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Pricing and Vertical Organization of Differentiated Products

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Abstract: This paper investigates differentiated product pricing and vertical organization under imperfect competition. We develop a conceptual model of multiproduct pricing to examine how the exercise of market power varies with substitution/complementarity relationships among products and vertical structures. The analysis is applied to US soybean seed pricing during the period between 2000 and 2007. It considers two vertical structures: Vertical integration and licensing. We find evidence that vertical organization has significant effects on prices. These effects vary depending on the institutional setup and the bundling of genetic material. The empirical evidence shows that, in a multi-market context, complementarity and economies of scope can mitigate the price enhancements associated with market power. Our analysis indicates that market concentration studies that neglect vertical structures fail to capture the linkages between market structure and pricing.

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

JEL Code: L13, L4, L65

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Pricing and Vertical Organization of Differentiated Products

1. INTRODUCTION

Economists understand the role of imperfect competition in horizontal markets: High market concentration leads oligopolies to exercise market power and increase output prices. However, production processes often involve multiple stages. This raises questions about the ways in which firms organize themselves in and across those stages. A great deal of research has been dedicated to studying how market power is exercised 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). Yet, the implications of vertical control remain subjects of debate (e.g., Tirole 1992; Whinston 2006). One school of thought—often associated with the University of Chicago—stresses the notion that greater vertical control leads to efficiency gains. Yet concerns linger about potential adverse effects of vertical control, including the impact on foreclosures and possible efficiency losses associated with reduced competition (e.g., Whinston 2006; Rey and Tirole 2008).

Adding differentiated products to the analysis further complicates matters. Previous work has often circumvented this complication by focusing on monopolies or on perfect substitutes in 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. Understanding the economics of vertical structures requires a refined conceptual approach that captures the role of imperfect competition under differentiated products. And to be useful, the analysis must be empirically tractable.

Our paper addresses both of these issues. We begin by developing a Cournot model of pricing for differentiated products under imperfect competition and across different vertical organizations. Our analysis illustrates how price enhancements that are related to the exercise of market power are influenced by substitution/complementarity relationships across vertical channels. We offer a structural representation of price determination, and explicitly characterize the market power component.

Economists have come to rely on the Herfindahl-Hirschman Index (HHI) to assess horizontal market concentration (e.g., Whinston 2006). Our analysis extends it by developing a vertical HHI (termed VHHI) that captures the ways in which market concentration and vertical organization interact to influence market power, and consequently, the prices of differentiated products. Gans (2007) introduced the concept of VHHI. Our approach extends Gans (2007) by allowing for both horizontal and vertical product differentiation in final goods. Unlike Gans (2007), we do not impose restrictions on production technologies or on upstream and downstream firms' trading patterns. As such, our approach applies more broadly.[2]

We also present an econometric application to the pricing of US soybean seeds that illustrates the usefulness of our approach. While the theoretical model motivates the VHHI measures, our econometric analysis involves the empirical estimation of a hedonic linear pricing equation that utilizes our VHHIs to investigate the role of imperfect competition in both horizontal and vertical markets. It also examines bundling behavior (where bundling involves patented genetic material incorporated in seeds by biotech firms). To our knowledge, this is the first study that examines how bundling behavior and pricing vary under alternative vertical structures.

[2] See Chavas and Shi (2010) for a detailed discussion about how our approach differs from that of Gans (2007).

The soybean seed market makes an excellent case study for three reasons. First, in the 1980s, the industry engaged in a flurry of mergers that resulted in a few large biotech firms dominating the US soybean seed industry (Fernandez-Cornejo 2004). In the late 1980s, the top four largest firms accounted for 40% of the soybean seed market, a substantial rise from 5.2% in 1980 (Fernandaz-Cornejo 2004). Our data show that this percentage further increased to 55% in 2007. These four firms have also exhibited a trend toward greater vertical integration over time (as further discussed below). As Graff, Rausser and Small (2003) have noted, these structural changes have been motivated in part by complementarities of assets within and between the agricultural biotechnology and seed industries. Thus, it seems likely that seed markets have become highly concentrated because vertical and horizontal integration have created efficiency gains (particularly due to economies of scope in the production of genetic traits). However, biotech firms can also use their market power to increase seed prices, which can adversely affect economic efficiency and farmers' profits (e.g., Fulton and Giannakas 2001; Fernandez-Cornejo 2004).

The US soybean seed market is also remarkable in that firms' merger/acquisition behavior has been changing the industry's vertical structures. Although biotech firms have relied extensively on licensing their technologies to seed companies, they have recently increased their use of vertical control through integration. Our data show that vertical integration in the US single-traited soybean seed market has increased from 13% in 2000 to 26% in 2007. Are these changes motivated by efficiency gains, or do they reflect attempts to increase market power? We attempt to answer these questions by empirically investigating the economics of how differentiated products are priced under alternative vertical structures.

Finally, we are interested in this industry because the recent biotechnology revolution has pushed firms to differentiate their products by patenting genetic materials. Our analysis assesses the pricing and bundling implications associated with alternative forms of product differentiation in the US soybean seed market. Our analysis also reveals that institutional setup can affect soybean seed pricing. Beginning in the 1970s, the US soybean seed industry experienced a rapid shift from public sector to private sector breeding. Publicly developed varieties' acreage shares decreased from over 70% in 1980 to 10% in the mid-1990s (Fernandez-Cornejo 2004) and to 0.5% in 2007, according to our data.[3] Such changes were initiated largely by advances in breeding technology (including biotechnology) and changes in the intellectual property protection of life forms. Presently, how these institutional changes impact pricing is not well understood. Our study provides new and useful information about these effects.

Our econometric analysis examines the interactions between product differentiation and pricing. The empirical evidence illustrates how market concentration and vertical organization relate to market power, and consequently, to soybean seed prices. We find that these relationships vary based upon seed providers' institutional setups. We document that publicly sourced seeds are priced significantly lower than are privately sourced seeds. Our investigation also indicates that complementarity and economies of scope can mitigate market power-related price enhancements within the privately sourced seed market. Our empirical analysis shows how market concentration studies that ignore vertical structures (e.g., those that utilize a traditional HHI) fail to capture the linkages between market structure and pricing. For example, we find that seeds sold through vertically integrated structures are priced higher than are those that are

[3] Within the conventional seed market, however, publicly sourced soybean seed varieties accounted for approximately 10% of the acreage in 2007.

licensed. Furthermore, although we fail to reject component pricing[4] under licensing, we strongly reject component pricing under vertical integration, where the evidence points to sub-additive pricing.

Our analysis is organized in the following manner. In Section 2 we present a conceptual framework for multiproduct pricing under imperfect competition. We develop a Cournot model that motivates the VHHIs and captures the role of imperfect competition in both vertical and horizontal markets. In Sections 3 and 4 we present an econometric specification of pricing and its application to the US soybean seed market. The model provides a basis to investigate the joint role of vertical organization and market power (using our VHHIs measures). In Section 5 we discuss our estimation method and econometric results, and in Sections 6 and 7 we report our empirical findings and evaluate their implications. In Section 8 we offer some concluding thoughts.

2. MODEL

Consider a market involving a set $\mathbf{N} \equiv \{1, \ldots, N\}$ of N firms that produce a set $\mathbf{K} \equiv \{1, \ldots, K\}$ of K outputs. Output production and marketing involves upstream markets under a set $\mathbf{V} \equiv \{1, \ldots, V\}$ of V alternative vertical structures (e.g., vertical contracts or ownership). We use $\mathbf{y}^n = (y_{11}^n, \ldots, y_{k\tau}^n, \ldots, y_{KV}^n\} \in \Re_+^{KV}$ to denote the vector of output quantities that are produced by the n-th firm, where $y_{k\tau}^n$ represents the k-th output quantity produced by the n-th firm under the τ-th vertical structure, $k \in \mathbf{K}$, $n \in \mathbf{N}$, $\tau \in \mathbf{V}$. We assume that the vertical structures can support product differentiation and price discrimination schemes. This means that products and prices can vary across vertical structures (e.g., from differences in quality, label and/or packaging).

[4] Under component pricing, the price a bundle equals the sum of its individual components' prices. Alternatively, sub-additive pricing applies if the bundle price is less than the sum of components' prices.

Within this context, the price-dependent demand for the *k*-th output under the *τ*-th vertical structure is $p_{k\tau}(\sum_{n\in\mathbf{N}}\mathbf{y}^n)$.

