products were also perfect substitutes? Following the same arguments, this would imply that $c_{km} = c$ and $\alpha_{km} = \alpha$, and that the law of one price would apply across horizontal markets: $p_m = p$. Then, letting $Y = \sum_{m\in\mathbf{Q}} Y_m$, multiplying the right-hand side of (4') by $\frac{Y_m}{Y}$ and summing over $m\in\mathbf{Q}$ would give

$$M = [c - \alpha] \cdot H \cdot Y , \tag{4''}$$

where $H \equiv \sum_{n\in\mathbf{N}} w^n \cdot w^n$, $w^n = \frac{\sum_{m\in\mathbf{Q}}\sum_{u\in\mathbf{V}} y^n_{mu}}{Y}$ is the n-th firm's overall market share. M in (4") gives the market power component of price p when all products are perfect substitutes. In this case, note that H is the classical HHI providing a measure of overall market concentration. And it satisfies $H = \sum_{m\in\mathbf{Q}} \sum_{k\in\mathbf{Q}} H_{km} \cdot \frac{Y_k}{Y} \cdot \frac{Y_m}{Y} = \sum_{m\in\mathbf{Q}} \sum_{k\in\mathbf{Q}} \sum_{u\in\mathbf{V}} \sum_{\tau\in\mathbf{V}} H_{km,u\tau} \cdot \frac{Y_{ku}}{Y} \cdot \frac{Y_{m\tau}}{Y}$, i.e. it is a weighted average of our VHHI's $H_{km,u\tau}$. This makes it clear that when all products are perfect substitutes, our approach reduces to a single market analysis and to the HHI approach commonly found in the literature (e.g., Whinston 2006). It also shows how our VHHI generalizes previous analyses in the presence of product differentiation (when products are not perfect substitutes). It identifies the roles of substitution/complementarity among products and their effects on pricing under imperfect competition. Importantly, our generalization allows for product differentiation both in horizontal and vertical organizations.

Equation (3) indicates that the VHHI's $H_{km,u\tau}$ provide the relevant information to assess the role of market power in horizontal and vertical markets. It can provide a basis for empirical investigations of the pricing of differentiated products in a vertical sector under imperfect competition. This is illustrated next in an application to the U.S. cottonseed industry. In this application, the upstream firm develops the seed production technology (i.e., a biotech firm developing patented genetic material that can be inserted in the basic seed), and the downstream firm uses the upstream technology to produce and sell the biotech seeds to farmers.

3. Data and Model Specification

Our analysis uses a data set providing detailed information on the U.S. cottonseed market. The data were collected by **dmr**kynetec [hereafter dmrk]. The dmrk data come from a stratified sample of U.S. cotton farmers surveyed annually in 2002-2007.[5] The survey provides farm-level information on seed purchases, acreage, seed types, technology fees, and seed prices. It was

[5] The survey is stratified to over-sample producers with large acreage.

collected using computer assisted telephone interviews. Farmers typically buy their seeds locally, and seeds are usually developed for different agro-climatic conditions in different regions. We define the "local market" at the Crop Reporting Districts (CRD)[6] level. Our analysis focuses on the High Plains of Texas and Oklahoma, a major cotton-producing region.

Using equation (3), we introduce a price equation with binary terms that partitions cottonseed transactions based on different genetic characteristics and different vertical structures. Equation (3) reflects a structural approach that evaluates the components of multiproduct pricing under imperfect competition and modal vertical structures. We focus our attention on the case of two vertical structures: vertical integration (v) and licensing (ℓ). Let $D_\tau \in \{0, 1\}$ be dummy variables for vertical structures, satisfying $D_\tau = 1$ for the τ-th vertical structure and $D_\tau = 0$ otherwise, $\tau \in \mathbf{V} = \{\ell, v\}$. We consider 4 seed types ($Q = 4$): conventional ($T_1 = 1$), single trait herbicide tolerance HT ($T_2 = 1$), single trait insect resistance IR ($T_3 = 1$), and bundling/stacking of HT and IR ($T_4 = 1$). Since the conventional seeds do not include any patented biotech trait, we assume the vertical structure for the conventional seed being not integrated (i.e. only ℓ).

Note that our analysis allows costs (both fixed and variable) to vary across vertical structures. Under vertical integration v, the R&D fixed cost can be recovered directly by the integrated firm but the firm may possibly incur additional transaction costs associated with integration. Under licensing ℓ, a royalty fee is paid by the seed company (licensee) to the biotech firm (licensor). The fee raises the marginal cost of the licensee and should help the licensor recover its R&D investment. In general, the two vertical structures can vary both in terms of efficiency and in terms of exercise of market power. Also, both assessments can be affected by the multi-product nature of the market. For example, the presence and magnitude of economies

[6] A crop-reporting district (CRD) is defined by the US Department of Agriculture to reflect local agro-climatic conditions. In general, a CRD is larger than a county but smaller than a state.

of scope can vary between vertical structures. And as discussed above, the presence of complementarity (or substitution) across vertically differentiated products can reduce (enhance) the firms' ability to exercise market power. The empirical analysis presented below will shed some useful lights on these issues.

