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On Pricing and Vertical Organization of Differentiated Products

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Abstract: This paper investigates the pricing and vertical organization of differentiated products under imperfect competition. In a multiproduct context, a Cournot model is used to examine how substitution/complementarity relationships among products and vertical structures can affect the exercise of market power. This motivates a generalization of the Herfindahl-Hirschman index (termed VHHI) capturing how market concentration and vertical structures interact to influence prices of differentiated products. The analysis is applied to pricing of soybean seeds in the US over the period 2000-2007. We consider two vertical structures employed by biotech firms: vertical integration and licensing. The econometric analysis finds evidence that vertical organization has significant effects on seed prices. These effects are found to vary depending on the institutional setup and the bundling of genetic material. The empirical evidence shows that complementarity and economies of scope can reduce the effects of market concentration on prices.

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

JEL Code: L13, L4, L65

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On Pricing and Vertical Organization of Differentiated Products

1. Introduction

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

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

This paper addresses both challenges. First, it develops a Cournot model of the effects of vertical structures on the pricing of differentiated products under imperfect competition. The analysis shows how substitution/complementarity relationships across vertical channels can affect the exercise of market power. It provides a structural representation of price determination with an explicit characterization of market power effects. The Herfindahl-Hirschman index (HHI) has been commonly used to assess horizontal market concentration (e.g., Whinston 2008). We propose a vertical HHI (termed VHHI) that captures how market concentration and vertical organization interact with each other in influencing the pricing of differentiated products.

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

The advances in agricultural biotechnology have also led to the bundling of patented genetic traits, where multiple traits are stacked within a seed. The economic literature has analyzed three types of bundle pricing: component pricing where the price of a product is set equal to the sum of the value of its components; pure bundling where consumers are restricted to choose between either a fixed bundle of components or nothing at all; and mixed bundling where products are offered both bundled and unbundled, each being priced separately (e.g., Adams and Yellen 1976; McAfee et al. 1989; Whinston 1990). Our analysis investigates the nature of bundle pricing in the US soybean biotech seed industry. To our knowledge, previous literature has not studied how bundling behavior and pricing can vary under alternative vertical structures. Our empirical investigation provides new and useful insights into the interactions between bundle pricing and vertical organization.

The soybean seed market makes an excellent case study for three reasons. First, a flurry of mergers in the 1990s led a few large biotech firms to dominate the US soybean seed industry (Fernandez-Cornejo 2004). The top four largest firms accounted for 40% of the soybean seed market in the late 1980s, a substantial rise from 5.2% in 1980 (Fernandaz-Cornejo 2004). Our data show that this percentage further increased to 55% in 2007. As noted by Graff, Rausser and Small (2003), these mergers have been motivated in part by the complementarities of assets within and between the agricultural biotechnology and seed industries. This means that seed markets may be highly concentrated due to the efficiency gains obtained from greater integration (e.g., due to economies of scope in the production of genetic traits). But market power by biotech firms can also be used to increase seed prices, leading to adverse effects on economic efficiency and farmers' profits (e.g., Fulton and Giannakas 2001; Fernandez-Cornejo 2004).

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

Finally, the biotechnology revolution has stimulated the development of product differentiation involving patented genetic material. Our analysis of the soybean seed market helps assess the pricing implications of alternative forms of product differentiation. In addition, the seeds can differ by the institutional setup of providers. The US soybean seed industry has experienced a rapid shift from public sector breeding to private sector breeding since the 1970s. The acreage share of publicly developed varieties decreased from over 70% in 1980 to 10% in the mid-1990s (Fernandez-Cornejo, 2004), and is 0.5% in 2007 according to our data.[2] Such changes were caused in large part by advances in breeding technology (including biotechnology) and changes in the intellectual property protection of life forms since the 1980s. At this point, the implications of such institutional changes for pricing are not well understood. Our study provides new and useful information of these effects.

Our econometric analysis examines the nature of product differentiation and pricing. The empirical evidence shows how market concentration and vertical organization interact to affect soybean seed prices. It finds that such effects vary with the vertical organization and the institutional setup of the seed providers. As expected, we find that publicly sourced seeds are priced significantly lower than privately sourced seeds. We uncover evidence that complementarity and economies of scope can reduce the effects of market concentration on prices of privately sourced seeds. We also find that seeds sold through vertically integrated structure are priced higher than those through licensing, but not for seeds that bundle more than one biotech trait. In addition, we fail to reject component pricing under licensing. But we

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

strongly reject component pricing under vertical integration, where the evidence points to sub-additive pricing.

The paper is organized as follows. Section 2 presents a conceptual framework of multiproduct pricing under imperfect competition. It develops a Cournot model introducing the VHHIs capturing the effects of imperfect competition in both vertical and horizontal markets. Sections 3 and 4 present an econometric application to the US soybean seed market. Using the VHHIs as measures of market concentrations, we evaluate how market power affects pricing of differentiated products under alternative vertical structures. The estimation method and econometric results are discussed in section 5. Sections 6 and 7 report the empirical findings and evaluate their implications. Finally, section 8 concludes.

