An Analysis of Pricing in the U.S. Cotton Seed Market

by

Guanming Shi

Department of Agricultural & Applied Economics
University of Wisconsin
gshi@wisc.edu

Kyle Stiegert

Department of Agricultural & Applied Economics
University of Wisconsin
kwstiegert@wisc.edu

and

Jean Paul Chavas

Department of Agricultural & Applied Economics
University of Wisconsin
jchavas@wisc.edu

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Abstract: The purpose of the research in this paper is to investigate the impact of differentiated vertical strategies by agricultural biotechnology firms in the U.S. cottonseed market. The model advances the measurement of industry concentration to consider substitution/ complementarity relationships among differentiated products delivered under different vertical structures. We find evidence of sub-additive pricing in the stacking of bundled biotech traits. Prices paid by farmers for cottonseed sold under vertical integration are found to be higher than under licensing. The model is flexible and allows for evaluation of the effects of changing market structures. The parameters on traditional measures of concentration indicate that higher concentration leads to higher prices. The effects of cross-market concentrations stress the need to conduct the analysis in a multi-market context.

Key Words: Modal Vertical Strategy, imperfect competition, cotton seed, biotechnology

JEL Code: L13, L4, L65

1. Introduction

The advent of biotechnology seeds has been a catalyst for much change directly or indirectly impacting virtually all parts of the global agro-food complex. Within the agricultural biotech industry itself, the strategies to profit from patented seed traits have been a major driver of firm behavior. In some cases, agricultural biotechnology firms will license patented traits to downstream seed firms. This generates a stream of revenue from technology fees assessed on bags of seed sold to producers. In other cases, agricultural biotech firms with trait patents merge with seed firms to produce and market biotech seeds within a single enterprise. The stakes of the game are quite high and include control of large shares of high-valued end-use markets involving billions of dollars of sales.

When firms possess intellectual property rights (IPRs) such as in the case of agricultural biotechnology firms, differing incentives exist for vertical integration, strategic alliances, and contracting. Graff, Rausser and Small (2003) suggest that vertical integration may be motivated by the complementarity of assets in the agricultural biotechnology and seed industries. If IPRs are well defined and transaction costs are low, contracting and strategic alliances are more likely. However, if IPRs are not well defined, biotech companies might have an incentive to integrate downstream. Goodhue, Rausser, Scotchmer and Simon (2002) point out that the incentives to vertically merge might be driven by differing expected profits between eventual buyers and sellers of assets.

There are also compelling arguments in the literature that the vertical integration occurring in the agricultural biotechnology industry may be motivated by firm strategic considerations (e.g., Kalaitzandonakes and Hayenga, 2000; Fernandez-Cornejo, 2004; Shi, 2009). Complex strategic possibilities emerge when vertically integrated biotechology (VIB) firms also derive revenue from technology fees generated by competing firms' seed sales. The VIB firm may want to raise the technology fee on other seed firms so that its own seed division gains a competitive advantage in final seed sales. In other instances, the biotech firm may want to lower the tech fee to give their contracted seed firms a pricing advantage leading to widespread and rapid adoption of their patented traits.

Several other dimensions of the industry are likely to also impact these decisions. Seed breeding is an inexact science and developing the highest quality seeds for differing agronomic conditions requires considerable investments in human and capital resources many years prior to a successful seed release. The VIB firm may have seed that competes well in some regions and not well in other regions. The VIB firm may find it advantageous to license its traits to firms that do not compete with its seed division in certain regions. The VIB firm could strategically control the introduction of traits in various licensing arrangements in ways that help assure the continued growth of its own seed division. Additionally, the seed available for sale in the current year is constrained by the amount grown for the seed industry in the previous year.

The purpose of the research in this paper is to investigate the impact of different vertical strategies by the biotechnology firms in the U.S. cottonseed market. The model advances the measurement of industry concentration to consider substitution/complementarity relationships among differentiated products delivered under different modes of vertical structure. More specifically, we evaluate vertically aligned markets with both integrated and licensing components. The Herfindahl-Hirschman index (HHI) has been commonly used in applied industrial organization as a measure of market concentration (e.g., Winston, 2006). We generalize this measure into vertical Herfindahl-Hirschman indexes (termed VHHI) that capture both horizontal and vertical market concentration under product differentiation. In turn, the VHHIs are incorporated into a model of price determination capturing the effects of imperfect competition on pricing. The model is developed under the presumption of quantity setting strategies, which fits reasonably well with the market institutions for agricultural seeds. Due to long production lags, the quantity of seed produced in a given year is chosen ahead of the pricing decision.