We assume that efficient contracts exist among all firms. This means that upstream production and marketing decisions are efficient and made in ways consistent with the maximization of aggregate profit across all marketing channels.[5] Given these conditions, we explore how firms exercise market power and examine how this affects both horizontal and vertical markets. The *n*-th firm's profit is $\pi^n = \sum_{k\in\mathbf{K}}\sum_{\tau\in\mathbf{V}}[p_{k\tau}(\sum_{n\in\mathbf{N}}\mathbf{y}^n)\cdot y_{k\tau}^n] - C_n(\mathbf{y}^n)$, where $C_n(\mathbf{y}^n)$ denotes the *n*-th firm's cost of producing $\mathbf{y}^n$. We assume a Cournot game. Under differentiability, the decisions of the *n*-th firm satisfies $\pi^n \geq 0$, along with the profit maximizing condition with respect to the *k*-th output in the *τ*-th vertical structure, $y_{k\tau}^n$,

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

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

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

$k \in \mathbf{K}$ and $\tau \in \mathbf{V}$. Equation (1c) is the complementary slackness condition. It applies irrespective of whether the *k*-th output is produced by the *n*-th firm in the *τ*-th vertical structure ($y_{k\tau}^n > 0$), or not ($y_{k\tau}^n = 0$). And it remains valid regardless of how many of the *K* products the firm chooses to sell. Additionally, equation (1c)'s validity is unaffected by the vertical structure that the *n*-th firm chooses to market its products. This means that, under imperfect competition, equation (1c) is broad enough to allow for interactions among firms both horizontally and vertically. As such, this equation can be used to explore the foreclosure strategies that have been the subject of much recent scrutiny (e.g., Ordover, Saloner, and Salop 1990; Whinston 2006; Rey and Tirole 2008).

[5] Note that the presence of efficient vertical contracts rules out vertical externalities. In Footnote 7 we briefly discuss the effects of vertical externalities.

We assume that the cost function takes the form $C_n(\mathbf{y}^n) = F_n(\mathbf{R}^n) + \sum_{k\in\mathbf{K}}\sum_{\tau\in\mathbf{V}} c_{k\tau} y^n_{k\tau}$ + $0.5\sum_{k,m\in\mathbf{K}}\sum_{\tau,u\in\mathbf{V}} c_{mk,u\tau} y^n_{mu} y^n_{k\tau}$, where $\mathbf{R}^n = \{(j,\tau)\colon y^n_{j\tau} > 0, j\in\mathbf{K}, \tau\in\mathbf{V}\}$ is the set of products produced at positive levels by the n-th firm. Here, we use $F_n(\mathbf{R}^n) \geq 0$ to denote fixed cost that satisfies $F_n(\emptyset) = 0$, while $\sum_{k\in\mathbf{K}}\sum_{\tau\in\mathbf{V}} c_{k\tau} y^n_{k\tau} + 0.5\sum_{k,m\in\mathbf{K}}\sum_{\tau,u\in\mathbf{V}} c_{mk,u\tau} y^n_{mu} y^n_{k\tau}$ denotes variable cost. Note that the presence of fixed costs (where $F_n(\mathbf{R}^n) > 0$ for $\mathbf{R}^n \neq \emptyset$) can imply increasing returns to scale. Then, marginal cost pricing would imply negative profit, and any sustainable equilibrium would necessarily be associated with departures from marginal cost pricing. The fixed cost $F_n(\mathbf{R}^n)$ can come from upstream markets (e.g., R&D cost that an upstream firm incurs when developing a new technology) or downstream markets (such as the expense of establishing a vertical structure).

Total cost $C_n(\mathbf{y}^n)$ can reflect economies of scope. Indeed, scope economies can exist when outputs exhibit complementarity. Complementarity occurs when $\frac{\partial^2 C_n(y^n)}{\partial y^n_{mu}\partial y^n_{k\tau}} < 0$, i.e. when the production of output y^n_{mu} reduces the marginal cost of $y^n_{k\tau}$ for $m \neq k$ and $u \neq \tau$ (Baumol et al. 1982, p. 75). Furthermore, economies of scope can arise when fixed cost $F_n(\mathbf{R}^n)$ satisfies $F_n(\mathbf{R}^n_a) + F_n(\mathbf{R}^n_b) > F_n(\mathbf{R}^n_a \cup \mathbf{R}^n_b)$ for some $\mathbf{R}^n_a$, $\mathbf{R}^n_b \subset \mathbf{R}^n$, i.e. when the joint provision of $\mathbf{y}^n_a = \{y^n_{ju} : (j,u) \in \mathbf{R}^n_a\}$ and $\mathbf{y}^n_b = \{y^n_{ju} : (j,u) \in \mathbf{R}^n_b\}$ reduces fixed cost (Baumol et al., 1982, p. 75). This situation may apply to either upstream technologies (e.g., R&D investment in upstream technology exhibiting synergies in the joint production of $\mathbf{y}^n_a$ and $\mathbf{y}^n_b$) or to downstream technologies. In this latter case, a firm may generate efficiency gains if selling multiple products across multiple vertical structures reduces aggregate fixed cost.

The above arguments show how our approach can capture efficiency gains. However, our model is also able to represent the exercise of market power. Let $\frac{\partial p_{mu}}{\partial y_{k\tau}} = \alpha_{mk,u\tau}$ with $\alpha_{mm,uu} < 0$. The marginal cost of $y^n_{k\tau}$ is $\frac{\partial C_n(\mathbf{y}^n)}{\partial y^n_{k\tau}} = c_{k\tau} + \sum_{m\in\mathbf{K}} \sum_{u\in\mathbf{V}} c_{mk,u\tau} y^n_{mu}$, with $c_{mm,uu} \geq 0$ and $c_{mk,u\tau} = c_{km,\tau u}$. We use $Y_{k\tau} = \sum_{n\in N} y^n_{k\tau}$ to denote the aggregate output quantity of the *k*-th product in the *τ*-th vertical structure. Assuming that $Y_{k\tau} > 0$, define $S^n_{k\tau} = \frac{y^n_{k\tau}}{Y_{k\tau}} \in [0, 1]$ as *n*-th firm's market share for the *k*-th product in the *τ*-th vertical structure. We divide equation (1c) by $Y_{k\tau}$ and sum across all $n \in \mathbf{N}$ to 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 may also be 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 $H_{mk,u\tau} = \sum_{n\in\mathbf{N}} s^n_{mu} s^n_{k\tau}$.

Equation (3) is a price-dependent supply function for the *k*-th product in the *τ*-th vertical structure. It includes the term

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

In (4), $M_{k\tau}$ is associated with the exercise of market power. Note that $H_{mk,u\tau} \in [0, 1]$, and that $H_{mk,u\tau} \to 0$ under perfect competition, when there are many active firms. It follows that $M_{k\tau} \to 0$ under perfect competition. At the opposite extreme, $H_{mk,u\tau} = 1$ under a monopoly, when there is a single active firm. In general, $H_{mk,u\tau}$ increases with market concentration. As such, the term $M_{k\tau}$ in (4) is the price component of equation (3) that captures the market power effects of imperfect competition. In our analysis below, we make extensive use of equations (3) and (4).

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), $H_{11,11}$ is the traditional Herfindahl-Hirschman Index (HHI), which measures market concentration. The HHI is commonly used to analyze the exercise of market power (e.g., Whinston 2006). Given a positive marginal cost ($c_{11,11} \geq 0$) and a negative demand slope ($\alpha_{11,11} < 0$), equations (3) – (4) indicate that an increase in the HHI, $H_{11,11}$, which simulates 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 regarded $H_{11,11} > 0.1$ as an indication of a concentrated market, in which the exercise of market power may raise competitive concerns (e.g., Whinston 2006).