2. The Model

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

Each firm maximizes profit within and across marketing channels. We assume the existence of contracts (implicit or explicit) between the upstream technology provider and the downstream firm. Such contracts mean that production and marketing decisions are made efficiently so as to maximize firm profit in the vertical channel.[3] In this context, we want to examine how the exercise of market power can affect both horizontal and vertical markets. The profit of the n-th firm is $\sum_{k\in\mathbf{K}}\sum_{\tau\in\mathbf{V}}[p_{k\tau}(\sum_{n\in N} y^n)\cdot y^n_{k\tau}]$ - $C_n(y^n)$, where $C_n(y^n)$ denotes the n-th firm's cost of producing y^n. Assuming a Cournot game and under differentiability, the profit maximizing decision of the n-th firm for the k-th output in the τ-th vertical structure $y^n_{k\tau}$ satisfies

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

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

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

Equation (1c) is the complementary slackness condition which applies whether the k-th output is produced by the n-th firm in the τ-th vertical structure ($y^n_{k\tau} > 0$) or not ($y^n_{k\tau} = 0$). Equation (1c) remains valid whether or not the n-th firm produces the k-th output, i.e. it applies no matter how many of the K products the firm chooses to sell. And equation (1c) holds irrespective of the vertical structure chosen by the n-th firm in marketing its products. It means that, under imperfect competition, equation (1c) allows for situations where the actions of one firm can restrict the involvement of other firms in given vertical markets. As such, it can represent foreclosure strategies that have been the subject of much scrutiny (e.g., Ordover, Saloner, and Salop 1990; Whinston 2006; Rey and Tirole 2008).

We assume that the cost function takes the form $C_n(y^n) = F_n(\mathbf{R}_n) + \sum_{k\in\mathbf{K}}\sum_{\tau\in\mathbf{V}} c_{k\tau} y^n_{k\tau}$ + $0.5\sum_{k,m\in\mathbf{K}}\sum_{\tau,u\in\mathbf{V}} c_{mk,u\tau} y^n_{mu} y^n_{k\tau}$, where $\mathbf{R}_n = \{(j, \tau)\text{: } y^n_{j\tau} > 0, j\in\mathbf{K}, \tau\in\mathbf{V}\}$ is the set of positive

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[3] Note that the presence of efficient vertical contracts rules out vertical externalities. Taking into consideration the effects of vertical externalities is briefly discussed in footnote 5.

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

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

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

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

which can be alternatively written as

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

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

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

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

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

Equation (4) provides useful information on the structural determinants of $M_{k\tau}$. When there is a single product ($K = 1$) and a single vertical structure ($V = 1$), note that $H_{11,11}$ is the traditional Herfindahl-Hirschman index (HHI) providing a measure of market concentration. The HHI is commonly used in the analysis of the exercise of market power (e.g., Whinston 2008). Given positive marginal cost ($c_{11,11} \geq 0$) and negative demand slope ($\alpha_{11,11} < 0$), equations (3)-(4) indicate that an increase in the HHI, $H_{11,11}$, (simulating an increase in market power) is associated with an increase in M_{11}, and thus an increase in price, p_{11}. As a rule of thumb, regulatory agencies have considered that $H_{11,11} > 0.1$ corresponds to concentrated markets where the exercise of market power can potentially raise competitive concerns (e.g., Whinston 2006).

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

$\alpha_{mk,\tau\tau}$] would be positive when $y^n_{m\tau}$ and $y^n_{k\tau}$ behave as substitutes on both the supply and demand side. And it would be negative when $y^n_{m\tau}$ and $y^n_{k\tau}$ behave as complements on both the supply and demand side. From equations (3) and (4), it follows that the qualitative effects of the market concentration terms $\{H_{mk,\tau\tau}\}$ on $M_{k\tau}$ and on price, $p_{k\tau}$, depend on the nature of substitution or complementarity among outputs (through the terms $[c_{mk,\tau\tau} - \alpha_{mk,\tau\tau}]$).[4] A rise in $H_{mk,\tau\tau}$ would contribute to an increase (a decrease) in $M_{k\tau}$ when two products within a vertical channel ($y_{k\tau}$ and $y_{m\tau}$) are substitutes (complements).

Of special interest here are the effects of vertical structures on pricing. Consider the case where $u \neq \tau$ and $k = m$. Then, equations (3) and (4) also show how vertical structures influence prices. They show that a rise in VHHI $H_{kk,u\tau}$ would be associated with an increase (a decrease) in $M_{k\tau}$ if $[c_{kk,u\tau} - \alpha_{kk,u\tau}] > 0$ (< 0).[5] This indicates that, for a given product *k*, the sign of $[c_{kk,u\tau} - \alpha_{kk,u\tau}]$ affects the nature and magnitude of departure from competitive pricing. As just discussed, we expect $[c_{kk,u\tau} - \alpha_{kk,u\tau}] > 0$ (< 0) when product *k* exhibits substitution (complementarity) across vertical structures *u* and τ. Thus the terms $H_{kk,u\tau}$'s in equations (3)-(4) show how the nature of substitution or complementarity across vertical structures influences the effects of market concentration on prices. It indicates that a rise in $H_{kk,u\tau}$ would contribute to an increase (a decrease) in $M_{k\tau}$ when the *k*th product across two vertical channels (y_{ku} and $y_{k\tau}$) are substitutes (complements).[6]