We begin with a standard model of hedonic pricing given by:

$$p_{m\tau} = \beta_{m\tau} + \delta_{m\tau} T_m D_\tau + \boldsymbol{\varphi}\mathbf{X} + \varepsilon_{m\tau}\,, \tag{5a}$$

where the price for a seed of type m sold under the τ-th vertical structure is hypothesized to vary with its characteristics (e.g., following Rosen 1974), $\mathbf{X}$ is a vector of covariates that capture various aspects of the market for seeds and $\varepsilon_{m\tau}$ is an error term with mean zero and finite variance. The middle term on the righthand side of equation (5a) contains two binary variables that control for the seed type (T_m) and the vertical structure (D_τ). As shown in equations (2)-(4), we introduce market power effects in (5a) by specifying

$$\beta_{m\tau} = \beta_0 + \sum_{k=1}^{4} \sum_{u \in \mathbf{V}} \beta_{km,u\tau} H_{km,u\tau} Y_{ku} T_m D_\tau\,, \tag{5b}$$

where $\beta_{km,u\tau} \equiv [c_{km,u\tau} - \alpha_{km,u\tau}]$, $H_{km,u\tau} = \sum_{n \in \mathbf{N}} s_{ku}^n s_{m\tau}^n$ is the VHHI defined in (3), and s_{ku}^n is the market share of the n-th firm in the market for the k-th seed type under the u-th vertical structure. When $k \neq m$ and $u \neq \tau$, $H_{km,u\tau}$ provides a measure of cross-market concentration across product types k and m and across vertical structures u and τ. Also, following (4), it follows from (5b) that the market power component in (5a)-(5b) is given by

$$M_{m\tau} = \sum_{k \in \mathbf{Q}} \sum_{u \in \mathbf{V}} \beta_{km,u\tau}\; H_{km,u\tau}\; Y_{ku}\; T_m\, D_\tau\,, \tag{6}$$

where $M_{m\tau} \to 0$ under perfect competition. Equation (6) provides a convenient measure of the effect of imperfect competition under various vertical structures.

To illustrate, the equation estimated for the price of the conventional seed ($T_1 = 1$) is

$$p_{1\ell} = \beta_0 + \sum_{k=1}^{4}(\beta_{k1,\ell\ell}H_{k1,\ell\ell}Y_{k\ell} + \beta_{k1,v\ell}H_{k1,v\ell}Y_{kv})T_1D_\ell + \delta_{1\ell}T_1D_\ell + \boldsymbol{\varphi}\mathbf{X} + \varepsilon_{1\ell},$$

and for the single trait IR seed (T_3 = 1), the price equations for licensed and integrated seeds are, respectively,

$$P_{3\ell} = \beta_0 + \sum_{k=1}^{4}(\beta_{k3,\ell\ell}H_{k3,\ell\ell}Y_{k\ell} + \beta_{k3,v\ell}H_{k3,v\ell}Y_{kv})T_3D_\ell + \delta_{3\ell}T_3D_\ell + \boldsymbol{\varphi}\mathbf{X} + \varepsilon_{3\ell},$$

and

$$p_{3v} = \beta_0 + \sum_{k=1}^{4}(\beta_{k3,\ell v}H_{k3,\ell v}Y_{k\ell} + \beta_{k3,vv}H_{k3,vv}Y_{kv})T_3D_v + \delta_{3v}T_3D_v + \boldsymbol{\varphi}\mathbf{X} + \varepsilon_{3v}.$$

Similar equations can be written for the single trait HT seed (T_2 = 1) and for the bundled/stacked seed (T_4 = 1). The number of observations of vertically integrated IR seeds and stacked seeds (T_{3v} and T_{4v}) is not sufficient in our sample for valid construction of the VHHI's. Therefore, in the example given above for the IR seed market, all of the $\beta_{k3,\tau v}$ terms are set equal to zero. Similar terms for the stacked seed market are also set to zero. The vertical components of the characteristic effects for the IR and stacked seed markets are estimated (i.e. the δ_{3v} and δ_{4v} terms).

Each CRD is presumed to represent the relevant market area for each transaction; thus, all H terms are calculated at that level. Each purchase observation is at the farm- level. The price p in equation (5a) is the net seed price paid by farmers (in \$ per bag[7]). Table 1 contains summary statistics of the data used in the analysis.

The relevant covariates **X** include location, year dummies, each farm's total cotton acreage, and binary terms covering the range of how each purchase was sourced. The location

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[7] In the cottonseed market, farmers used to pay the price in two parts: the "seed price" and then the "technology fee" if the seed were a biotech seed with patented genetic trait technology. More recently, biotech companies changed the pricing scheme, so that farmers only pay a single price that contains both the "seed price" and the "technology fee". To facilitate the analysis of pricing over the study period, we normalize the two part seed pricing in earlier years into the same single pricing format in recent years, i.e., \$ per bag, with 250,000 seeds per bag.

variables are defined as state dummies, capturing spatial heterogeneity in cropping systems and state institutions. Since the CRDs in the two states in our sample are adjacent to each other, we do not expect weather patterns and yield potential to differ substantially across the state border. The year dummies are included to capture the advances in genetic technology, and possible event effects throughout the years of the study. Farm acreage captures possible price discrimination effects related to farm size. Note that farmers may choose different sources for different seed varieties. Including source of purchase as an explanatory variable in (5a) captures possible price discrimination schemes affecting the seed price paid by farmers.

We address two critical econometric issues. First, the potential for endogeneity of the VHHIs is a concern for our econometric estimation of equation (5a)-(5b).[8] Firms' strategies may affect seed pricing, quantity sold (Y), and hence market concentrations (as measured by H) jointly. When some of the determinants of these strategies are unobserved by the econometrician, the interaction terms, $H \cdot Y$, may be correlated with the error term in equation (5a). This would lead to biased and inconsistent parameter estimates. We tested for possible endogeneity of the H's and Y's using a C statistic calculated as the difference of two Sargan statistics (Hayashi 2000, p. 232). The test is robust to violations of the conditional homoscedasticity assumption (Hayashi 2000, p. 232).[9] In our case, the C statistic is 94.60 (with p-value less than 0.01), showing strong statistical evidence against the null hypothesis of exogeneity.