As applied to the U.S. cottonseed market, the econometric analysis provides useful information on the implications of product differentiation for cottonseed prices. 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 seeds (where HT and IR traits are bundled together). We find evidence of sub-additive pricing in stacked seeds. The analysis also allows an evaluation of the effects of imperfect competition on pricing. As expected, we find that increased market concentration tends to increase price in the corresponding market. But our estimates also show evidence of cross-market complementarities that mitigate the price-enhancing effects of market power. Finally, we document how vertical organization affects cottonseed pricing.

2. Model

The industrial organization model in this paper is designed from quantity setting games to evaluate markets with significant product differentiation and modal vertical strategies. Shi, Chavas, and Stiegert (2008) developed the framework for multiproduct markets, and Shi and Chavas (2009) extended the model to incorporate its vertical components. In this paper, we briefly describe the model in the context of the biotech cottonseed market. The final goods market is comprised of N firms producing up to M outputs: $\mathbf{N} = \{1, \ldots, N\}$; $\mathbf{M} = \{1, \ldots, M\}$. The production and marketing of final goods engages potentially an upstream technology markets under V alternative vertical structures (e.g., vertical contract, integration). The output vector produced by the n-th firm is denoted by $y^n = (y^n_{11}, \ldots, y^n_{m\tau}, \ldots, y^n_{MV}\} \in \Re^{MV}_{+}$. Here, $y^n_{m\tau}$ denotes the quantity the m^{th} good produced by the n^{th} firm under the τ^{th} vertical structure, $m \in \mathbf{M}$, $n \in \mathbf{N}$, $\tau \in \mathbf{V} \equiv \{1, \ldots, V\}$.

Each firm maximizes profit within and across marketing channels. With the potential for implicit or explicit contracts between upstream technology provider and the downstream firm, we want to examine how the exercise of market power can affect both horizontal and vertical markets for cottonseed. We place no restriction on how pricing occurs in different vertical structures. In other words, through a flexible set of firm choices (different labels, brands, advertising, selling strategies, etc.) prices for a given product are allowed to vary across vertical structures. The price-dependent demand for the m^{th} output under the τ^{th} vertical structure is $p_{m\tau}(\sum_{n\in N} y^n)$.

Profit for the n^{th} firm is: $\sum_{m\in\mathbf{M}}\sum_{\tau\in\mathbf{V}}[p_{m\tau}(\sum_{n\in N} y^n)\cdot y^n_{m\tau}]$ - $C_n(y^n)$, where $C_n(y^n)$ represents the n-th firm's total costs of production and marketing. Assuming Cournot behavior in the final goods market, the Kuhn-Tucker conditions for the n^{th} firm for the m^{th} output in the τ^{th} vertical structure $y^n_{m\tau}$ are:

$$p_{m\tau} + \sum_{k\in\mathbf{M}}\sum_{u\in\mathbf{V}} \frac{\partial p_{m\tau}}{\partial y^n_{ku}} \cdot y^n_{m\tau} - \frac{\partial C_n}{\partial y^n_{m\tau}} \le 0, \tag{1a}$$

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

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

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. And it applies for any vertical structure selected by the firm.