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

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

[6] Our analysis implicitly assumes that vertical contracts are efficient. Possible inefficiencies in vertical contracts have been discussed (e.g., Spengler 1950; Tirole 1992). They include situations of "double marginalization" where a failure to deal with vertical externalities can induce a reduction in perceived

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

Under conditions of perfect substitution across vertical structures, equation (2) becomes

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

for $k \in \mathbf{K}$ and $\tau \in \mathbf{V}$. Denote the aggregate market share of the τ-th vertical structure for the k-th product by $S_{k\tau} = \frac{Y_{k\tau}}{Y_k} \in [0, 1]$, where $Y_k \equiv \sum_{n\in N} \sum_{\tau\in V} y^n_{k\tau} > 0$. Multiplying (2') by $S_{k\tau}$ and summing across all $\tau \in \mathbf{V}$ gives

$$p_{k\tau} = c_k + \sum_{m\in\mathbf{K}} (c_{mk} - \alpha_{mk}) \sum_{n\in\mathbf{N}} S^n_m S^n_k Y_m\,, \tag{2''}$$

where $S^n_k = \frac{\sum_{\tau\in\mathbf{V}} y^n_{k\tau}}{\sum_{n\in\mathbf{N}} \sum_{\tau\in\mathbf{V}} y^n_{k\tau}} \in [0, 1]$ is the market share of the n-th firm for the k-th product. Note that the right-hand side of (2") does not depend on the vertical structure τ. This gives the desired result: under perfect substitution, pricing is independent of vertical structures as $p_{k\tau} = p_k$ for all $\tau \in \mathbf{V}$. Under equation (2"), equations (3) and (4) would become

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demand and inefficient price enhancements. Note that, in our case, such reductions in perceived demand could be captured by changes in the demand slope parameters α's.

$$p_k = c_k + \sum_{m\in\mathbf{K}} (c_{mk} - \alpha_{mk}) H_{mk} Y_m \ , \qquad (3')$$

and

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

where $H_{mk} = \sum_{n\in\mathbf{N}} S_m^n \cdot S_k^n$. Note that, when $k = m$, H_{kk} reduces to the standard HHI that would be obtained ignoring vertical structures.[7] Equations (2") and (3') are the pricing rules that would apply under perfect substitution across vertical structures. In contrast to equations (2) and (3), they show that vertical structures no longer affect pricing.

Equation (3) shows that our VHHIs $H_{mk,u\tau}$ provide the relevant information to assess the role of market power across vertical structures. As just discussed, this applies in the presence of product differentiation where products are not perfect substitutes across vertical structures. Besides being consistent with Cournot-imperfect competition for differentiated products, equation (3) provides a convenient basis for supporting an empirical analysis of how market power gets exercised in vertical channels. Below, this is used to analyze the pricing implications of product differentiation, bundling and vertical structures in the US soybean seed industry.

3. Data

Our analysis relies on an extensive data set providing detailed information on the US soybean seed market. The data were collected by **dmr**kynetec [hereafter dmrk]. The dmrk data come from a stratified sample of US soybean farmers surveyed annually from 2000 to 2007.[8]

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[7] Comparing (3) and (3'), there exists a close relationship between $H_{mk} \equiv \sum_{n\in\mathbf{N}} S_m^n S_k^n$ and our VHHIs $H_{mk,u\tau} = \sum_{n\in\mathbf{N}} s_{mu}^n s_{k\tau}^n$. The general relationship is: $H_{mk} = \sum_{u\in\mathbf{V}} \sum_{\tau\in\mathbf{V}} H_{mk,u\tau} \frac{Y_{mu}}{Y_m} \frac{Y_{k\tau}}{Y_k}$, showing that H_{mk} is a weighted average of our VHHIs $H_{mk,u\tau}$, with market shares as weights.

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

The survey provides farm-level information on seed purchases, acreage, seed types, and seed prices. It was collected using computer assisted telephone interviews.