To correct for potential endogeneity bias, we employ an instrumental variable (IV) estimation method. The instruments include the product of the lagged values of H and the lagged values of Y, and the lagged values of Y alone. It is critical that our choice of instruments

[8] The endogeneity of our VHHI terms is at the heart of the foundational points emerging from the Chicago School. Indeed, if increased concentration evolves from the incentives associated with the drive toward efficiency, then price and market structure are jointly determined.

[9] Under conditional homoskedasticity, the C statistic is numerically equivalent to a Hausman test statistic.

satisfy the orthogonality conditions. The Hansen *J* statistic was used to test if the instruments are uncorrelated with the disturbance. Our estimated *J*-statistic was statistically insignificant (with *p*-value of 0.22), suggesting that we have good candidates for instruments. Good instruments should also provide information identifying the parameters: they should not be "weak instruments". In the presence of heteroscedastic errors, we used the Bound et al. (1995) measures and the Shea (1997) partial R^2 statistic to test for weak instruments. Following Staiger and Stock (1997), the test results indicated no statistical evidence that our instruments are weak. Finally, The Kleibergen-Paap weak instrument test was conducted (Kleibergen and Paap 2006),[10] yielding a test statistic of 13.28. Using the critical values presented in Stock and Yogo (2005), this indicated again that our analysis does not suffer from weak instruments.

A second econometric concern involved the potential for heteroskedastic disturbances in the error term in (5a). A Pagan-Hall test[11] of the IV model found strong evidence against homoscedasticity. Unobserved farm-specific factors such as variations in pest populations, soil quality, rainfall, temperature, etc. are likely sources of the heteroscedasticity. While it is reasonable to anticipate these factors to differ across farms, they are not likely to be much different within a farm. This suggests that the variance of the error term in (5a) would exhibit heteroscedasticity, with clustering at the farm level.

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[10] Note that, in contrast with the Cragg-Donald test, the Kleibergen-Paap test remains a valid test for weak instruments in the presence of heteroscedasticity.

[11] Compared to the conventional Breusch-Pagan test, the Pagan-Hall test is a more general test for heteroscedasticity in an IV regression: it remains valid in the presence of heteroscedasticity (Pagan and Hall 1983).

4. Econometric Results

Equations (5a)-(5b) were estimated using the dmrk farm-level data for Texas and Oklahoma. The model was estimated using two-stage least squares (2SLS) with heteroscedasticity-robust standard errors under clustering. Because the demand for seed is a derived demand from farmers' profit maximization, the willingness to pay can be interpreted in terms of marginal profit and the demand slope is the second derivative of farmers' profit. By Young's theorem, this implies the symmetry restrictions $\frac{\partial p_{mu}}{\partial y_{k\tau}} = \frac{\partial p_{k\tau}}{\partial y_{mu}}$. Given that $\frac{\partial p_{mu}}{\partial y_{k\tau}} = \alpha_{mk,u\tau}$, $c_{mk,u\tau} = c_{km,\tau u}$, and $\beta_{mk,u\tau} = [c_{mk,u\tau} - \alpha_{mk,u\tau}]$, the following tests of such restrictions are evaluated:

(I) H_0: $\beta_{mk,\ell\ell} = \beta_{km,\ell\ell}$,

(II) H_0: $\beta_{mk,\ell v} = \beta_{km,v\ell}$,

where the β's are the coefficients of the corresponding VHHI's. Using a Wald test, we failed to reject the null hypotheses in I and II. As a result, we imposed the symmetry restrictions in the analysis presented below.

Table 2 reports the regression results. For comparison purpose, the ordinary least squares (OLS) estimation results with robust standard errors are also reported. The OLS estimation results differ from the 2SLS results substantially, suggesting that our use of IV estimation is needed to deal with endogeneity bias. The analysis presented below relies on the IV/2SLS estimates.

We first discuss the estimates of how prices vary across seed types and vertical structures, followed by a discussion of the estimated effects of market power. Compared to conventional seeds, the results show that all biotech seeds receive a price premium that varies with the vertical structure. The coefficients of the T_iD_v's (i^{th} seed under integrated vertical structure) and T_iD_ℓ's (i^{th} seed under licensing vertical structure), i = 2, 3, 4, are each positive and statistically significant. Ranging from \$75.12 to \$162.88, they show evidence of significant premiums for these biotech traits. Additionally, the stacked biotech seeds are sold at a higher price than the single trait biotech seeds. However, the additional premium is lower than the premium of that relevant trait in the single trait system (as further discussed in section 5).

The model incorporates market share information about each seed type in different vertical structures using the VHHIs. All of the coefficients on the own VHHI terms, i.e. the classical HHI terms ($H_{11,\ell\ell}$, $H_{22,vv}$, $H_{22,\ell\ell}$, $H_{33,\ell\ell}$, and $H_{44,\ell\ell}$) are positive and all but one ($H_{22,\ell\ell}$) is statistically different from zero. These findings reveal that direct competition of similar types of seeds (i.e. conventional, HT-vertically integrated, IR-licensed, and stacked HT/IR-licensed) matters a great deal in the prices that farmers pay. The positive sign for $H_{11,\ell\ell}$, confirms that, for conventional seeds, higher market concentration is associated with higher prices. Similar findings are present for vertically integrated herbicide tolerance ($H_{22,vv}$), licensed insect resistant ($H_{33,\ell\ell}$) and licensed stacked traited ($H_{44,\ell\ell}$) seeds. Note that we broke out the traditional HHIs in the HT market into two modes of vertical delivery: integration (v) and licensing (ℓ). The traditional HHI for the integrated HT market was significant (but not so for the licensed HT market).