For the n-th firm, the cost function $C_n(y^n)$ includes fixed cost $F_n(\mathbf{S}_n)$ satisfying $F_n(\varnothing) = 0$, where $\mathbf{S}_n = \{(j, \tau)\text{: } y^n_{j\tau} > 0, j\in\mathbf{M}, \tau\in\mathbf{V}\}$ is the set of positive outputs. The cost function is assumed to take the form $C_n(y^n) = F_n(\mathbf{S}_n) + \sum_{m\in\mathbf{M}}\sum_{\tau\in\mathbf{V}} c_{m\tau} y^n_{m\tau} + ½\sum_{m,k\in\mathbf{M}}\sum_{\tau,u\in\mathbf{V}} c_{km,u\tau} y^n_{ku} y^n_{m\tau}$, where the second and third terms represent linear and quadratic variable cost, respectively. This implies that marginal costs are linear: $\frac{\partial C_n(y^n)}{\partial y^n_{m\tau}} = c_{m\tau} + \sum_{k\in\mathbf{M}}\sum_{u\in\mathbf{V}} c_{km,u\tau} y^n_{m\tau}$, $m \in \mathbf{M}$, $\tau\in\mathbf{V}$ for all

$n \in \mathbf{N}$. Fixed costs can affect pricing. Under a given vertical structure, such fixed costs can come from two potential sources: the upstream industry (e.g., the investment in R&D for a trait); and the downstream industry (e.g., fixed cost of seed development and/or setup cost of establishing a vertical structure). In either case, fixed costs must be recovered and may require departures from marginal cost pricing to sustain the viability of the firm. In addition, efficiency gains may be possible under alternative vertical organizations and through scope economies. Such scenarios indicate that vertical structures would play a role in pricing. Scope economies would occur when $F_n(\mathbf{S}^a) + F_n(\mathbf{S}^b) > F_n(\mathbf{S}^a \cup \mathbf{S}^b)$ for some $\mathbf{S}^a \subset \mathbf{M} \cup \mathbf{V}$ and $\mathbf{S}^b \subset \mathbf{M} \cup \mathbf{V}$, i.e. when the joint provision of $y^a = \{y^n_{ju} : ((j,\tau) \in \mathbf{S}^a\}$ and $y^b = \{y^n_{ju} : ((j,\tau) \in \mathbf{S}^b\}$ reduces fixed cost (Baumol, Panzar and Willig, 1982, p. 75). This can apply to fixed cost in the upstream technology (e.g., R&D investment contributing to the joint production of y^a and y^b) as well as fixed cost in the downstream technology (e.g., setup 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 y^a and y^b. In the second case, efficiency gains could be generated from producing and selling multiple products in multiple vertical structures.

Let $\frac{\partial p_{ku}}{\partial y_{m\tau}} = \alpha_{km,u\tau}$ with $\alpha_{kk,uu} < 0$. The marginal cost of $y^n_{m\tau}$ is

$\frac{\partial C_n(y^n)}{\partial y^n_{m\tau}} = c_{m\tau} + \sum_{k\in\mathbf{M}} \sum_{u\in\mathbf{V}} c_{km,u\tau} y^n_{m\tau}$, with $c_{kk,uu} \geq 0$ and $c_{km,u\tau} = c_{mk,\tau u}$. Let $Y_{k\tau} = \sum_{n\in N} y^n_{k\tau}$ be the aggregate output of the k^{th} product in the τ^{th} vertical structure, $k \in \mathbf{M}$, $\tau \in \mathbf{V}$. Assume that $Y_{m\tau} > 0$, define $s^n_{m\tau} = \frac{y^n_{m\tau}}{Y_{m\tau}} \in [0, 1]$ as the market share of the n^{th} firm for the m^{th} product in the τ^{th} vertical structure. Dividing equation (1c) by $Y_{m\tau}$ and summing across all $n \in \mathbf{N}$**,** we obtain the following result.

<u>Proposition 1</u>: The pricing of the m-th product under the τ^{th} vertical structure satisfies

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

where

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

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

Following Shi and Chavas (2009), the term defined in (3), $H_{km,u\tau}$, is the vertical Herfindahl-Hirschman index (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. It will be useful to identify this part explicitly by defining

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

Given $H_{km,u\tau} \to 0$ under prefect competition and using (2), it follows that $IC_{m\tau}$ in (4) provides a measure of the effects of imperfect competition on prices. There are four terms that frame $IC_{m\tau}$ in equation (4) and each provide information about how noncompetitive pricing can arise, reflecting the exercise of market power in the m^{th} product market using the τ^{th} vertical structure. 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, $IC_{m\tau}$ in (4) provides a convenient measure of how market concentration and the exercise of market power affect pricing. Equations (2)-(4) are central to our empirical analysis below.