In equations (2) – (4), we extend the HHI to explore various vertical structures (when V > 1) and a multi-product scenario (when K > 1). We define $H_{mk,u\tau}$ as a vertical Herfindahl-Hirschman index (VHHI). When $m \neq k$ and $u = \tau$, a rise in the "cross-market" VHHI $H_{mk,\tau\tau}$ is associated with an increase (a decrease) in price if [$c_{mk,\tau\tau} - \alpha_{mk,\tau\tau}$] > 0 (< 0). Given that $\alpha_{mk,\tau\tau}$ = $\frac{\partial p_{m\tau}}{\partial y_{k\tau}^n}$, we follow Hicks (1939) and note that $\alpha_{mk,\tau\tau} < 0$ (> 0), when products m and k are substitutes (complements) on the demand side. This occurs in situations where an increase in quantity $y_{k\tau}^n$ tends to decrease (increase) the marginal value of $y_{m\tau}^n$. Similarly, $c_{mk,\tau\tau} = \frac{\partial^2 C_n(y^n)}{\partial y_{m\tau}^n \partial y_{k\tau}^n} > 0$ (< 0), when products m and k are substitutes (complements) on the supply side. This corresponds to situations where an increase in output quantity $y_{k\tau}^n$ tends to increase (decrease) the marginal cost of producing $y_{m\tau}^n$. We note that the complementary case (where $c_{mk,\tau\tau} < 0$) can generate economies of scope (Baumol et al. 1982, p. 75), where multi-output production reduces costs. In general, the term [$c_{mk,\tau\tau} - \alpha_{mk,\tau\tau}$] is positive when $y_{m\tau}^n$ and $y_{k\tau}^n$ behave as substitutes on both the supply and demand sides, and it is negative when $y^n_{m\tau}$ and $y^n_{k\tau}$ behave as complements on both the supply and demand sides.

Equations (3) and (4) illustrate how the nature of substitution and complementarity among outputs (captured by the terms $[c_{mk,\tau\tau} - \alpha_{mk,\tau\tau}]$)[6] affects how the market concentration terms $H_{mk,\tau\tau}$ impact $M_{k\tau}$ and the price $p_{k\tau}$. A rise in $H_{mk,\tau\tau}$ contributes to an increase (decrease) in the market power component $M_{k\tau}$ when two products $y_{k\tau}$ and $y_{m\tau}$ are substitutes (complements).

We are particularly interested in the effects of vertical structures on pricing. Consider the case where $u \neq \tau$ and $k = m$. In this situation, equations (3) and (4) indicate how vertical structures influence prices. They illustrate that a rise in VHHI $H_{kk,u\tau}$ is associated with an increase (decrease) in $M_{k\tau}$ if $[c_{kk,u\tau} - \alpha_{kk,u\tau}] > 0$ (< 0). As discussed above, we expect $[c_{kk,u\tau} - \alpha_{kk,u\tau}] > 0$ (< 0) when product *k* exhibits substitution (complementarity) across vertical structures *u* and *τ*. Terms $H_{kk,u\tau}$s in equations (3) – (4) therefore delineate how substitution or complementarity across vertical structures influences the pricing effects of market concentration. A rise in $H_{kk,u\tau}$ thus contributes to an increase (decrease) in $M_{k\tau}$ when the *k*-th products across two vertical channels (y_{ku} and $y_{k\tau}$) are substitutes (complements).[7]

This leads us to ask whether there are conditions under which vertical structures have no effect on prices. Below, we show that these situations may occur if products, on both the demand

[6] Identifying the role of substitution/complementarity in the exercise of market power is not a new process (e.g., Tirole 1992; Venkatesh and Kamakura 2003; Whinston 2006; Rey and Tirole 2008). However, our VHHI measure explicitly link substitution/complementarity.

[7] Our analysis implicitly assumes that vertical contracts are efficient. Previous research has discussed possible inefficiencies in vertical contracts (Spengler 1950; Tirole 1992). These include "double marginalization" situations, wherein a failure to deal with vertical externalities can contribute to cost increases. While these inefficiencies would affect cost in equations (2)-(3), such effects are neglected in our analysis.

and supply sides, are perfect substitutes across vertical structures. Perfect substitution on the supply side corresponds to situations wherein the cost function takes the form $C_n(\mathbf{y}^n)$ = $C_n(\sum_{\tau\in\mathbf{V}} y_{1\tau}^n,...,\sum_{\tau\in\mathbf{V}} y_{K\tau}^n)$, which implies 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 occurs 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, and we use these hypotheses to evaluate the effects of vertical structures on pricing. We present these in our empirical analysis in Sections 4 and 5.

We use $S_k^n = \frac{\sum_{\tau\in\mathbf{V}} y_{k\tau}^n}{Y_k} \in [0, 1]$ to denote the aggregate market share of the n-th firm for the k-th product, where $Y_k \equiv \sum_{\tau\in\mathbf{V}}\sum_{n\in\mathbf{N}} y_{k\tau}^n > 0$. Under conditions of perfect substitution across vertical structures (where $c_{k\tau} = c_k$, $c_{mk,u\tau} = c_{mk}$ and $\alpha_{mk,u\tau} = \alpha_{mk}$), the law of one price applies, with $p_{k\tau} = p_k$ for all $\tau \in \mathbf{V}$. Multiplying Equation (2) or (3) by $\frac{Y_{m\tau}}{Y_m}$ and summing across τ yields:

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

where $H_{mk} = \sum_{n\in\mathbf{N}} S_m^n \cdot S_k^n$. In equation (3'), the market power component given in equation (4) becomes

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

When we compare (4) and (4'), we find 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: $H_{mk} = \sum_{u\in\mathbf{V}}\sum_{\tau\in\mathbf{V}} H_{mk,u\tau} \frac{Y_{mu}}{Y_m}\frac{Y_{k\tau}}{Y_k}$, which shows that H_{mk} is a weighted average of our VHHIs, $H_{mk,u\tau}$, with market shares as weights.

If we take the analysis one step further, what happens to equation (3) or (3') if horizontal products are also perfect substitutes? Using the same arguments, we find that this implies that $c_k = c_0$, $c_{km} = c$ and $\alpha_{km} = \alpha$. Under perfect substitution across all products, the law of one price applies, with $p_{k\tau} = p$ for all $k \in \mathbf{K}$ and all $\tau \in \mathbf{V}$. Then, if we let $Y = \sum_{m\in\mathbf{K}} Y_m$, multiply the right-hand side of (3') by $\frac{Y_m}{Y}$ and sum over $m\in\mathbf{K}$, we get

$$p = c_0 + [c - \alpha] \cdot H \cdot Y\,, \qquad (3'')$$

where $H \equiv \sum_{n\in\mathbf{N}} (w^n)^2$, $w^n = \frac{\sum_{m\in\mathbf{K}}\sum_{u\in\mathbf{V}} y^n_{mu}}{Y}$ is the n-th firm's overall market share.

In equation (3''), the price market power component given in equations (4) and (4') becomes

$$M = [c - \alpha] \cdot H \cdot Y\,. \qquad (4'')$$

In this case, we note that H is the standard HHI that measures overall market concentration. Additionally, it satisfies $H = \sum_{m\in\mathbf{K}}\sum_{k\in\mathbf{K}} H_{km} \frac{Y_k}{Y}\frac{Y_m}{Y} = \sum_{m\in\mathbf{K}}\sum_{k\in\mathbf{K}}\sum_{u\in\mathbf{V}}\sum_{\tau\in\mathbf{V}} H_{km,u\tau} \frac{Y_{ku}}{Y}\frac{Y_{m\tau}}{Y}$, i.e. it is a weighted average of our VHHIs, $H_{mk,u\tau}$. Thus, when all products are perfect substitutes, our approach reduces to a single market analysis and to the HHI approach that is commonly found in the literature (e.g., Whinston 2006).

This analysis illustrates how our VHHI approach is able to generalize previous investigations to situations where product differentiation is present. We also identify the roles that product substitution/complementarity play, and illustrate how they affect pricing under imperfect competition. Most significantly, our generalization allows for product differentiation in both horizontal and vertical markets.

Equation (3) is consistent with Cournot-imperfect competition. It provides useful information on the effects of market power in vertical channels and with differentiated products. It also helps to illustrate the linkages between market power and bundle pricing. When product differentiation involves bundling decisions, equation (3) shows how bundle pricing would be influenced by complementarity or substitutability among products, as evidenced by demand or by marginal costs of production (as captured by the VHHIs). Below, we illustrate the usefulness of our approach by presenting an econometric analysis of the role of product differentiation, bundling and vertical structures in pricing, with an application to the US soybean seed industry.

3. DATA

Our analysis relies on an extensive data set that provides detailed information about the US soybean seed market. The data were collected by **dmr**kynetec [hereafter dmrk] [8] from a stratified sample of farmers who were surveyed annually between 2000 and 2007.[9] The survey provides farm-level information about seed purchases, acreages, seed types and prices. Farmers typically buy their seeds locally, and seeds suitable for planting at local market differ from region to region; thus, we define the "local market" at the Crop Reporting District (CRD)[10] level, and consider only those transactions that occurred in CRDs that included more than ten farms sampled in every year. Our data set contains a total of 75,560 farm-level purchase observations, from 18 states, which were collected over a span of eight years (2000 – 2007). These are not panel data, given that the farm sample changes from year to year.