We have argued in section 2 that the effects of VHHI $H_{km,u\tau}$, $k \neq m$, and/or $u \neq \tau$ depend on the substitutability/complementarity relationship between the type-k seed in u-th market structure and the type-m seed in τ -th market structure. We expect that an increase in the VHHI will be associated with a rise (decrease) in the price if the two types of seed are substitutes (complements). For the four cross-market VHHIs associated with the conventional seed price ($H_{21,\ell\ell}$, $H_{21,v\ell}$, $H_{31,\ell\ell}$, $H_{41,\ell\ell}$), all are negative and all but $H_{21,\ell\ell}$, is statistically different from zero. These results provide evidence that there exist strong complementarity relationships between conventional seeds and other types of seeds.

Of the three cross VHHIs that may be associated with the pricing of HT biotech seed in the vertically integrated structure ($H_{12,\ell v}$, , $H_{32,\ell v}$, $H_{42,\ell v}$), all have statistically significant coefficients. The coefficient on $H_{32,\ell v}$ is positive and the remaining two ($H_{12,\ell v}$, $H_{42,\ell v}$) are negative. Of the three cross VHHIs that may be relevant to the pricing of HT biotech seed in the licensing structure ($H_{12,\ell\ell}$, $H_{32,\ell\ell}$, $H_{42,\ell\ell}$), only the coefficient on $H_{42,\ell\ell}$ is statistically significant. For the HT market, we also capture the cross effects derived from the two vertical structures: vertically integrated HT seed market's impacts on the HT licensed market ($H_{22,\ell v}$) and vice versa ($H_{22, v\ell}$). Both of these terms are positive and statistically significant, but the magnitude of each effect is quite different. The impact of vertical integration on the licensed market is stronger than the impact of licensing on the vertically integrated market.

Under symmetry restrictions, several of the coefficients of VHHIs involving the licensed *IR* seed and the stacked HT/IR seeds have been discussed. The effect of the VHHI between the licensed *IR*1 seed and the licensed stacking seed ($H_{43,\ell\ell}$) is negative and statistically significant. As discussed above, this implies a complementary relationship.

One focus of our study is the relationship between vertical organization and pricing. Our analysis allows us to evaluate whether seed pricing varies in a similar way with market concentration under alternative vertical structures. This corresponds to the following set of hypotheses:

(III) H_0: $\beta_{km,\ell\ell} = \beta_{km,v\ell} = \beta_{km,vv} = \beta_{km,\ell v}$.

We conducted Wald tests for the null hypotheses $H_{21,\ell\ell} = H_{21,v\ell}$, $H_{42,\ell\ell} = H_{42,\ell v}$, and $H_{23,\ell\ell} = H_{23,v\ell}$. All are rejected at the 5% significance level. This provides strong statistical evidence that vertical organization matters. It indicates that vertical structures interact with the exercise of market power as related to pricing. Further implications of the estimated model are evaluated below (see section 5) with a focus on changing market conditions.

Table 2 also shows how prices vary over time. The year dummy variables show dramatic effects during our study period: in 2004, seed price is $18.29 per bag higher than in 2003, and the price in 2005 is $25.42 per bag less than in 2003. Prices in 2006 increased from the previous year to $58.38 per bag higher than in 2003, and increased further in 2007 to $76.22 per bag higher than in 2003. Given that the mean price is about $122.80 per bag, this gives an annual rate of change between 15% and 70%. Our state dummy variable was insignificant, indicating that prices are not different between Texas and Oklahoma. Table 2 also indicates that the method of purchase does not affect prices. Finally, it shows that the farm size effect is not statistically significant.

5. Implications

While the results in Table 2 reveal the factors affecting the price of cottonseeds, the effects of changes in market conditions are complex in a multi-market context. In this section, we explore the implications of our econometric estimates by simulating how alternative market scenarios are associated with changes in cottonseed pricing. We focus our attention on two sets of scenarios: 1) the impact of stacking/bundling of biotech traits; and 2) the impacts of market size and changing market structures. To support hypothesis testing across scenarios, all simulated prices are bootstrapped.

5.1. Effects of Stacking/Bundling in Different Markets

The implications of stacking for cottonseed prices are presented in Table 3. Evaluated at market conditions in Texas in 2006, Table 3 shows that the prices for biotech seeds (T_2, T_3 and T_4) are significantly higher than the price of conventional seeds (T_1). This is true under both licensing and vertical integration. The price premium paid for biotech traits (compared to conventional seeds) implies that biotech seeds provide farm productivity gains (by increasing yield and reducing labor or pesticide inputs). It also indicates that these gains generate farm profits that are captured in part by biotech and seed firms.