It is clear that public policy concerns about imperfect competition (i.e. merger policy, price fixing, cartels, abuse of dominance) remains principally concerned with the potential negative impacts of concentration on competition (Coates and Ulrich, 2009). Various measures of market concentration have been used to assess firms' exercise of market power. One common and time-honored measure is the Herfindahl-Hirschman Index (HHI), defined as the sum of squared market shares across all firms in the relevant market. When there is a single product (M = 1) and a single vertical structure (V = 1), note that $H_{11,11}$ is the traditional HHI. As a rule of thumb, HHI > 0.18 is considered as a threshold that raises concerns about the degree of competition (Whinston, 2008). As Coates and Ulrich (2009) report, the decision to challenge mergers at the Federal Trade Commission remains focused on HHIs mainly in the 0.20 to 0.50 range. Given $c_{11,11} \geq 0$ and $\alpha_{11,11} < 0$, 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 IC_{11}, and thus an increase in price p_{11}.

Equations (2)-(4) extend the HHI to a multi-product context (when $M > 1$) 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 $IC_{m\tau}$ 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 and magnitude of departure from competitive conditions. Since $\alpha_{km,\tau\tau} = \dfrac{\partial p_{k\tau}}{\partial y^n_{m\tau}}$ 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, $c_{km,\tau\tau} = \dfrac{\partial^2 C_n(y^n)}{\partial y^n_{k\tau} \partial y^n_{m\tau}}$ > 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 increase (decrease) the marginal cost of $y^n_{k\tau}$. Note that the complementary case (where $c_{km,\tau\tau} < 0$) contributes to economies of scope (Baumol et al., p. 75), where multi-output production reduces cost. 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), it follows that the qualitative effects of the market concentration terms $\{H_{km,\tau\tau}\}$ on $IC_{m\tau}$ and on price $p_{m\tau}$ 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 contribute to an increase (a decrease) in $IC_{m\tau}$ 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 structures influence prices. They show that a rise in VHHI $H_{mm,u\tau}$ would be associated with an increase (a decrease) in $IC_{m\tau}$ 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 and magnitude of 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 effects of market concentration on prices. It indicates that a rise in $H_{mm,u\tau}$ would contribute to an increase (a decrease) in $IC_{m\tau}$ when y_{mu} and $y_{m\tau}$ are substitutes (complements).

Are there conditions under which vertical structures would have no effect on the Lerner index? Intuitively, 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 $C_n(y^n) = C_n(\sum_{\tau\in\mathbf{V}} y^n_{1\tau},\ldots,\sum_{\tau\in\mathbf{V}} y^n_{M\tau})$, implying that $c_{m\tau} = c_m$ and $c_{km,u\tau} = c_{km}$ for $m \in \mathbf{M}$ and τ and $u \in \mathbf{V}$. Similarly, perfect substitution on the demand side corresponds to situations where $\frac{\partial p_{ku}}{\partial y_{m\tau}} \equiv \alpha_{km,u\tau} = \alpha_{km}$ for $k, m \in \mathbf{M}$ and all $u, \tau \in \mathbf{V}$. As shown by Shi and Chavas (2009), perfect substitution across vertical structures implies that prices in (2) no longer depend on vertical organization, with $p_{m\tau} = p_m$ for all $\tau \in \mathbf{V}$. This indicates how to test for the effects of vertical structures on prices. It involves the restrictions of perfect substitution: $c_{m\tau} = c_m$, $c_{km,u\tau} = c_{km}$ and $\alpha_{km,u\tau} = \alpha_{km}$ for $k, m \in \mathbf{M}$ and all $u, \tau \in \mathbf{V}$. These restrictions become simple testable hypotheses in equations (2)-(4). They will be tested empirically below in our investigation of the effects of vertical structures on pricing.

Equation (3) shows that our VHHI's $H_{km,u\tau}$ provide the relevant information to assess the role of market power in a vertical sector. As just discussed, this applies in the presence of product differentiation where products are not perfect substitutes across vertical structures. Below, we analyze the pricing implications of vertical structures with an application to the US cottonseed industry. In this application, the upstream firm develops the seed production technology (e.g., a biotech firm developing patented 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. In this context, we will investigate the pricing implications of vertical ownership versus licensing in the US cottonseed industry.