Since farmers typically buy their seeds locally, and seeds suitable for planting in the local market are often different across regions, our analysis defines the "local market" at the Crop Reporting District (CRD)[9] level. To guarantee reliable measurement of market concentrations, our analysis focuses on those CRDs with more than ten farms sampled every year between 2000 and 2007. The data contain 76,308 observations from 76 CRDs in 18 different states.[10] On average, around 3000 farmers are included in the sample every year, of which between 30-50% remain in the sample for the next year.[11]

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

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

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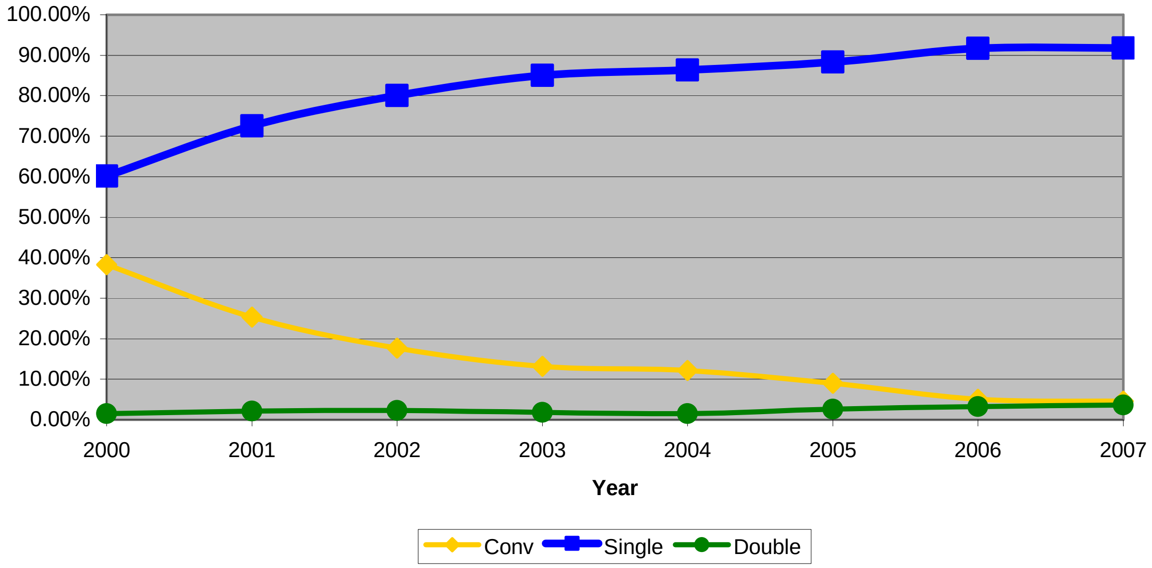
[9] A crop-reporting district (CRD) is defined by the US Department of Agriculture to reflect local agro-climatic conditions. In general, a CRD is larger than a county but smaller than a state.

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

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

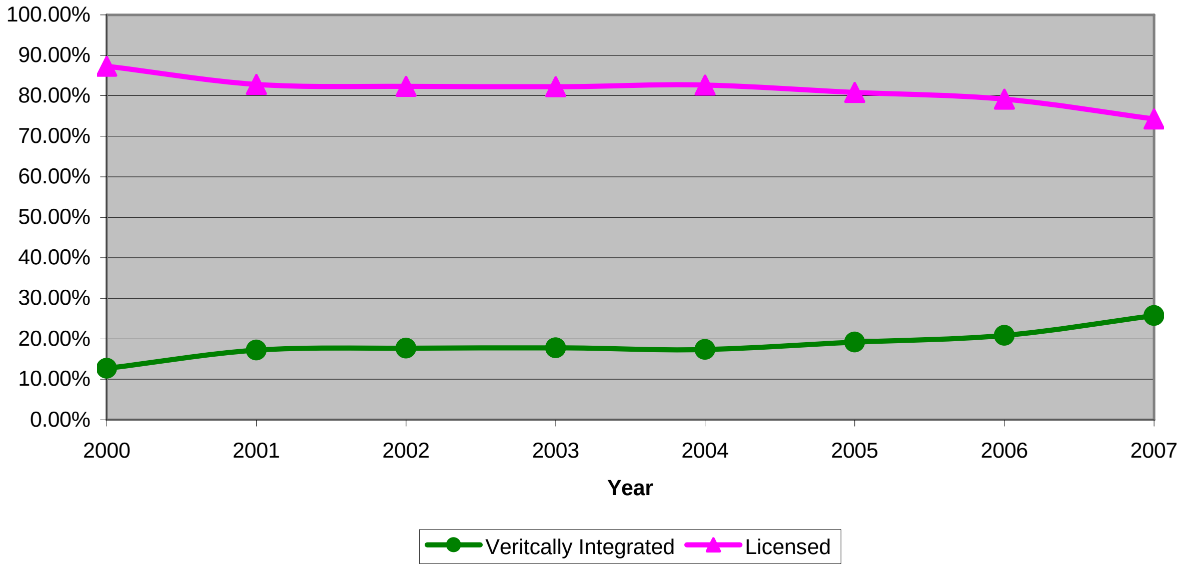
Typically, the biotech seeds can be distributed by seed companies affiliated with the biotech companies who own that trait, and/or by those not affiliated. According to patent law, if a non-affiliated seed company wants to produce a seed with the patented trait, it needs to obtain a license from the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