Table 3 shows that the price of stacked seeds (T_4) is higher than the price of single-trait seeds (T_2 or T_3). It also reports stacking effects by comparing the price premium of stacked seeds (T_4) versus the sum of the premium for single-trait seeds (T_2 and T_3). The results show that the premium for stacked seeds is less than the sum of the premium for single trait seeds. The difference is statistically significant. This infers a rejection of component pricing for biotech seeds (where seeds would be valued as the sum of their component values) in favor of sub-additive pricing (where stacked/bundled seeds are sold at a discount compared to the pricing of the individual components). To the extent that both HT and IR technology increases productivity, this provides an incentive for farmers to purchase stacked/bundled seeds (as compared to single-trait biotech seeds). The discounting of bundled traits may reflect complementarities and economies of scope in the production and marketing of biotech traits. In this case, the joint production and marketing of biotech traits may contribute to lowering cost, which may be shared in part with farmers in the form of price discounts offered by seed companies.

Table 3 also shows how vertical structures affect pricing. It reports that seed prices are lower under licensing than under vertical integration. The difference is statistically significant for HT (T_2) and stacked seeds (T_4). This indicates that vertical integration contributes to increasing the price paid by farmers.[12] Finally, Table 3 shows that stacking effects do not vary systematically across vertical structures: sub-additivity in pricing applies under both vertical integration and licensing, and the associated price discounts are not statistically different between the two vertical organizations.

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[12] Note that such effects could be due to quality differences between seeds sold under vertical integration versus licensing. However, data on productivity would be needed to address this issue.

5.2. Effects of Changing Market Size and Market Structures

The effects of changing market conditions are examined by evaluating two effects: the impact of changing market size (as measured by the *Y*); and the impact of changing market concentrations (as measured by the *H*). For simplicity, we focus our attention on observed changes taking place between 2002 and 2006.

The effects of changing market sizes between 2002 and 2006 are reported in the top panel in Table 4, holding the *H*'s (HHIs and VHHIs) at their 2002 level. From 2002 to 2006, both the conventional seed and HT licensed seed have exhibited a declining market share, while the shares in integrated HT, IR and stacked seeds have increased. The results show that, *ceteris paribus*, changing market sizes implies that the price of conventional seed decreases by \$12.06 (significant at the 1% level), the price of licensed HT seed decreases by \$16.91 (significant at the 5% level), the price of the licensed stacking seed increases by \$27.83 (significant at the 10% level) and the price of vertically integrated HT seed increases by \$23.56 (significant at the 10% level). This documents significant correlation of market sizes with seed pricing.

The effects of changing own market concentrations (as measured by the own VHHIs) between 2002 and 2006 are reported in the middle panel in Table 4, holding the *Y*s and cross VHHIs at their 2002 level. From 2002 to 2006, all own VHHIs ($H_{11\ell\ell}$, $H_{22\ell\ell}$, H_{22vv}, $H_{44\ell\ell}$) decreased, with the exception of $H_{33\ell\ell}$, which increased. These own-market concentration measures indicate a trend toward greater competition between 2002 and 2006 in the Texas cottonseed market. One primary source of the increased competition was the successful entry by Bayer CropScience through its FiberMax flagship brand. The results show that, *ceteris paribus*, changing own-market concentrations implied that, except for the licensed IR seeds, all price changes are negative. This is consistent with the patterns of changes in the own VHHIs. The price reduction is $1.78 for the conventional seed, $0.56 for the integrated HT seed, and $3.96 for the stacked seed (all significant at the 1% level).

Finally, the effects of changing all market concentrations (as measured by both the own VHHIs and the cross VHHIs) between 2002 and 2006 are reported in the bottom panel in Table 4, holding the *Y*s at their 2002 level. During these four years, eight cross VHHIs decreased ($H_{12\ell\ell}$, $H_{14\ell\ell}$, $H_{24\ell\ell}$, $H_{24v\ell}$, $H_{13\ell\ell}$, $H_{23\ell\ell}$, $H_{23v\ell}$, $H_{32\ell\ell}$), while two cross VHHIs increased ($H_{12\ell v}$ and $H_{22\ell v}$). There are several possible reasons for these structural changes taking place. Certainly, the emergence of Bayer CropScience and possibly the reactions by other firms to this entrant has had an effect. The results show that, *ceteris paribus*, recent changes in market concentrations implied some increases in all prices. Contrasting the results in the middle panel and the bottom panel in Table 4 illustrates the important role played by cross-market concentration. Generally declining levels of own VHHIs are associated to three statistically significant price declines. However, by including the cross VHHIs in the simulation, two of the prices are now statistically significant and higher in 2006 compared to 2002: the price of vertically integrated HT seed (+$73.30, significant at the 1% level) and that of the licensed stacked seeds (+$16.82, significant at the 1% level). These results underscore the fact that complementarity effects identified in our econometric analysis impact the linkages between market concentrations and pricing. This also stresses the importance of evaluating changing market structures in a multi-product framework.

5.3. Decomposition of the market power effect

Equations (4) and (6) indicate that the market power component of pricing (as measured by *M*) involves two multiplicative components: a component associated with market concentration (called the *H* effect), and a component associated with market size (called the *Y* effect). When market conditions change due to firm entry or merger activities, the market power component *M* will be affected by both *H* and *Y*. This raises the question: how much of the total change in M is due to the market concentration effect H, and how much is due to the market size effect Y? To answer this question, we propose to decompose the total market power component M ($H \cdot Y$) into two parts. Consider a change from (H_0, Y_0) to (H_1, Y_1). The associated change in M is $\Delta M(H \cdot Y) = M(H_1 \cdot Y_1) - M(H_0 \cdot Y_0)$. This can be decomposed as follows:

$$\Delta M(H \cdot Y) = \{M(H_1 \cdot Y_0) - M(H_0 \cdot Y_0)\} + \{M(H_1 \cdot Y_1) - M(H_1 \cdot Y_0)\}$$
$$= \{H \text{ effect}\} + \{Y \text{ effect}\}.$$

The purpose of our next simulation is to evaluate two specific time periods when identifiable changes were likely to have affected the market. The period 2002-2004 includes the years that Bayer CropScience significantly gained in market share (as discussed above). The second period, 2005-2006, covers the years when Monsanto became a vertically integrated biotech firm after merging with an established seed company (Stoneville).