The biotech soybean seed industry currently markets herbicide tolerance (*HT*) traits. These patented genetic traits are inserted in seeds by biotech firms and designed to make it easier for farmers to control weeds, thus contributing to higher yields and improved agricultural productivity. Below, we use the labels *HT*1 and *HT*2 to delineate the two major *HT* traits. Different biotech companies own these traits, and they also own subsidiary seed companies,

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[8] **dmr**kynetec changed its name to GfK Kynetec in May 2009. Its web address is www.gfk.com, and the seed data set is a product called TraitTrak.

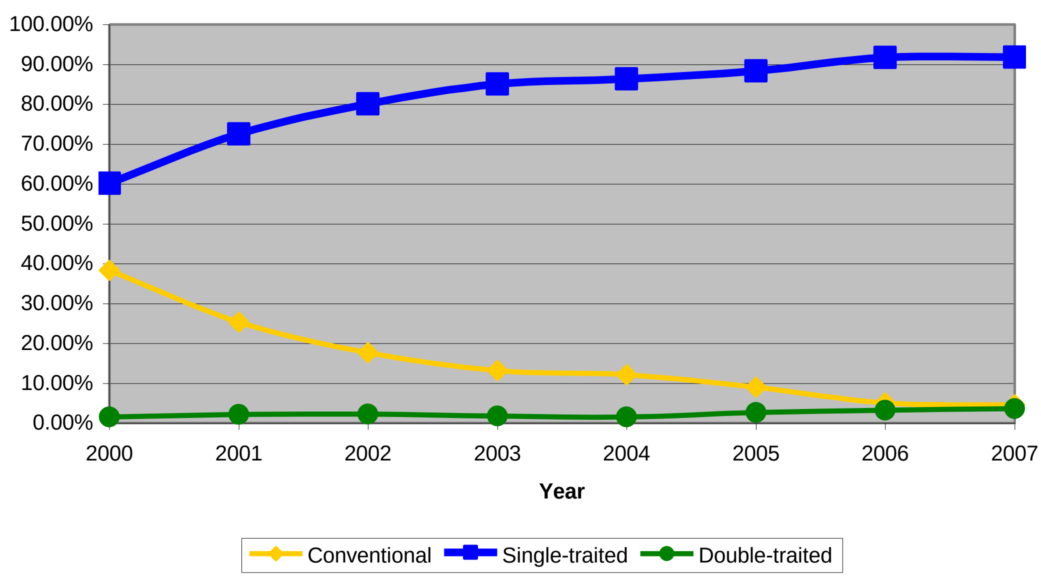
[9] The survey was stratified to over-sample producers with large acreages, and was collected using computer assisted telephone interviews.

[10] The U.S. Department of Agriculture delineates crop-reporting districts (CRD) in order to reflect local agro-climatic conditions. CRDs are generally larger than counties, but are smaller than states.

which market the biotech seeds. Some biotech seeds contain only one of these traits, while others include a bundle of both *HT*1 and *HT*2 traits, a scenario called "double stacking".

Figure 1 illustrates how soybean acreage shares have evolved over time, and reflects adoption rates for different types of soybean seeds in the US between 2000 and 2007. The acreage share of conventional seeds has decreased rapidly, from 38.3% of the market in 2000 to 4.6% in 2007. Single-traited biotech seeds dominate the market, and have accounted for over 90% of acreage share since 2006. "Double stacked" seeds have carved out a small market share, and have exhibited a rising trend since 2005.

Figure 1. US Soybean Seed Adoption Rates by Acreage Share, 2000 – 2007.



Biotech seeds are distributed by seed companies affiliated with the biotech companies that own a particular trait, and by seed companies that are unaffiliated. US patent law states that if a non-affiliated seed company wants to produce a seed that contains a patented trait, it is required to obtain a license from the patent owner, the related biotech company. Affiliated seed companies are exempt from this requirement.[11] Therefore, we consider two vertical structures, **V** = {v, ℓ}, where v corresponds to *vertical integration* (wherein a seed company is affiliated with a related biotech firm) and ℓ corresponds to *licensing* (wherein an unaffiliated seed company licenses a trait from a biotech firm). As noted earlier, the proportion of vertically integrated seed increased from 13% of the single-traited market in 2000 to 26% in 2007. Among those farmers who adopted some biotech seeds in 2007, 57% purchased them only through the licensed channel, 16% bought seeds only through the integrated channel and 27% bought their seeds from both channels.

Figure 2 shows the trend in our constructed VHHIs. We use subscript 0 to denote the conventional seed market and subscript 1 to indicate the single-traited *HT*1 market. Market concentration in the conventional seed market ($H_{00,\ell\ell}$) increased substantially over the years: It was 0.231 in 2000 and grew to 0.623 in 2007. Cross-market concentration between the integrated *HT*1 and conventional seed markets ($H_{01,\ell v}$) also rose especially after 2005: Cross-concentration was 0.128 in 2000, 0.192 in 2005 and climbed to 0.395 in 2007. Market concentration in the licensed *HT*1 market ($H_{11,\ell\ell}$) and cross-market concentration between the licensed *HT*1 and conventional seed markets ($H_{01,\ell\ell}$) exhibit no dramatic changes over the study period.

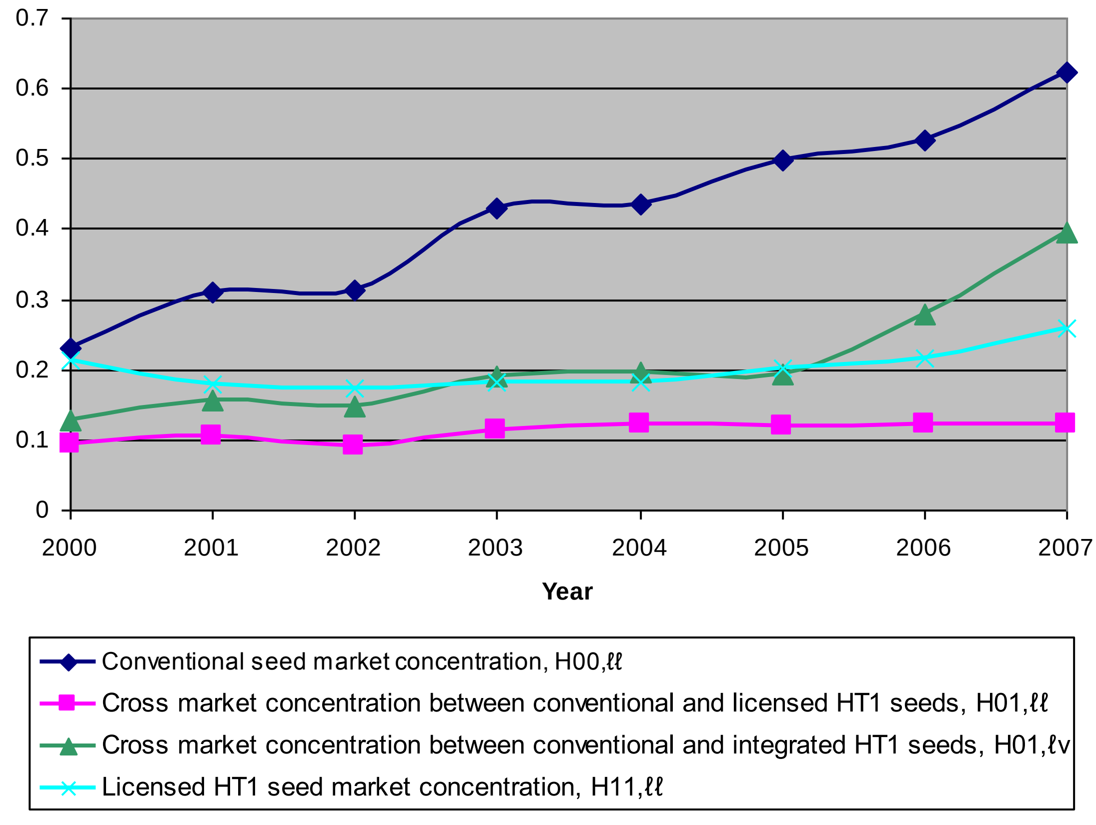
4. ECONOMETRIC SPECIFICATION

We use equation (3) (see Section 2) as the basis for our analysis of US soybean seed prices. As derived, equation (3) is a structural equation that expresses the determinants of pricing for differentiated products under alternative vertical structures in situations of imperfect competition. Our attention is focused on two vertical structures: vertical integration, v, and

[11] The affiliated subsidiary seed company may still operate under a license from the biotech company, but the licensing terms are understandably different from those for unaffiliated firms.

licensing, ℓ; and on four seed types, each containing genetic traits that are available individually or bundled/stacked. Let $T_k \in \{0, 1\}$ be dummy variables for seed types, satisfying $T_k = 1$ for seed type k and $T_k = 0$ otherwise, $k \in \mathbf{K} = \{0, \ldots, 3\}$, with $\sum_{k=0}^{3} T_k = 1$: conventional ($T_0 = 1$), single-traited $HT1$ ($T_1 = 1$), single-traited $HT2$ ($T_2 = 1$), and $HT1$ and $HT2$ bundled/stacked ($T_3 = 1$). Additionally, 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, $\tau \in \mathbf{V} = \{\ell, v\}$.