3. Empirical Model

Our analysis uses a data set providing detailed information on the US cotton seed market. The data were collected by **dmr**kynetec [hereafter dmrk]. The dmrk data come from a stratified sample of US cotton farmers surveyed annually in 2000, 2002-2007.[1] The survey provides farm-level information on seed purchases, acreage, seed types, and seed prices. It was collected using computer assisted telephone interviews. Farmers typically buy their seeds locally, and seeds are usually developed for different agro-climate conditions in different regions. We define the "local market" at the Crop Reporting Districts (CRD)[2] 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 measures the determinants 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: 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 seed does not need to add any additional biotech trait, we assume the vertical structure for the conventional seed is not integrated (i.e. only ℓ).

Note that our analysis allows cost (both fixed and variable) to vary across vertical structures. Under vertical integration v, R&D fixed cost can be recovered directly by the

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

[2] 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.

integrated firm but the biotech firm may possibly face higher cost of integration. Under licensing ℓ, a royalty fee is paid by the seed company to the biotech firm. The fee raises the marginal cost of the licensing firm and should help the biotech firm recover its R&D investment. In general, the two vertical structures can vary both in terms of efficiency (e.g., which structures have lower cost?) 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 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 start with a standard model of hedonic pricing 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 m sold with in the τ-th vertical structure

$$p_{m\tau} = \beta_{m\tau} + \sum_{k=1}^{4} \sum_{u \in \mathbf{V}} \delta_{k\tau} T_k D_u + \phi \mathbf{X} + \varepsilon_{m\tau}, \tag{5a}$$

where $\mathbf{X}$ is a vector of other relevant covariates, and $\varepsilon_{m\tau}$ is an error term with mean zero and finite variance.

As shown in equations (2)-(4), we introduce market power effects in (5a) by specifying

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

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

$$IC_{m\tau} = \sum_{k=1}^{4} \sum_{u \in \mathbf{V}} \beta_{km,u\tau} H_{km,u\tau} Y_{ku} T_k D_u \ , \tag{6}$$

where $IC_{m\tau} \to 0$ 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 conventional seeds ($T_1 = 1$) is

$$p_{1\ell} = \beta_0 + \sum_{k=1}^{4} (\beta_{k1,\ell\ell} H_{k1,\ell\ell} Y_{k\ell} + \beta_{k1,v\ell} H_{k1,v\ell} Y_{kv}) T_1 D_\ell + \delta_{1\ell} T_1 D_\ell + \phi X + \varepsilon_{1\ell} \ ,$$

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

$$p_{2\ell} = \beta_0 + \sum_{k=1}^{4} (\beta_{k2,\ell\ell} H_{k2,\ell\ell} Y_{k\ell} + \beta_{k2,v\ell} H_{k2,v\ell} Y_{kv}) T_2 D_\ell + \delta_{2\ell} T_2 D_\ell + \phi X + \varepsilon_{2\ell} \ ,$$

and

$$p_{2v} = \beta_0 + \sum_{k=1}^{4} (\beta_{k2,\ell v} H_{k2,\ell v} Y_{k\ell} + \beta_{k2,vv} H_{k2,vv} Y_{kv}) T_2 D_v + \delta_{2v} T_2 D_v + \phi X + \varepsilon_{2v} \ .$$

Similar equations can be written IR seed ($T_3 = 1$) and for the bundled/stacked seed ($T_4 = 1$). However, the number of observations of vertically integrated seeds for these two types (T_{3v} and T_{4v}) are not sufficient in our sample for valid construction of the VHHI's. Therefore, for these two seed types, we examine the characteristic effects under different vertical structure, and the market concentration effects in the licensed markets only.