Table 5 shows the estimated market power effect M and its components along with associated standard errors for both scenarios. The first scenario (2002-2004) is presented in the first two columns of results. Of the five seed types (T_1, T_2 licensed, T_2 integrated, T_3 and T_4 licensed) analyzed, the total market power component is negative and significant for conventional seed and for vertically integrated HT seed. Based on the decomposition of H and Y, this result is driven mostly by the Y effects. The H effects are all positive but only statistically significant for the licensed stacked seed. However, when combined with the negative Y effects, its net effect is not significant. The simulation results show that, in a market experiencing dramatic changes in terms of entry/exit, market size has important effects on pricing.

When market conditions changed from 2005 to 2006, the total change on M is positive for the vertically integrated HT biotech seed and the licensed stacked seed (both statistically significant), and is negative for the other three markets but only significant in the conventional seed case. When statistically significant, the H effects are all positive. They are the major driving force for positive change in the total market power component in the integrated HT biotech seed market and the licensed stacking seed market. In the conventional seed market, the *Y* effects are negative and dominate the positive *H* effect, leading to a negative and significant overall change in the market power component. The *Y* effects are not statistically significant in all other cases.

The patterns of decomposition differ between the two scenarios. This indicates how pricing behavior can change with market conditions. For example, entry/exit and merger/acquisition can affect both market size and multi-market concentrations. In our simulations, the different sign of the two components also suggests the importance of complementarity and substitutability across products, with net effects that depend on market conditions.

6. Conclusion

This paper has investigated the impact of differentiated products and vertical strategies by the biotechnology firms in the U.S. cottonseed market. The approach advances the measurement of industry concentration to consider substitution/complementarity relationships among differentiated products delivered under different vertical structures. The model is flexible and allows for evaluation of the implications of market restructuring.

Applied to pricing in the U.S. cottonseed market, the econometric analysis provides useful information on the implications of product differentiation and vertical organization. It evaluates the differential pricing of conventional seeds as well as patented biotech seeds, including herbicide tolerance (HT) seeds, insect resistant (IR) seeds, and stacked/bundled seeds. The model provides for a considerable flexibility in understanding the pricing of cottonseed with different GM traits sold in different vertical structures. Three major results are reported. First, we find that own-market concentration is positively associated with higher prices. This results fits the long-standing interpretation that increasing concentration infers market power to firms that in turn raise price. Second, our estimates show evidence of cross-market complementarities that imply lower prices will occur in the presence of increased concentration across different seed markets. These complementary effects are important and suggest that firms may pass on efficiency gains (perhaps from scope economies) to farmers in the form of lower prices. Finally, our analysis shows that vertical organization affects pricing. We find that pricing of cottonseed is higher under vertical integration than under a licensing arrangement.

We also performed simulations that measure price changes in response to changes in groups of variables. These simulations provided additional insights on the pricing of cottonseeds in ways that capture the complex interactions in the VHHI and market size. When we focused a simulation on only changes to the own VHHI, i.e., the classical HHIs, the results underscored the changing price structure in each seed market under different vertical structures. In three seed markets (conventional, HT-licensed, and IR-licensed), lower concentration led to price declines. However, increased concentration in stacked IR/HT seeds and in vertically integrated HT seeds both led to higher prices. A more comprehensive simulation was also conducted for two periods (2002-2004) and (2005-2006) and we decomposed the overall change in the market power component into two parts: the market size effect and the market concentration effect. The simulations illustrated the joint effects of changes in own and cross-market concentrations along with the effects of expanding or contracting markets. The results provide a foundation for a better understanding of new entrants and mergers in markets with complex vertical and product different. This simulation approach is applicable for pre-merger analysis of industries producing differentiated products and exhibiting similar market complexities.

Table 1. Summary statistics.[a,b]

Variable	Number of observations	Mean	Standard Deviation	Minimum	Maximum
Net Price ($/bag)	4660	122.76	85.39	7.45	642.65
Farm size (acre)	4660	1186.85	1027.21	8	10040
$H_{11,\ell\ell}$[c]	41	0.553	0.243	0.180	1
$H_{12,\ell\ell}$	37	0.433	0.241	0.147	1
$H_{12,\ell v}$	14	0.375	0.235	0.029	0.838
$H_{13,\ell\ell}$	20	0.510	0.289	0.143	1
$H_{14,\ell\ell}$	36	0.467	0.195	0.194	0.831
$H_{22,\ell\ell}$	42	0.599	0.253	0.211	1
$H_{22,\ell v}$	15	0.199	0.131	0.010	0.431
$H_{22,vv}$	20	0.884	0.193	0.504	1
$H_{23,\ell\ell}$	22	0.522	0.256	0.148	1
$H_{23,v\ell}$	9	0.544	0.268	0.089	1
$H_{24,\ell\ell}$	42	0.548	0.252	0.109	1
$H_{24,v\ell}$	15	0.375	0213	0.032	0.717
$H_{33,\ell\ell}$	22	0.864	0.224	0.354	1
$H_{34,\ell\ell}$	22	0.578	0.193	0.270	1
$H_{44,\ell\ell}$	42	0.634	0.213	0.337	1

[a] The data contain 4660 observations from 6 CRDs spanning 7 years (2000, 2002-2007).