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



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

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



4. Econometric specification

Our analysis of the determinants of soybean seed prices builds on equation (3). As derived, equation (3) is a structural equation reflecting the determinants of pricing under imperfect competition of differentiated products under alternative vertical structures. As noted above, we focus our attention on the case of two vertical structures: *vertical integration*, v, and *licensing*, ℓ, and four seed types, each with genetic traits that can be present either individually or bundled/stacked together. Let $T_k \in \{0, 1\}$ be dummy variables for seed types, satisfying $T_k = 1$ for the k-th seed type and $T_k = 0$ otherwise, $k \in \mathbf{K} = \{1, \ldots, 4\}$, with $\sum_{k=1}^{4} T_k = 1$: conventional ($T_1 = 1$), single trait $HT1$ ($T_2 = 1$), single trait $HT2$ ($T_3 = 1$), and bundling/stacking of $HT1$ and $HT2$ ($T_4 = 1$). Let $D_\tau \in \{0, 1\}$ be dummy variables for vertical structures, satisfying $D_\tau = 1$ for the τ-th vertical structure and $D_\tau = 0$ otherwise, $\tau \in \mathbf{V} = \{\ell, v\}$.

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

We start with a standard 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 k sold in the τ-th vertical structure

$$P_{k\tau} = \beta_{k\tau} + \sum_{m\in\mathbf{K}} \sum_{u\in\mathbf{V}} \delta_{m\tau} T_m D_u + \phi X + \varepsilon_{k\tau} \ , \tag{5a}$$

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

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

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

where $\beta_{mk,u\tau} = [c_{mk,u\tau} - \alpha_{mk,u\tau}]$ and $H_{mk,u\tau} = \sum_{n\in\mathbf{N}} s^n_{mu} s^n_{k\tau}$ is the VHHI, s^n_{mu} being the market share of the n-th firm in the market for the m-th seed type under the u-th vertical structure. Since $H_{mk,u\tau}$

= 0 under competitive conditions, it follows from (5b) that that the exercise of market power in (5a)-(5b) is given by

$$M_{k\tau} = \sum\nolimits_{m \in \mathbf{K}} \sum\nolimits_{u \in \mathbf{V}} \beta_{mk,u\tau} H_{mk,u\tau} Y_{mu} T_m D_u \ , \tag{6}$$

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

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

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

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

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

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

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

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

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

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

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

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

5. Econometric estimation

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

Table 1. Summary statistics

Variable[c]	Number of observations[a,b]	Mean	Standard Deviation	Minimum	Maximum
Net Price ($/bag)	76306	22.82	5.51	0	43
Farm size (acre)	76308	618.51	658.34	45	24000
$H_{11,\ell\ell}$	564	0.412	0.280	0.063	1
$H_{12,\ell\ell}$	520	0.110	0.093	6.04E-05	0.606
$H_{12,\ell v}$	308	0.180	0.180	0.001	1
$H_{22,\ell\ell}$	608	0.201	0.094	0.065	0.805
$H_{22,vv}$	601	1	0	1	1

[a]/ The data contain 76308 observations from 76 CRDs spanning 8 years (2000-2007). For the net price, two observations have missing value, thus the total number of observation becomes 76306.

[b]/ For the market concentration measurements *H*'s, we only report the summary statistics of those non zeros at the CRD level, therefore the number of observations is at most 76× 8 = 608.

[c]/ Two VHHI's are not reported in the table: $H_{22,\ell v} = H_{22,v\ell} = 0$, as no company can be both vertically integrated and non-integrated in the same market. Moreover, $H_{12,\ell\ell} = H_{21,\ell\ell}$ and $H_{12,\ell v} = H_{21,v\ell}$ by symmetry in construction.

One econometric issue in the specification (5a)-(5b) is the endogeneity of the VHHIs. Both market concentrations (as measured by *H*), quantity sold (*Y*) and seed pricing are expected to be jointly determined as they both depend on firm strategies in the seed market. To the extent that some of the determinants of these strategies are unobserved by the econometrician, this would imply that the interaction terms, $H \cdot Y$, are correlated with the error term in equation (5a). In such situations, least-squares estimation of (5a)-(5b) would yield biased and inconsistent parameter estimates. The solution is to consider estimating equation (5a)-(5b) using an instrumental variable (IV) estimation method that corrects for endogeneity bias. To address this issue, we first test for possible endogeneity of the *H*'s and *Y*'s using a *C* statistic calculated as the difference of two Sargan statistics (Hayashi 2000, p. 232). Under the null hypothesis of exogeneity of *H* and *Y*, the *C* statistic is distributed as Chi-square with degrees of freedom equal to the number of variables tested. The test is robust to violations of the conditional homoscedasticity assumption (Hayashi 2000, p. 232).[12] In our case, the *C* statistic is 19.83, showing strong statistical evidence against the null hypothesis of exogeneity.

The presence of endogeneity motivates the use of an IV estimator. We rely on the lagged value of each *H* interacted with the lagged value of *Y* as instruments. A series of tests was conducted to support this choice (see below). On that basis, equation (5a)-(5c) was estimated by two-stage-least-squares (2SLS).