Figure 2. VHHIs Over Time, 2000 – 2007



Our analysis allows for fixed and variable costs to vary across vertical structures. Under vertical integration, an integrated firm can recover R&D fixed costs directly through seed sales;

however, biotech firms may face higher integration costs. Under a licensing scenario, a seed company pays a licensing fee to a biotech firm to help it recover its R&D investment. In general, the two vertical structures vary in terms of efficiency and in the exercise of market power. The multi-product nature of the market also affects the assessment of both efficiency and exercise of market power. , For example, as noted above, complementarity across vertically differentiated products can contribute to economies of scope, while also reducing the firms' ability to exercise market power. Alternatively, substitutability across vertical structures could help enhance the exercise of market power.

We shed some light on these issues in our empirical analysis below. We begin with a standard hedonic pricing model wherein the price of a good varies with the characteristics it includes (following Rosen 1974). Consider a hedonic equation that represents the determinants of price p for seed type k sold in the τ-th vertical structure:

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

where **X** is a vector of other relevant covariates and $\varepsilon_{\kappa\tau}$ is an error term with mean zero and finite variance. Specification (5a) allows prices to vary across seed types and vertical structures. In equation (5a), price p represents the net seed price that farmers pay (in $ per 50lb bag).[12] It is measured for each seed purchase taking place at the farm-variety level.

As we did with equations (3) – (4), we introduce market power effects in (5a) by specifying

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

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

[12] Seeds are usually sold at a list price less a discount that is available at the point of sale. Our study utilizes the after-discount "net price".

terms at the crop reporting district (CRD) level, assuming that it is the relevant local market for farmers. Since $H_{mk,u\tau} = 0$ under competitive conditions, we capture the exercise of market power in (5a) – (5b) through the term:

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

where $M_{k\tau} = 0$ under perfect competition. Equation (6) measures the effects of imperfect competition under various vertical structures.

Since conventional seeds contain no added biotech traits, we assume that the vertical structure for conventional seed is "un-integrated" (ℓ). Thus, building on (5a) – (5b), we estimate the equation for conventional seeds ($T_0 = 1$) as:

$$p_{0\ell} = \beta_0 + \sum_{m\in\mathbf{K}} (\beta_{m0,\ell\ell} H_{m0,\ell\ell} Y_{m\ell} + \beta_{m0,v\ell} H_{m0,v\ell} Y_{mv}) T_0 D_\ell + \delta_{0\ell} + \boldsymbol{\varphi}\mathbf{X} + \varepsilon_{0\ell} \,,$$

For *HT*1 seed ($T_1 = 1$), the price equations for licensed and integrated seeds are:[13]

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

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

The **X** covariates in equation (5a) include location, year dummies, individual farms' total corn acreages, and binary terms that capture alternative purchase sources. Farmers can obtain various types of seeds from multiple sources. We use purchase source to describe possible price discrimination schemes that affect the prices that farmers pay for their seeds. We define the location variables as state dummy variables, which reflect spatial heterogeneity in cropping systems, weather patterns and yield potentials. We also include year dummies in order to capture structural changes over time and advances in genetic technologies. We use the farm acreage variable to catch possible price discrimination that may be related to bulk purchases.

[13] Similar equations can be written for *HT*2 ($T_2 = 1$) and bundled/stacked seeds ($T_3 = 1$). However, our sample includes an insufficient number of observations for these seed types, and this prevents us from obtaining reliable measures of the VHHIs. Therefore, for these two seed types, we explore merely how prices vary across characteristics and vertical structures.

We also include entry and exit dummies for a specific type of seed if it is in its first year on the market (*Entry* = 1) or in its last year on the market (*Exit* = 1). These dummies capture firms' possible strategic pricing behavior. This includes the possibility that new seeds may be priced lower in an effort to speed up their adoption. Similarly, "old varieties" may be priced lower to slow down their elimination from the market.

As mentioned in Section 3, since the 1980s the soybean industry has transitioned away from using publicly-bred seed, in favor of privately-bred varieties. Our model is based on profit maximizing behavior that may not apply to public breeders. Almost all of the observations in our data indicate that publicly-sourced seeds are conventional seeds. We expect pricing in the public sector to differ from that of the private sector. On this basis, we have introduced a dummy variable that captures institutional structure: *Pub* = 1 represents the public sector and *Pub* = 0 signifies the private sector. In equation (5b) we include the dummy variable *Pub* as both an intercept shifter and a slope shifter.

5. ECONOMETRIC ESTIMATION

In table 1 we report summary statistics for key variables used in the analysis. The mean value of conventional seed HHI, $H_{11,\ell\ell}$, is 0.412, which is more than twice the Department of Justice's threshold of 0.18 for identifying "significant market power". Biotech seeds in the licensed channel exhibit greater competition than do conventional seeds, and have a mean value of $H_{22,\ell\ell}$ at 0.201. We observe significant changes in the VHHIs across regions and over time (see figure 2), and 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 about the effects of these changes.

Table 1. Summary Statistics

Variable[b]	Number of Observations[a]	Mean	Standard Deviation	Min.	Max.
Net Price ($/Bag)	75560	23.05	5.04	2.46	43
Farm Size (Acre)	75560	619.0	656.5	4	24000
Conventional Seed Market Concentration, $H_{00,\ell\ell}$	564	0.412	0.280	0.063	1
Cross-Market Concentration (Conventional and Licensed *HT*1), $H_{01,\ell\ell}$	520	0.110	0.093	6.04E-05	0.606
Cross-Market Concentration (Conventional and Integrated *HT*1), $H_{01,\ell v}$	308	0.180	0.180	0.001	1
Licensed *HT*1 seed market concentration, $H_{11,\ell\ell}$	608	0.201	0.094	0.065	0.805
Integrated *HT*1 seed market concentration, $H_{11,vv}$	601	1	0	1	1

[a]/ For the market concentration measurements *H*s, we report only the summary statistics for those non zeros at the CRD level. Therefore the number of observations is, at most, 76 × 8 = 608.
[b]/ Two VHHIs are not reported in the table: $H_{11,\ell v} = H_{11,v\ell} = 0$, because in the soybean industry, we do not observe companies that are both vertically integrated and licensed in the same market. This is not a general case: For example, these measures are nonzero in the cotton seed market. Moreover, $H_{01,\ell\ell} = H_{10,\ell\ell}$ and $H_{01,\ell v} = H_{10,v\ell}$ by symmetry in construction.

One econometric issue in the specification (5a)-(5b) is the endogeneity of the VHHIs. We expect that market concentration (as measured by *H*), quantity sold (*Y*) and seed price will be jointly determined, given that each is dependent upon a firm's market strategies. Due to the fact that the econometrician does not observe some of the determinants of these strategies, this implies that terms $H \cdot Y$ are correlated with the error term in equation (5a). In such situations, least-squares estimation of (5a) – (5b) yields biased and inconsistent parameter estimates. One can deal with this issue by using an instrumental variable (IV) method to estimate equations (5a) – (5b).

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 for *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).[14] In our case, the *C* statistic is 33.93, with a *p*-value of less than 0.0001, and this offers strong statistical evidence against the null hypothesis of exogeneity.

The presence of endogeneity motivates the use of an IV estimator, and this raises the issue of selecting appropriate instruments. The instruments need to satisfy two conditions: First, to solve the issue of simultaneous equation bias, they should be orthogonal to the error term in (5a). Second, they should be relevant variables that can identify the appropriate parameters, (i.e., they should not be "weak instruments").