[b] For the market concentration measurements H's, we only report the summary statistics of those non zeros at the CRD level, therefore the number of observations is at most $6\times7 = 42$.

[c] The subscripts for seed types are defined as: 1 for conventional, 2 for HT, 3 for IR, and 4 for HT/IR stacked. The subscripts for vertical structure are defined as: ℓ for licensing and v for vertical integration. Moreover, by symmetry, $H_{ij,\ell\ell} = H_{ji,\ell\ell}$ and $H_{ij,\ell v} = H_{ji,v\ell}$, $i \neq j$.

Table 2. OLS and 2SLS estimation with robust standard errors clustered at farm level.[a]

Dependent Variable: Net Price (\$/bag)	OLS		2SLS	
	Coefficient	t-statistic	Coefficient	Robust z statistic
Seed type effects, benchmark is T_1: Conventional seed				
T_2D_ℓ (HT under licensing)	79.47***	16.93	85.24***	11.71
T_2D_v (HT under vertical integration)	56.24***	9.86	79.95***	7.37
T_3D_ℓ (IR under licensing)	70.18***	6.87	75.13***	4.95
T_3D_v (IR under vertical integration)	121.76***	12.27	130.32***	11.46
T_4D_ℓ (stacked seed under licensing)	118.82***	25.38	120.20***	18.81
T_4D_v (stacked seed under vertical integration)	157.32***	27.47	162.88***	25.09
Market concentration				
$H_{11,\ell\ell}T_1D_\ell Y_{1\ell}$ (on conventional seed)	0.113***	3.91	0.198***	4.41
$H_{21,\ell\ell}T_1D_\ell Y_{2\ell}$ (on conventional seed), and $H_{12,\ell\ell}T_2D_\ell Y_{1\ell}$ (on HT1 under licensing)	-0.024	-0.53	-0.075	-1.04
$H_{21,v\ell}T_1D_\ell Y_{2v}$ (on conventional seed), and $H_{12,\ell v}T_2D_v Y_{1\ell}$ (on HT1 under vertical integration)	-0.412***	-5.51	-0.715***	-3.61
$H_{31,\ell\ell}T_1D_\ell Y_{3\ell}$ (on conventional seed), and $H_{13,\ell\ell}T_3D_\ell Y_{1\ell}$ (on IR1 under licensing)	-0.150	-0.54	-0.636**	-2.03
$H_{41,\ell\ell}T_1D_\ell Y_{4\ell}$ (on conventional seed), and $H_{14,\ell\ell}T_4D_\ell Y_{1\ell}$ (on stacked seed under licensing)	-0.231***	-3.85	-0.180*	-1.90
$H_{22,\ell v}T_2D_v Y_{2\ell}$ (on HT under vertical integration)	0.431	0.75	4.249***	3.01
$H_{22,vv}T_2D_v Y_{2v}$ (on HT under vertical integration)	0.860**	2.26	4.482***	5.09
$H_{32,\ell v}T_2D_v Y_{3\ell}$ (on HT under vertical integration), and $H_{23,v\ell}T_3D_\ell Y_{2v}$ (on IR under licensing)	0.168	0.26	6.824***	3.10
$H_{42,\ell v}T_2D_v Y_{4\ell}$ (on HT under vertical integration), and $H_{24,v\ell}T_4D_\ell Y_{2v}$ (on stacked seed under licensing)	0.094	0.16	-5.735***	-3.36
$H_{22,\ell\ell}T_2D_\ell Y_{2\ell}$ (on HT under licensing)	0.086	0.90	0.061	0.39
$H_{22,v\ell}T_2D_\ell Y_{2v}$ (on HT under licensing)	0.366	1.59	1.643***	2.64
$H_{32,\ell\ell}T_2D_\ell Y_{3\ell}$ (on HT under licensing), and $H_{23,\ell\ell}T_3D_\ell Y_{2\ell}$ (on IR under licensing)	0.068	0.14	0.937	0.91
$H_{42,\ell\ell}T_2D_\ell Y_{4\ell}$ (on HT under licensing), and $H_{24,\ell\ell}T_4D_\ell Y_{2\ell}$ (on stacked seed under licensing)	-0.199*	-1.69	-0.495**	-2.45
$H_{33,\ell\ell}T_3D_\ell Y_{3\ell}$ (on IR under licensing)	-0.101	-0.04	7.573*	1.74
$H_{43,\ell\ell}T_3D_\ell Y_{4\ell}$ (on IR under licensing), and $H_{34,\ell\ell}T_4D_\ell Y_{3\ell}$ (on stacked seed under licensing)	0.261	0.52	-2.665***	-3.01
$H_{44,\ell\ell}T_4D_\ell Y_{4\ell}$ (on stacked under licensing)	0.731***	5.30	1.248***	5.37
Other variables				
Location (Oklahoma)	8.79	1.62	5.26	0.77
Year 2004	21.25***	5.38	18.29***	3.26
Year 2005	-19.91***	-5.75	-25.42***	-4.92
Year 2006	69.35***	17.91	58.38***	10.43
Year 2007	77.98***	19.86	76.22***	14.95
Total cotton acreage by each farm (1000 acre)	-0.448	-0.50	-0.82	-0.63
Constant	22.86***	5.31	24.16***	4.15
Number of observations[b]	3518			

[a] Statistical significance is noted as: * 10% level, ** 5% level, and *** 1 % level; The R^2 for the OLS estimation is 0.61. For the 2SLS estimation, the centered R^2 is 0.59, and un-centered R^2 is 0.88.