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 farm-variety level. The price p in equation (5a) is net seed price paid by farmers (in $ per bag[3]). Table 1 contains summary statistics from 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 variables are defined as state dummies, capturing spatial heterogeneity in cropping systems and state level institutions such as the effectiveness of the state extension systems. Since the CRDs in the two states in our sample are adjacent to each other, we do not expect weather patterns, and yield potential differ much across the state border. The year dummies are included to capture the advances in hybrid and 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 (4a) captures possible price discrimination schemes affecting the seed price paid by farmers.

[3] In the cottonseed market, farmers used to pay the price in two parts: the "seed price" and then the "technology fee". More recently, biotech companies changed the pricing scheme, so that farmers only pay a single price which 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.

Table 1. Summary statistics

Variable	Number of observations[a,b]	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
$H_{11,\ell\ell}$	41	0.553	0.243	0.180	1
$H_{12,\ell\ell}$ [c]	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 6×7 = 42.
[c]/ By symmetry, $H_{ij,\ell\ell} = H_{ji,\ell\ell}$ and $H_{ij,\ell v} = H_{ji,v\ell}$, $i \neq j$.

4. Econometric Results

Equations (5a)-(5b) were estimated using the dmrk farm-level data for the High Plains region of Texas and Oklahoma. The model was estimated using two-stage least squares (2SLS) to deal with the possible endogeneity of the *H*'s and *Y*'s. 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 pretests 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 and symmetry restrictions were imposed.

Table 2 reports the model estimation using 2SLS, with heteroscedastic-robust standard errors under clustering. 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. Being in the range 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, while the additional premium seems to be lower than the premium of that relevant trait in the single trait system. Of course, such price premiums must be justified in cost/time savings to the farmer and/or increased yields derived from a bag of planted seed.

The model incorporates market share information about each seed type in different vertical structures using the VHHIs. All of the traditional 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 leads to 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. This seems to infer that farmers purchasing seed with licensed biotech traits do not have a strong purchase preference and are more apt to substitute with other seed types than farmers that purchase from the integrated seed company.

We have argued in section 2 that the effects of VHHI $H_{mk,u\tau}$, $k \neq m$, and/or $u \neq \tau$ 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 four cross market VHHIs that may affect 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 complementarity relationships between conventional seeds and other type of seeds.

Of the three cross VHHIs that may affect the pricing of HT biotech seed in the vertically integrated structure ($H_{12,\ell v}$, , $H_{32,\ell v}$, $H_{42,\ell v}$), all are statistically significant., $H_{32,\ell v}$ is positive and the remaining two ($H_{12,\ell v}$, $H_{42,\ell v}$) are negative. Of the three cross VHHIs that may affect the pricing of HT biotech seed in the licensing structure ($H_{12,\ell\ell}$, $H_{32,\ell\ell}$, $H_{42,\ell\ell}$), only the $H_{42,\ell\ell}$ 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. It seems the impact of the vertical integration on the licensed market is over twice as strong as the impact of licensing on the vertically integrated market. This is consistent with our earlier finding that the traditional HHI for vertically integrated HT markets was significant while the licensed market was not.

Under the symmetry restrictions, several of the coefficients of VHHIs affecting 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. This implies a complementary relationship.

One area of interest is the issue of vertical organization's affect on pricing. From our results, we can evaluate whether market concentrations have similar impacts on seed prices in alternative vertical structures from 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 test for the null hypotheses $H_{21,\ell\ell} = H_{21,v\ell}$, $H_{42,\ell\ell} = H_{42,\ell v}$, and $H_{23,\ell\ell} = H_{23,v\ell}$, and all are rejected at 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 they affect pricing. Further implications of the estimated model are evaluated below (see section 5) with a focus on the effects of changing market conditions on cottonseed pricing.