Lags in the seed production process motivate seed companies to make production decisions at least a year ahead of marketing decisions. Therefore, lag values are part of the information set that seed companies have available to them at the time they make their production decisions. Although our data set is not a panel at the farm-level (due to the fact that the farm sample changes from year to year), we do have panel data on CRD-level concentration measure *H*s and on each seed type's market size *Y*s. Thus, the *H* and *Y* lagged values are good candidates for instruments. On that basis, we use the one-year lagged *Y* and the interaction between the one-year lagged value of each *H* and the one-year lagged value of *Y* as instruments.

Below we present a series of tests that support this choice. We evaluate the properties of the error term in (5a), and note that, on average, each farm purchases three different seed varieties. Unobserved factors that affect seed prices may be farm-specific, in that they may differ across farms. This suggests that the error term in (5a) may exhibit heteroscedasticity. We use a

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

Pagan-Hall test[15], and find strong evidence against homoscedasticity, with a Chi-square statistic of 203.9 and a *p*-value of less than 0.0001. On that basis, we use heteroscedastic-robust standard errors to estimate equations (5a) – (5b). We also cluster the standard errors at the farm level.[16] Indeed, if unobserved factors are farm-specific, the error terms in (5a) will be correlated across observations associated with a given farm.

Finally, we assess the validity of the instruments. Equation (5a)-(5c) was estimated by two-stage-least-squares (2SLS). The Hansen over-identification test is not statistically significant, and has a *p*-value of 0.23. This indicates that our instruments satisfy the required orthogonality conditions. To test for "weak instruments" in the presence of heteroscedastic errors, we use the Bound *et al.* (1995) measures and the Shea (1997) partial R^2 statistic. Following Staiger and Stock (1997), the test results do not provide evidence that our instruments are weak. The Kleibergen-Paap weak instrument test (Kleibergen and Paap, 2006)[17] yields a test statistic of 21.89. Using the critical values presented in Stock and Yogo (2005), this indicates again that our instruments are not weak.

6. RESULTS

In table 2 we report the results of our 2SLS IV estimation for equations (5a) – (5b) with heteroscedastic-robust standard errors under clustering. For comparison purposes, we also report the ordinary least square (OLS) estimation results. The OLS estimates of the market concentration parameters differ substantially from those of the 2SLS results, and this suggests

[15] The Pagan-Hall test is a more general test for heteroscedasticity in an IV regression than is the Breusch-Pagan test. Pagan-Hall remains valid in the presence of heteroscedasticity (Pagan and Hall 1983).

[16] We also tried clustering the standard errors at CRD×Year level. The results were qualitatively similar.

[17] Note that unlike the Cragg-Donald test for weak instruments, the Kleibergen-Paap remains valid under heteroscedasticity.

the presence of endogeneity. Given that IV estimation corrects for endogeneity bias, our discussion below focuses on the 2SLS estimates.

We begin by discussing our estimates of how prices vary across seed types and vertical structures, and then shift our attention to the estimated effects of market power.

The Effects of Various Seed Characteristics

Table 2 indicates that publicly-bred conventional seeds are priced significantly lower than those that are privately-bred, at a discount of $5.05 per bag. This is consistent with our expectation that private and publicly-sourced seed companies rely on different pricing rules. The results show that all biotech seeds receive a price premium over private conventional seeds; however, this premium varies by vertical structure. The coefficients of the δ_{iv}s (seed *i* under an integrated vertical structure) and $\delta_{i\ell}$s (except for $\delta_{2\ell}$) (seed *i* under a licensing scenario), $i = 1, 2, 3$, are each positive and statistically significant. These coefficients range from $2.18 to $7.76, and they show evidence of significant premiums for these biotech traits. The coefficient, $\delta_{2\ell}$, which represents *HT*2 biotech seed under licensing agreements, is not statistically different from zero. For all three types of biotech seeds, those sold under the vertical integration scenario are priced higher than are those that are produced and marketed under licensing agreements.

Market Concentration and Vertical Structures

Our model utilizes the VHHI to capture market share information about each seed type in different vertical structures. In Section 2, we argued that the impacts of VHHI $H_{mk,u\tau}$, $k \neq m$, depend on substitutability/complementarity relationships between type-*m* seed in *u*-th market structure and type-*k* seed in *τ*-th market structure. If the two types of seed are substitutes

Table 2. OLS and IV (2SLS) Regression with Robust Standard Errors.[a]

Dependent Variable: Net Price ($/Bag)	**OLS**		**2SLS**	
	Coefficient	**T-statistics**	**Coefficient**	**Robust Z Statistics**
Effects of Seed Characteristics: Benchmark Is Private T_1: Conventional Seed				
δ_0 public (Publicly-Sourced Conventional Seed)	-4.35***	-19.03	-5.05***	-10.71
$\delta_{1\ell}$ (*HT1* Under Licensing)	7.51***	101.65	7.38***	29.70
δ_{1v} (*HT1* Under Vertical Integration)	7.89***	96.60	7.76***	30.33
$\delta_{2\ell}$ (*HT2* Under Licensing)	0.44***	3.94	0.00	0.00
δ_{2v} (*HT2* Under Vertical Integration)	2.02***	9.48	2.18***	5.23
$\delta_{3\ell}$ (Stacked Under Licensing)	7.69***	50.78	7.45***	25.77
δ_{3v} (Stacked Under Vertical Integration)	8.01***	87.50	7.75***	30.56
Market Concentration and Vertical Structures				
$H_{00,\ell\ell}T_0D_\ell Y_{0\ell}$ (Conventional Seed)	0.025***	3.26	0.163**	2.58
$H_{00,\ell\ell}T_0D_\ell Y_{0\ell}$*_pub* (Publicly-Sourced Conventional Seed)	-0.071	-0.25	-0.156*	-1.89
$H_{10,\ell\ell}T_0D_\ell Y_{1\ell}$ (Conventional Seed)	-0.047***	-3.59	-0.261***	-3.85
$H_{10,\ell\ell}T_0D_\ell Y_{1\ell}$*_pub* (Publicly-Sourced Conventional Seed)	0.102*	1.84	0.330***	3.22
$H_{10,v\ell}T_0D_\ell Y_{1v}$ (Conventional Seed)	-0.055**	-2.15	0.009	0.10
$H_{10,v\ell}T_0D_\ell Y_{1v}$*_pub* (Publicly-Sourced Conventional Seed)	-0.020	-0.25	-0.029	-0.21
$H_{01,\ell\ell}T_1D_\ell Y_{0\ell}$ (*HT1* Under Licensing)	-0.060***	-6.02	-0.145***	-3.01
$H_{11,\ell\ell}T_1D_\ell Y_{1\ell}$ (*HT1* Under Licensing)	0.012***	2.99	5.88E-05	0.017
$H_{01,\ell v}T_1D_v Y_{0\ell}$ (*HT1* Under Vertical Integration)	0.041***	4.43	0.075	1.58
$H_{11,vv}T_1D_v Y_{1v}$ (*HT1* Under Vertical Integration)	-0.004	-1.40	-0.021***	-2.62
Other Variables				
Exit	-0.35***	-12.36	-0.33***	-8.43
Entry	0.21***	9.92	0.03	0.99
Year 2002	0.14***	4.70	0.33**	6.03
Year 2003	-0.32***	-8.37	-0.09	-1.18
Year 2004	2.28***	60.29	2.48***	34.54
Year 2005	5.17***	138.94	5.39***	60.56
Year 2006	6.06***	131.62	6.29***	56.92
Year 2007	6.27***	165.80	6.49***	65.21
Total Soybean Acreage by Individual Farm (1000 Acre)	-0.286***	-13.57	-0.273***	-4.99
Constant	16.65***	175.92	16.98***	64.84
Number of observations	64550			

[a] Statistical significance is noted by * at the 10 percent level, ** at the 5 percent level, ** at the 1 percent level. The R^2 is 0.77 for the OLS estimation. For the 2SLS estimation, the centered R^2 is 0.74, and un-centered R^2 is 0.99. In order to save space, we do not report results for the location and purchase source effects; however, we discuss these in the text.

(complements), we expect that an increase in the VHHI will be associated with a rise (decrease) in prices.