[b] The number of observations differs from the one reported in table 1 because data in 2002 are used for instruments only.

Table 3 – Effects of Bundling/Stacking in Different Markets on Seed Prices, \$/bag.[a,b]

Seed type	Licensed		Vertically integrated		Difference between vertical structures
	Expected Seed Price	Price difference from T_1	Expected Seed Price	Price difference from T_1	
T_1 (Conventional)	36.75	N/A	N/A	N/A	N/A
T_2 (HT biotech)	123.73	86.98*** (4.25)	172.53	135.79*** (15.16)	-48.81*** (15.40)
T_3 (IR biotech)	141.98	105.23*** (16.14)	172.18	135.43** (11.28)	-30.20 (18.45)
T_4 (stacked biotech)	150.66	113.92*** (11.21)	204.63	167.88*** (6.20)	-53.96*** (11.49)
Stacking effect (T_4 vs. T_2+T_3)	-78.29*** (23.37)		-103.34*** (19.41)		25.05 (19.58)

[a] Bootstrapped standard errors are in parentheses. Statistical significance is noted as: * 10% level, ** 5% level, and *** 1% level.

[b] Market statistics are based on the Texas market in 2006.

Table 4 – Simulated Effects of Changing Market Size and Structure (2002-2006).[a]

Seed type	**Licensed**			**Vertically integrated**		
	2002 Seed Price	2006 Seed Price	2002-2006 Price Difference	2002 Seed Price	2006 Seed Price	2002-2006 Price Difference
Simulation: Market Size Changes Holding VHHIs constant						
T_1 (Conventional)	47.68*** (4.92)	35.62*** (5.06)	-12.06*** (3.05)	N/A	N/A	N/A
T_2 (HT biotech)	123.67*** (7.19)	106.76*** (8.71)	-16.91** (7.95)	103.94*** (10.30)	127.50*** (15.79)	23.56* (14.38)
T_3 (IR biotech)	117.78*** (47.22)	102.23*** (18.56)	-15.55 (45.66)	N/A	N/A	N/A
T_4 (stacked biotech)	124.66*** (13.13)	152.49*** (13.49)	27.83* (16.22)	N/A	N/A	N/A
Simulation: Own VHHI Changes Holding cross VHHIs and Market Size constant						
T_1 (Conventional)	47.68*** (4.92)	45.89*** (4.99)	-1.78*** (0.39)	N/A	N/A	N/A
T_2 (HT biotech)	123.67*** (7.19)	121.82*** (5.62)	-1.85 (4.44)	103.94*** (10.30)	103.39*** (10.28)	-0.56*** (0.12)
T_3 (IR biotech)	117.78*** (47.22)	117.88*** (47.19)	0.10 (0.06)	N/A	N/A	N/A
T_4 (stacked biotech)	124.66*** (13.13)	120.70*** (13.71)	-3.96*** (0.73)	N/A	N/A	N/A
Simulation: Changing Own and Cross VHHIs Holding Market Size Constant						
T_1 (Conventional)	47.68*** (4.92)	48.25*** (4.90)	0.57 (1.57)	N/A	N/A	N/A
T_2 (HT biotech)	123.67*** (7.19)	125.64*** (5.91)	1.96 (3.36)	103.94*** (10.30)	177.25*** (30.67)	73.30*** (27.95)
T_3 (IR biotech)	117.78*** (47.22)	120.05*** (29.89)	2.28 (18.60)	N/A	N/A	N/A
T_4 (stacked biotech)	124.66*** (13.13)	141.49*** (9.33)	16.82*** (4.81)	N/A	N/A	N/A

[a] Bootstrapped standard errors are in parentheses. Statistical significance is noted as: * 10% level, ** 5% level, and *** 1% level.

Table 5: Decomposition of the total market power effects, $/bag.[a,b]

	Scenario I: from 2002 to 2004		Scenario II: from 2005 to 2006	
	Estimated Effect	Standard Error	Estimated Effect	Standard Error
Conventional Seed, T_1				
Total Effect	-4.34***	1.53	-1.70***	0.53
H Effect	0.71	0.98	2.32***	0.50
Y Effect	-5.04***	1.02	-4.02***	0.82
Licensed HT Biotech Seed, $T_{2\ell}$				
Total Effect	-0.77	4.30	-2.86	2.27
H Effect	1.58	2.79	-1.14	1.13
Y Effect	-2.35	2.01	-1.72	2.09
Vertically Integrated HT Biotech Seed, T_{2v}				
Total Effect	-23.33***	7.30	39.80***	7.67
H Effect	11.14	10.41	52.28***	16.53
Y Effect	-34.47**	16.92	-12.47	11.20
Licensed IR Biotech Seed, $T_{3\ell}$				
Total Effect	-8.27	24.19	-3.20	5.92
H Effect	15.66	11.06	-6.51	16.81
Y Effect	-23.93	16.94	3.31	17.54
Licensed HT/IR Stacked Biotech Seed, $T_{4\ell}$				
Total Effect	12.51	10.20	18.56***	3.09
H Effect	15.69***	5.78	12.99***	5.16
Y Effect	-3.18	6.67	5.57	5.24

[a] Statistical significance is noted as: * 10% level, ** 5% level, and *** 1 % level.

[b] Scenario I includes the years when Bayer CropScience gained market share; scenario II covers the years when Monsanto became a vertically integrated biotech firm after merging with an established seed company (Stoneville).

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