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

We estimated an Arellano-Bond dynamic panel regression of a reduced form model for the $H \cdot Y$'s that also includes lagged $H \cdot Y$'s as explanatory variables. The Arellano-Bond estimation

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

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

allows for a test of serial correlation of the associated error term. Given lagged *HY*'s, the test results failed to find evidence of serial correlation in the reduced-form error terms (reflecting unobservable factors affecting the $H \cdot Y$'s). This lack of serial correlation indicates that lagged $H \cdot Y$'s are good candidates for instruments.[14] But good instruments should provide information identifying the parameters, i.e. they should not be "weak instruments". In the presence of heteroscedastic errors, we used the Bound et al. (1995) measures and the Shea (1997) partial R^2 statistic to test for weak instruments. Following Staiger and Stock (1997), the test results indicated no statistical evidence that our instruments are weak. Finally, The Kleibergen-Paap weak instrument test was conducted (Kleibergen and Paap, 2006),[15] yielding a test statistic of 28.71. Using the critical values presented in Stock and Yogo (2005), this indicated again that our analysis does not suffer from weak instruments.

6. Results

Table 2 reports the IV estimation of equations (5a)-(5b) using 2SLS, with heteroscedastic-robust standard errors under clustering. We first discuss the estimates of how prices vary across seed types and vertical structures, followed by a discussion of the estimated effects of market power.

Characteristics effects

From table 2, publicly bred conventional seeds are priced significantly lower than the privately bred ones, at a discount of $4.44 per bag. This is consistent with our expectation that publicly-sourced seed companies and private companies use different pricing rules. Compared to

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[14] Note that, since our model is just identified, the Hansen over-identification test is not applicable.

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

private conventional seeds, the results show that all biotech seeds receive a price premium, but this price premium varies with the vertical structure. The coefficients of the T_iD_v's (i-th seed under integrated vertical structure) and T_iD_ℓ's (except for T_3D_ℓ) (i-th seed under licensing vertical structure), $i = 2, 3, 4$, are each positive and statistically significant. Being in the range from \$2.43 to \$7.90, they show evidence of significant premiums for these biotech traits. The coefficient of T_3D_ℓ (type 3 biotech seed under licensing) is also positive but not statistically significant. For all three biotech seeds, the coefficients show that seeds sold under vertical integration are priced higher than those produced and marketed under licensing.

Market concentration effects and vertical structures

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

For the three VHHIs that may affect the conventional seed price ($H_{11,\ell\ell}$, $H_{21,\ell\ell}$, $H_{21,v\ell}$), the public sector effect is separated from the private sector effect through the interaction between the public dummy and the VHHIs. Again, table 2 shows strong statistical evidence that the public sector follows different pricing rules (compared to the private sector). For the private sector, the effect of the traditional HHI ($H_{11,\ell\ell}$) is positive and statistically significant at the 5 percent level. However, this positive effect disappears for the public sector. The effect of the VHHI between licensed $HT1$ seed and the conventional seed ($H_{21,\ell\ell}$) is negative for the private sector but positive for the public sector. The negative sign of $H_{21,\ell\ell}$ in the private sector suggests that the two products are complements either in supply or in demand or both. If complementarity exists in the demand side, it should affect the seed pricing in the public sector in a similar way, as farmers' demand complementarity should not be affected by the source of seeds. However, the coefficient of $H_{21,\ell\ell}$ is positive for public sourced conventional seed, which would offset the complementarity effects between the two seed types in the private sales. We thus infer that the complementarity between conventional and licensed *HT*1 seeds must come from the supply side, where the private sector differs from the public sector in significant ways. The coefficients of the VHHI between integrated *HT*1 seed and the conventional seed ($H_{21,v\ell}$) for the private and public sectors are not statistically significant.

Of the four coefficients on VHHIs that may affect the *HT*1 biotech seed, only the coefficient on VHHI between licensed *HT*1 seed and the conventional seed ($H_{12,\ell\ell}$) is statistically significant. The coefficient of $H_{12,\ell\ell}$ affecting the licensed *HT*1 seed is again negative, consistent with its effects in the conventional seed market. This suggests strong and symmetric complementarity between conventional and *HT*1 seeds on the supply side. Since complementarity contributes to economies of scope (as discussed in section 2), this provides indirect evidence that seed companies experience economies of scope in the production and marketing of both conventional seed and the licensed *HT*1 seeds. Note that the coefficient of the VHHI between integrated *HT*1 seed and the conventional seed ($H_{12,\ell v}$) is also negative, but not statistically significant. This may possibly reflect the presence of transaction costs in vertical integration (such as negotiation and re-organization) that may offset some of the efficiency gains from economy of scope.

Both $H_{22,\ell\ell}$ and $H_{22,vv}$, are standard Herfindahl indexes measuring market concentration in the *HT*1 seed market, licensed and integrated, respectively. Although the impact is positive for the licensed seed market (consistent with *a priori* expectation), neither variable has a statistically significant effect.