For the three VHHIs that relate to conventional seed prices ($H_{00,\ell\ell}$, $H_{10,\ell\ell}$, $H_{10,v\ell}$), the interaction between the public dummy and the VHHIs separates out the public sector and private sector effects. Table 2 offers strong statistical evidence that supports the notion that the public and private sectors follow different pricing rules. For the private sector, the coefficient of the traditional HHI ($H_{00,\ell\ell}$) is positive and statistically significant at the 5 percent level; however, for the public sector this positive effect disappears. The cross-market VHHI coefficient between licensed *HT*1 and conventional seeds ($H_{10,\ell\ell}$) is negative for the private sector and positive for the public sector. This suggests that in the private sector the two products are complements (in supply and/or in demand). If complementarity exists on the demand side, it should similarly affect seed pricing in the public sector. However, the coefficient, $H_{10,\ell\ell}$, is positive for publicly-sourced conventional seed, and this offsets the complementarity effects between licensed *HT*1 and conventional seeds. We thus infer that the complementarity between these two seed types likely comes from the supply side, wherein the private and public sectors appreciably differ. The VHHI coefficients for the private and public sectors that cross the integrated *HT*1 and conventional seeds ($H_{10,v\ell}$) are not statistically significant.

For the two cross-market VHHI coefficients that affects *HT*1 biotech seed, the coefficient, $H_{01,\ell\ell}$, which is associated with the pricing of licensed *HT*1 seed, is negative and statistically significant. This is consistent with the way it affects the conventional seed market through the VHHI $H_{10,\ell\ell}$. It suggests that conventional and licensed *HT*1 seeds exhibit strong and symmetric complementarity. We argued above that such complementarity likely comes from the supply side. Given that complementarity contributes to economies of scope (see Section 2), this result offers indirect evidence to support our assertion that seed companies experience economies of scope in their production and marketing of conventional and licensed *HT*1 seeds. We also note that the cross-market VHHI coefficient of integrated *HT*1 and conventional seeds ($H_{01,\ell v}$) is also negative, but not statistically significant. This result may reflect transaction costs present in vertical integration (such as those costs associated with negotiation and re-organization), and these may offset some of the efficiency gains that firms garner from economies of scope.

The own-market VHHIs, $H_{11,\ell\ell}$ and $H_{11,vv}$, are standard Herfindahl indices that measure market concentration in the licensed and integrated (respectively) *HT*1 seed markets. Although the impact is positive for the licensed *HT*1 seed market, which is consistent with our *a priori* expectation, its effect is not statistically significant. The coefficient of term $H_{11,vv}$ is negative and statistically significant, contrary to *a priori* expectation. However, we note that throughout our study period this market maintains a concentration measure, $H_{11,vv}$, of 1, which means that the market is monopolistic. Thus, our estimation of coefficient $H_{11,vv}$ relies entirely on observed variations in market size of integrated *HT*1 seed, Y_{1v}, which has been expanding over the years. The negative coefficient estimate may reflect the fact that this market expansion contributes to lower prices.

We then ask whether vertical organization affects prices. We investigate this issue by examining whether market concentrations relate to seed prices in similar ways under alternative vertical structures. We generate the following hypotheses: For a given seed type,

(I) H_0: $\beta_{10,\ell\ell} = \beta_{10,v\ell}$,

(II) H_0: $\beta_{01,\ell\ell} = \beta_{01,\ell v}$ and

(III) H_0: $\beta_{11,\ell\ell} = \beta_{11,vv}$, where the β's are the corresponding VHHI coefficients.[18]

The test results reject the null hypothesis for (I) and (II) at the 5% level of significance, but fail to reject the null hypothesis for (III) at the 10% level of significance. This result suggests that different vertical structures in the *HT*1 seed market generate different cross-market concentration effects on the pricing of conventional seeds (Hypothesis I). Moreover, this cross-market concentration in turn stimulates differing effects on the pricing of licensed *HT*1 and vertically integrated *HT*1 seeds (Hypothesis II). These results provide statistical evidence that it is essential to include vertical organization in the analysis. Our findings document how vertical structures significantly influence how firms exercise market power and price goods. We discuss these effects in greater detail below.

Other Factors

Table 2 illustrates variations in prices over time. The year dummies show a strong rising trend beginning in and continuing after 2004. In 2007, the price per bag of seed was \$6.49 higher than it was in 2001. Given that the mean price is approximately \$23.05 per bag, this demonstrates an annual growth rate higher than that of rate of inflation during the same time period.[19] Our estimates also indicate that soybean seeds sold in Corn Belt states are discounted more than those sold in other states. They also indicate how the source of purchase affects prices.

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[18] The demand for seed reflects farmers' desire to maximize their profits; thus, we can express the willingness to pay for a specific type of seed as marginal profit. The demand slope is therefore the second derivative of farmers' profit. Using Young's theorem, this implies the following 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 $\beta_{mk,u\tau} = [c_{mk,u\tau} - \alpha_{mk,u\tau}]$, we generate the following hypotheses for the relevant cross markets:

(IV) H_0: $\beta_{10,\ell\ell} = \beta_{01,\ell\ell}$,

(V) H_0: $\beta_{01,\ell v} = \beta_{10,v\ell}$.

We use a Wald test, and fail to reject these null hypotheses (whose *p*-values are 0.22 and 0.47, respectively). While the results we present below do not impose these null hypotheses, we note our main findings were not affected by imposing the above symmetry restrictions.

[19] The Department of Labor Statistics reported the average inflation rate from 2000 to 2007 at 2.78%.

Farmers who buy their seeds from a "farmer who is a dealer or agent" save $0.12 per bag by purchasing them directly from "a seed company or its representatives" and spend $0.27 more per bag if they buy seeds from cooperatives.

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

7. IMPLICATIONS

In this section, we use our empirical estimates to generate new insights about pricing within and across markets under various vertical structures. For illustration purposes, our analysis focuses on Illinois in 2004. Illinois is one of the largest soybean-producing states in the US, and it has the largest number of farms in our sample. We choose the year 2004 because it is in the middle of the sample period.

We present two sets of results. We begin by estimating how stacking influences seed prices under licensing and vertical integration scenarios. We then evaluate imperfect competition, and estimate the market power component of price, M, for different seed types. This analysis provides useful information about the extent of departure from competitive pricing.

The Effects of Bundling/Stacking

The literature on bundling 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, wherein seeds are priced as the sum of their component values. More generally, this allows us to investigate how prices vary across bundles within and across different vertical structures. We simulate our estimated model at sample means of relevant variables for Illinois in 2004 (including farm size and VHHIs).[20]

Table 3 reports the estimated bundling/stacking effects for different markets and vertical structures. The mean conventional seed price is $16.25 per bag, and we use this as a "base case" to evaluate both integrated and licensed market structures. Biotech traits add price premiums over conventional varieties. Additionally, in both vertical structures, stacked seeds exhibit a premium over single-traited seeds. The stacking effect reflects the difference between the price under component pricing and under bundling arrangements, and is -$2.57 per bag in the integrated market, but is not different from zero in the licensed market. These results indicate that component pricing applies under licensing, but not under vertical integration. The evidence illustrates sub-additive pricing under vertical integration, wherein the bundle is priced significantly less than the sum of its component values.

This sub-additive pricing may be driven by complementarities across differentiated commodities, or it may reflect the presence of economies of scope in the production of bundled/stacked seeds. This result is consistent with synergies in R&D investments across stacked seeds. For example, a given R&D investment may contribute to the production of multiple seed types, meaning that bundling can help reduce the overall cost of producing seeds. In this context, the fact that prices are sub-additive suggests that seed companies share with farmers some of the benefits of scope economies by offering them lower prices for bundled/stacked seeds.

[20] We set the purchase source as "Farmer who is a dealer or agent". We conduct our simulation by varying the seed type and vertical structure dummies, while keeping the corresponding variables at the sample mean level for IL. All simulated prices are bootstrapped.

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

Seed Type	Licensed (*l*)		Vertically integrated (v)		Difference Between Vertical Structures ($p_v - p_\ell$)
	Expected Seed Price	Difference in Price vs. Conventional	Expected Seed Price	Difference in Price vs. Conventional	
Conventional	16.25	N/A	N/A	N/A	N/A
*HT*1 Biotech	23.88	7.63*** (0.12)	24.38	8.13*** (0.12)	0.50*** (0.07)
*HT*2 Biotech	16.75	0.50** (0.21)	18.94	2.69*** (0.36)	2.17*** (0.38)
*HT*1&*HT*2 Stacked	24.21	7.96*** (0.20)	24.50	8.25*** (0.14)	0.31* (0.16)
Stacking Effect : *HT*1&*HT*2 vs. *HT*1+*HT*2	-0.17 (0.26)		-2.57*** (0.37)		-2.36*** (0.41)

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

Table 3 reports price differences across vertical structures, and shows that seed prices under vertical integration scenarios are significantly higher than those under licensing arrangements. Per bag, the price difference amounts to \$0.50, \$2.17 and \$0.31 for conventional, *HT*1 and *HT*2 seeds, respectively. This provides further evidence that vertical organization affects pricing, and indicates that the trend toward vertical integration pushes farmers to pay higher seed prices.