Table 2 – 2SLS estimation with robust standard errors clustered at farm level[a, b, c]

Dependent Variable: Net Price ($/bag)	Coefficient	Robust z statistics
Seed type effects, benchmark is T_1: Conventional seed		
T_2D_ℓ (HT in licensing structure)	85.24***	11.71
T_2D_v (*HT* in vertically integrated structure)	79.95***	7.37
T_3D_ℓ (IR in licensing structure)	75.13***	4.95
T_3D_v (IR in vertically integrated structure)	130.32***	11.46
T_4D_ℓ (stacking in licensing structure)	120.20***	18.81
T_4D_v (stacking in vertically integrated structure)	162.88***	25.09

Market concentration effects		
$H_{11,\ell\ell}T_1D_\ell Y_{1\ell}$ (on conventional seed)	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* in licensing structure)	-0.075	-1.04
$H_{21,v\ell}T_1D_\ell Y_{2v}$ (on conventional seed), and $H_{12,\ell v}T_2D_vY_{1\ell}$ (on *HT1* in vertically integrated structure)	-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* in licensing structure)	-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 stacking seed in licensing structure)	-0.180*	-1.90
$H_{22,\ell v}T_2D_vY_{2\ell}$ (on HT in vertically integrated structure)	4.249***	3.01
$H_{22,vv}T_2D_vY_{2v}$ (on HT in vertically integrated structure)	4.482***	5.09
$H_{32,\ell v}T_2D_vY_{3v}$ (on HT in vertically integrated structure), and $H_{23,v\ell}T_3D_\ell Y_{2v}$ (on IR in licensing structure)	6.824***	3.10
$H_{42,\ell v}T_2D_vY_{4v}$ (on HT in vertically integrated structure), and $H_{24,v\ell}T_4D_\ell Y_{2v}$ (on stacking seed in licensing structure)	-5.735***	-3.36
$H_{22,\ell\ell}T_2D_\ell Y_{2\ell}$ (on HT in licensing structure)	0.061	0.39
$H_{22,v\ell}T_2D_\ell Y_{2v}$ (on HT in licensing structure)	1.643***	2.64
$H_{32,\ell\ell}T_2D_\ell Y_{3\ell}$ (on HT in licensing structure), and $H_{23,\ell\ell}T_3D_\ell Y_{2\ell}$ (on IR in licensing structure)	0.937	0.91
$H_{42,\ell\ell}T_2D_\ell Y_{4\ell}$ (on HT in licensing structure), and $H_{24,\ell\ell}T_4D_\ell Y_{2\ell}$ (on stacking seed in licensing structure)	-0.495**	-2.45
$H_{33,\ell\ell}T_3D_\ell Y_{3\ell}$ (on IR in licensing structure)	7.573*	1.74
$H_{43,\ell\ell}T_3D_\ell Y_{4\ell}$ (on IR in licensing structure), and $H_{34,\ell\ell}T_4D_\ell Y_{3\ell}$ (on stacking seed in licensing structure)	-2.665***	-3.01
$H_{44,\ell\ell}T_4D_\ell Y_{4\ell}$ (on stacking seed in licensing structure)	1.248***	5.37
Other variables		
Location (Oklahoma)	5.26	0.77
Year 2004	18.29***	3.26
Year 2005	-25.42***	-4.92
Year 2006	58.38***	10.43
Year 2007	76.22***	14.95
Total acre grown cotton by each farm (1000 acre)	-0.82	-0.63
Constant	24.16***	4.15
Number of observations	3518	

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

[b] The centered R^2 is 0.59, and un-centered R^2 is 0.88.

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

Table 2 also shows how prices vary over time with respect other factors. The year dummy effects show dramatic changes 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. Price in 2006 increase from the previous year to $58.38 per bag higher than in 2003, and increase 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 change rate between 15% and 70%. Whether the seeds are sold in Texas or Oklahoma does not affect price. This is evidence that there are not statewide institutions, policies or programs that impact Oklahoma cottonseed sales differently than in the upland Texas region. There is also no evidence that the method of purchase affects prices. Finally, table 2 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 cotton seeds, 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 the effects of alternative market scenarios for cotton seed 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 sample means, Table 3 shows that the prices for biotech seeds ($\boldsymbol{T_2}$, $\boldsymbol{T_3}$ and $\boldsymbol{T_4}$) are significantly higher than the price of conventional seeds ($\boldsymbol{T_1}$). This is true under both licensing and vertical integration. The price premium paid for biotech traits (compared to conventional seeds) reflects that biotech seeds provide farm productivity gains (by increasing yield and reducing herbicide and pesticide use). It also indicates that these gains generate farm profits that are captured in part by seed companies (in the form of higher seed prices). Table 3 shows that the price of stacked seeds ($\boldsymbol{T_4}$) is higher than the price of single-trait seeds ($\boldsymbol{T_2}$ or $\boldsymbol{T_3}$). It also reports stacking effects by comparing the price premium of stacked seeds ($\boldsymbol{T_4}$) versus the sum of the premium for single-trait seeds ($\boldsymbol{T_2}$ and $\boldsymbol{T_3}$). 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. Evaluated at sample means, it reports that seed prices are lower under licensing than under vertical integration. The difference is statistically significant for HT ($\boldsymbol{T_2}$) and stacked seeds ($\boldsymbol{T_4}$). This indicates that vertical integration contributes to increasing the price paid by farmers. Without data on productivity, it is unclear whether such effects could be due to quality differences between seeds sold under vertical integration versus licensing. 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.