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

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

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

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

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

The test results reject the null hypothesis for (I) and (II) at 5% significance level and (III) at 10% significance level. It suggests that the conventional and *HT*1 cross-market concentration effects on the conventional seed are different with different vertical structures in the *HT*1 seed market (hypothesis I). Moreover, the own- and cross-market concentration effects are statistically different on *HT*1 seed with different vertical structures in the *HT*1 seed market (hypotheses II and III). As discussed in section 2, this provides statistical evidence that vertical organization matters. It indicates that vertical structures interact with the exercise of market power as they affect pricing. These effects are further discussed below. [16]

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

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

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

Table 2. IV (2SLS) regression 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 private T_1: Conventional seed		
T_1 public (conventional seed via public source)	-4.44***	-7.69
T_2D_ℓ (*HT1* in licensing structure)	7.28***	26.30
T_2D_v (*HT1* in vertically integrated structure)	7.75***	26.70
T_3D_ℓ (*HT2* in licensing structure)	0.21	0.66
T_3D_v (*HT2* in vertically integrated structure)	2.43***	4.39
T_4D_ℓ (stacking in licensing structure)	7.64***	22.87
T_4D_v (stacking in vertically integrated structure)	7.90***	27.44
Market concentration effects		
$H_{11,\ell\ell}T_1D_\ell Y_{1\ell}$ (on conventional seed)	0.145**	2.08
$H_{11,\ell\ell}T_1D_\ell Y_{1\ell}\_pub$ (on public-sourced conventional seed)	-0.160*	-1.70
$H_{21,\ell\ell}T_1D_\ell Y_{2\ell}$ (on conventional seed)	-0.227***	-3.12
$H_{21,\ell\ell}T_1D_\ell Y_{2\ell}\_pub$ (on public-sourced conventional seed)	0.270**	2.40
$H_{21,v\ell}T_1D_\ell Y_{2v}$ (on conventional seed)	0.050	0.56
$H_{21,v\ell}T_1D_\ell Y_{2v}\_pub$ (on public-sourced conventional seed)	-0.056	-0.37
$H_{12,\ell\ell}T_2D_\ell Y_{1\ell}$ (on *HT1* in licensing structure)	-0.265***	-3.04
$H_{22,\ell\ell}T_2D_\ell Y_{2\ell}$ (on *HT1* in licensing structure)	0.040	1.53
$H_{12,\ell v}T_2D_vY_{1\ell}$ (on *HT1* in vertically integrated structure)	-0.077	-0.83
$H_{22,vv}T_2D_vY_{2v}$ (on *HT1* in vertically integrated structure)	-0.003	-0.26
Other variables		
Exit	-0.22***	-4.77
Entry	-0.06	-1.48
Year 2002	0.20**	2.14
Year 2003	-0.66***	-5.60
Year 2004	2.45***	24.71
Year 2005	5.41***	42.52
Year 2006	6.21***	37.67
Year 2007	6.30***	41.13
Total acre grown soybean by each farm (1000 acre)	-0.259***	-4.22
Constant	16.88***	55.25
Number of observations	65237	

[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 0.63, and un-centered R^2 is 0.98.

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

Other factors

Table 2 shows how prices vary over time. The year dummy effects show a strong rising trend in and after 2004. In 2007, seed price is \$6.22 per bag higher than in 2001. Given that the mean price is about \$22.82 per bag, this gives an annual growth rate higher than the inflation rate over the same time period.[17] Our estimates show that soybean seeds are sold at a discount price in the Corn Belt compared to the non-Corn Belt states. They also indicate how the method of purchase affects prices. Compared to purchasing from "farmer who is a dealer or agent", seeds bought "directly from a seed company or their representative" cost \$0.24 less per bag, and those purchased from cooperatives cost \$0.34 more per bag.

The exit and entry dummies are all negative but only the exit dummy is statistically significant. Prior to the year of exit, seed price tends to discount by \$0.22 per bag, which may be due to the fact that the exiting seed's performance has deteriorated. The entry dummy has a negative coefficient. But it is not statistically significant, suggesting that new seeds are not priced differently from other seeds.

Finally, table 2 shows that the farm size effect is statistically significant: large farms within each state pay less for soybean seeds.

7. Implications

In this section, our empirical estimates are used to generate insights on pricing within and across markets under different vertical structures. For illustration purpose, our analysis focuses on Illinois in 2004. Illinois is one of the largest soybean-producing states in the US, and it has the

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

largest number of farms in our sample. The year 2004 is a convenient choice for being the middle of the sample period.

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

Bundling/Stacking effects

The bundling literature has identified situations in which component pricing may not apply (e.g., when demands are heterogeneous). Our analysis provides a basis for testing component pricing (where seeds are priced as the sum of their component values). More generally, it can be used to investigate how prices vary across bundles within and across different vertical structures. Next, these issues are evaluated by simulating our estimated model at sample means of relevant variables for Illinois in 2004 (including farm size and VHHIs).[18]

Table 3 reports the estimated bundling/stacking effects for different markets and vertical structures. The mean conventional seed price is $16.32 per bag. It is used as a "base case" to evaluate both integrated and licensed market structures. The biotech traits add price premiums over the conventional varieties. In addition the stacking premium is higher than single trait premium in both market structures. The stacking effect (reflecting the difference between what the price would be under component pricing and the bundled price) is -$1.96 per bag in the integrated market, but not different from zero in the licensed market. These results indicate that

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

component pricing applies under licensing. But they strongly reject component pricing under vertical integration. There, the evidence documents sub-additive pricing, where the price of the bundled good is priced significantly less than the sum of its component values. .

