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

by

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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

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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:

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

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

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

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 $F_n(\emptyset) = 0$, 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 $C_n(y^n) = C_n(\sum_{\tau\in\mathbf{V}} y^n_{1\tau},...,\sum_{\tau\in\mathbf{V}} y^n_{Q\tau})$, 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

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

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

$$P_{3\ell} = \beta_0 + \sum_{k=1}^{4} (\beta_{k3,\ell\ell} H_{k3,\ell\ell} Y_{k\ell} + \beta_{k3,v\ell} H_{k3,v\ell} Y_{kv}) T_3 D_\ell + \delta_{3\ell} T_3 D_\ell + \boldsymbol{\varphi}\mathbf{X} + \varepsilon_{3\ell} ,$$

and

$$p_{3v} = \beta_0 + \sum_{k=1}^{4} (\beta_{k3,\ell v} H_{k3,\ell v} Y_{k\ell} + \beta_{k3,vv} H_{k3,vv} Y_{kv}) T_3 D_v + \delta_{3v} T_3 D_v + \boldsymbol{\varphi}\mathbf{X} + \varepsilon_{3v} .$$

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.

[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.

[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 6×7 = 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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