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)	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] 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.

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 Ys); and the impact of changing market concentrations (as measured by the VHHIs). 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 Table 4, holding the 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. Table 4 shows that, ceteris paribus, changing market sizes implied that the price of conventional seed decrease by $12.06 (significant at 1% level), the price of licensed HT seed decrease by $16.91 (significant at 5% level), the price of the licensed stacking seed will increase by $27.83 (significant at 10%) and the price of vertically integrated HT seed increases by $23.56 (significant at 10%). This documents significant effects of market sizes on seed pricing.

Table 4 – Simulated Effects of Changing Market Sizes, 2002-2006.

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
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

[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.

The effects of changing own market concentrations (as measured by the traditional HHIs) between 2002 and 2006 are reported in Table 5, holding the Ys and cross VHHIs at their 2002 level. From 2002 to 2006, all traditional HHIs ($H_{11\ell\ell}$, $H_{22\ell\ell}$, 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, which reflects the successful entry by Bayer CropScience through its FiberMax flagship, starting in 1999 and taking off since 2002. Table 5 shows that, ceteris paribus, changing own-market concentrations implied that, except for the licensed IR1 seeds, all price changes are negative. This is consistent with the patterns of changes in traditional HHIs. The price reduction is $1.78 for the conventional seed, $0.56 for the integrated HT seed, and $3.96 for the stacking seed (all significant at 1% level).

Table 5 – Simulated Effects of Changing only HHIs, 2002-2006.

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
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

[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.

Finally, the effects of changing all market concentrations (as measured by both the HHIs and the VHHIs) between 2002 and 2006 are reported in Table 6, holding the Ys at their 2002 level. During these four years, eight 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 VHHIs increased ($H_{12\ell v}$ and $H_{22\ell v}$). This again may be due to the Bayer CropScience effect. Table 6 shows that, ceteris paribus, recent changes in market concentrations implied some increases in all prices. Contrasting the results in Tables 5 and 6 illustrates the important role played by cross-market concentration measures. In Table 5, generally declining levels of traditional HHIs led to three statistically significant price declines. By including the cross HHIs to 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 1% level) and that of the licensed stacked seeds (+$16.82, significant at 1% level).These results underscore 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.

Table 6 – Simulated Effects of Changing all Market Concentrations (HHIs and VHHIs), 2002-2006.

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
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] 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.

6. Conclusion

This paper has investigated the impact of differentiated 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 effects of changing market restructures.

Applied to the 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. We find evidence of sub-additive pricing in stacked seeds. The analysis also allows an evaluation of the effects of imperfect competition on pricing. As expected, we find that increased market concentration tends to increase price in the corresponding market. But our estimates also show evidence of cross-market complementarities that affects the linkages between market concentrations and pricing. Finally, we analyze how vertical organization affects pricing. We find that pricing of seed from VIB firms is higher than the price of biotech seeds sold under licensing arrangement. Additional research is needed to explain such pricing patterns.

Simulations of the estimated model provided additional insights on the pricing of cottonseeds. The first simulation documented the sub-additive pricing in stacked seeds. The second simulation showed how changing market sizes affected seed prices. The third and fourth simulations evaluated the effects of changing market structure (i.e. concentration) on prices. They illustrated the effects of changes in cross-market concentrations. This stresses the need to evaluate changes in both horizontal and vertical market structures in a multi-market context.

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