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

Seed type	**Licensed**		**Vertically integrated**		Difference between vertical structures
	Expected Seed Price	Price difference from T_1	Expected Seed Price	Price difference from T_1	
T_1 (Conventional)	16.32	N/A	N/A	N/A	N/A
T_2 ($HT1$ biotech)	23.71	7.39*** (0.13)	24.18	7.85*** (0.16)	-0.46*** (0.13)
T_3 ($HT2$ biotech)	16.86	0.54** (0.22)	18.65	2.33*** (0.50)	-1.77*** (0.52)
T_4 (stacked biotech)	24.29	7.97*** (0.24)	24.55	8.22*** (0.16)	-0.27 (0.20)
Stacking effect (T_4 vs. T_2+T_3)	0.04 (0.30)		-1.96*** (0.52)		1.96*** (0.56)

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

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

Transaction costs arise under both vertical integration and licensing. Table 3 reports that single trait seeds marketed under licensing are priced lower than in the integrated channel. This indicates that transaction costs under licensing may be less than that under vertical integration.

Estimated Market Power Effects

As discussed in sections 2 and 4, the market power effects can be measured by the term M in equation (4) or (6). Our estimated model allows us to evaluate M in equation (6). This provides a simple characterization of the strength of imperfect competition: it is zero under perfect competition, but non-zero under concentrated markets. From equation (5), M in (6) can be interpreted as a per-unit measure of the price enhancement associated with imperfect competition.

Evaluated at mean values, table 4 reports the estimated market power component M for selected seed types for Illinois in 2004. Table 4 also presents the corresponding relative measures $\frac{M}{p}$.[19] The market power measures M are statistically significant in the conventional seed market and in the licensed $HT1$ seed market. The market power measure for the conventional seed is \$0.54 per bag; it is statistically significant at 5% level. The corresponding relative measure $\frac{M}{p}$ is 0.0328, indicating that the exercise of market power component amounts to 3.28% of the seed price. For the licensed $HT1$ seed, the market power measure is positive but not statistically significant for the own market power increase. But table 4 reports negative and significantly effects (at the 10% level) of changing market concentration in both conventional and $HT1$seed markets on the price of licensed $HT1$ seeds. This provides empirical evidence that market power

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

affects seed prices differently across market structures. It also suggests that the cross-market power effect on price dominates the own market power effect in opposite directions in the licensed *HT*1 seed market. These results are due to our estimated complementarity effects that reduce the effects of market power on prices. Since complementarity reflects cross-markets effects, this stresses the need to address market power issues in a multi-market framework, involving both horizontal and vertical markets.

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

Seed type	**Mean Seed price** ($/bag)	**Market Power Component**[b]					
		T_1		T_2		T_1 & T_2	
		M (*$/bag*)	*M/p*	*M* (*$/bag*)	*M/p*	*M* (*$/bag*)	*M/p*
T_1 (Conventional)	16.47	0.54**	0.0328	N/A	N/A	-0.34	-0.0206
Licensed T_2 (*HT*1 biotech)	23.53	N/A	N/A	0.23	0.0098	-0.22*	-0.0093
Integrated T_2 (*HT*1 biotech)	23.58	N/A	N/A	-0.05	-0.0021	-0.23	-0.0098

[a] Statistical significance is noted by * at the 10 percent level, ** at the 5 percent level, and *** at the 1 percent level.
[b] The terms *M* are calculated at the difference between the predicted price when the *VHHI*s are set equal to the mean and the predicted price when the *VHHI*s are set equal to zero (which implies *M* being zero).

8. Concluding Remarks

The paper has developed a Cournot model of pricing of differentiated products under imperfect competition and alternative forms of vertical control. It proposes a new way to evaluate the exercise of market power in vertical structures. This involves a vertical HHI (termed VHHI) that captures how market concentration and vertical organization interact with each other in influencing the pricing of differentiated products.

The usefulness of the analysis is illustrated in an econometric application involving the estimation of a structural model of pricing where our VHHIs capture the effects of imperfect competition across both horizontal and vertical markets. Applied to US soybean seeds, the econometric analysis finds evidence that vertical organization has significant effects on seed prices. However these effects are found to vary with the institutional setup and the bundling of seeds. We find that component pricing applies to privately sourced seeds sold under licensing. But we reject component pricing in favor of sub-additive pricing for privately sourced seeds sold under vertical integration. We uncover evidence that complementarity and economies of scope can reduce the effects of market concentration on soybean seed prices. Since complementarity reflects cross-markets effects, this stresses the need to address market power issues in a multi-market framework, which is especially important for anti-trust analysis involving horizontal and vertical merger activities.

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