Estimated Market Power Component

The term *M* in equations (4) and (6) measures market power (see Sections 2 and 4). Our estimated model allows us to evaluate *M* in equation (6) and to characterize the strength of imperfect competition: Under perfect competition it is zero, but it is non-zero under concentrated markets. *M* can be interpreted as a measure of the price enhancements associated with imperfect competition.

To illustrate this, we evaluate three scenarios: S1, S2 and S3. Scenario S1 considers a case wherein concentration changes only in the conventional market: In Illinois, $H_{00,\ell\ell}$ shifts from zero to its sample mean, holding other *H*'s constant. In Scenario S2, we consider market concentration changes in the licensed *HT*1 seed market: In Illinois, we adjust $H_{11,\ell\ell}$ from zero to the sample mean (again holding other *H*'s constant). Finally, Scenario S3 considers the joint effects of Scenarios S1 and S2: We alter market concentrations in the conventional and licensed *HT*1 markets, and imply that all corresponding HHIs and VHHIs will also change. Table 4 reports the estimated changes in *M* under each scenario, and presents the corresponding relative measures $\frac{M}{p}$.[21]

Table 4. Estimated Market Power Component.[a]

Seed Type	**Mean Seed Price** ($/bag)	**Market Power Component**					
		Scenario S1		**Scenario S2**		**Scenario S3**	
		M ($/bag)	*M/p*	*M ($/bag)*	*M/p*	*M ($/bag)*	*M/p*
Conventional	16.47	0.60**	0.036	N/A	N/A	-0.52*	-0.032
Licensed *HT*1 Biotech	23.53	N/A	N/A	-1.50E-03	-6.37E-05	-0.25***	-0.011

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

For the conventional seed market scenario, S1, the estimated market power component (*M*) is positive and statistically significant, and is $0.60 per bag. The corresponding relative measure $\frac{M}{p}$ is 0.036, which suggests that the portion of the conventional seed price that is attributable to market power is 3.6%. Under Scenario S2, the market power component for licensed *HT*1 seed is not statistically different from zero.

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[21] Note that $\frac{M}{p}$ is related to the Lerner index, which is defined as $L = \frac{p - \partial C/\partial y}{p}$. This 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.

The Scenario S3 results are of particular interest. Recall that S3 evaluates the joint effects simulated in S1 and S2. Under Scenario S3, the market power components (*M*) are negative and significant for both the conventional and licensed *HT*1 markets. This contrasts with the S1 and S2 results, and provides empirical evidence that cross-market effects are important factor associated with seed prices. Most importantly, S1 does not show the negative market power effects observed in S3. This illustrates that the cross-market power effect dominates the own market power effect. We obtain these results because our estimated complementarity effects reduce the price enhancements that are associated with market power. Given that complementarity reflects cross-markets effects, this result underscores the need to address market power issues in a multi-market framework both horizontally and vertically.

8. DISCUSSION

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

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

References

Adams, W., and J. Yellen. "Commodity Bundling and the Burden of Monopoly." *Quarterly Journal of Economics* 90(1976): 475-98.

Baumol, W.J., J.C. Panzar and R.D. Willig. *Contestable Markets and the Theory of Industry Structure*. Harcourt Brace Jovanovich, Inc. New York, 1982.

Bound, J., D.A. Jaeger, and R. Baker. "Problems with Instrumental Variables Estimation When the Correlation between the Instruments and the Endogenous Explanatory Variable is Weak." *Journal of the American Statistical Association* 55(1995): 650-659.

Chavas, J.P. and G. Shi. "On Market Concentration and the Analysis of Vertical Market Structure." AAE Working paper, University of Wisconsin, Madison, 2010.

De Fontenay, C.C. and J.S. Gans. "Vertical Integration in the Presence of Upstream Competition" *Rand Journal of Economics* 36(3)(2005): 544-572.

Fernandez-Cornejo, J. *The Seed Industry in U.S. Agriculture: An Exploration of Data and Information on Crop Seed Markets, Regulation, Industry Structure, and Research and Development,* Resource Economics Division, Economic Research Service, U.S. Department of Agriculture, Agriculture Information Bulletin Number 786, 2004.

Fulton, M., and K. Giannakas. "Agricultural Biotechnology and Industry Structure." *AgBioForum* 4(2001): 137-151.

Gans, J.S. "Concentration-Based Merger Tests and Vertical Market Structure" *Journal of Law and Economics* 50(2007): 661-680.

Graff, G., G. Rausser and A. Small. "Agricultural Biotechnology's Complementary Intellectual Assets." *Review of Economics and Statistics* 85(2003): 349-363.

Hart, O. and J. Tirole. "Vertical Integration and Market Foreclosure" *Brookings Papers on Economic Activities, Microeconomics* (1990): 205-285.

Hayashi, F. *Econometrics* Princeton University Press, Princeton, 2000.

Hicks, J.R. *Value and Capital: An Inquiry into Some Fundamental Principles of Economic Theory* Clarendon Press, Oxford, 1939.

James, C. "Executive Summary of Global Status of Commercialized Biotech/GM Crops: 2007," *International Service for the Acquisition of Agri-Biotech Applications,* Ithaca, NY, 2007.

Kleibergen, F. and R. Paap. “Generalized Reduced Rank Tests Using the Singular Value Decomposition” *Journal of Econometrics* 133(2006): 97-126.

Lafontaine, F. and M. Slade. “Vertical Integration and Firm Boundaries: The Evidence”, *Journal of Economic Literature* 45(2007): 629-685.

McAfee, R. P., J. McMillan, and M. Whinston. “Multiproduct Monopoly, Commodity Bundling, and Correlation of Values.” *Quarterly Journal of Economics* 103(1989): 371-383.

McAfee, R.|P. and M. Schwartz. “Opportunism in Multilateral Contacting: Non-Discrimination, Exclusivity and Uniformity” *American Economic Review* 84(1994): 210-230.

O’Brien, D.P. and G. Shaffer. “Vertical Control with Bilateral Contracts” *Rand Journal of Economics* 23(1992): 299-308.

Ordover, J.A., G. Saloner and S.C. Salop. “Equilibrium Vertical Foreclosure.” *The American Economic Review* 80(1) (1990): 127-142.

Pagan, A.R. and D. Hall. “Diagnostic Tests as Residual Analysis.” *Econometric Reviews* 2(1983): 159-218.

Rey, P. and J. Tirole. “A Primer on Foreclosure”. *Handbook of Industrial Organization*, Vol III, Mark Armstrong and Robert Porter, Editors, North Holland, Amsterdam, 2008.

Rosen, S. “Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition,” *Journal of Political Economy* 82(1974): 34-55.

Shi, G. “Bundling and Licensing of Genes in Agricultural Biotechnology” *American Journal of Agricultural Economics* 91(1) (2009): 264-274.

Spengler, J. “Vertical Integration and Anti-trust Policy” *Journal of Political Economy* 58(4)(1950): 347-352.

Staiger, D. and J.H. Stock. “Instrumental Variables Regression with Weak Instruments.” *Econometrica* 65(3) (1997): 557-586.

Stock, J.H. and M. Yogo. “Testing for Weak Instruments in Linear IV Regression”. In D.W.K. Andrews and J.H. Stock, eds. *Identification and Inference for Econometric Models: Essays in Honor of Thomas Rothenberg*. Cambridge: Cambridge University Press (2005): 80-108.

Tirole, J. *The Theory of Industrial organization.* MIT Press, Cambridge, MA, 1992.

Venkatesh, R. and W. Kamakura. "Optimal Bundling and Pricing under a Monopoly: Contrasting Complements and Substitutes from Independently Valued Products." *Journal of Business* 76(2) (2003): 211-231.

Whinston, M.D. "Tying, Foreclosure and Exclusion." *American Economic Review* 80(1990): 837-859.

Whinston, M.D. *Lectures on Antitrust Economics*. MIT Press, Cambridge, MA, 2006.