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On Pricing and Vertical Organization of Differentiated Products: The Case of Soybean Seed Industry

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Abstract: This paper investigates the pricing and vertical organization of differentiated products under imperfect competition. In a multiproduct context, we examine how substitution/complementarity relationships among products and vertical structures can affect the exercise of market power. The analysis is applied to pricing of US soybean seeds from 2000-2007. We consider two vertical structures: vertical integration and licensing. We find evidence that vertical organization has significant effects on prices. These effects vary depending on the institutional setup and the bundling of genetic material. 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

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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 substitute 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 in 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 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 application to the US soybean seed industry, using a unique farm-level data set covering the period 2000-2007. The econometric analysis involves the estimation of the structural model where our VHHI's capture the effects of imperfect competition across both horizon and vertical markets. The analysis also examines the bundling of genetic traits in soybean seeds and its role in product differentiation (and price discrimination) under alternative vertical structures. The bundling of genetic material in seeds has arisen from the manipulations of (often patented) genes as implemented by biotech firms. 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 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 is a great 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' profit (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[2] 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, extensive product differentiation exists in the soybean seed industry. Indeed, biotech seeds are differentiated by genetic trait, bundling of traits, and vertical organization (through different labeling and packaging). Our analysis of the soybean seed market will help assess the pricing implications of alternative forms of product differentiation. In addition, the seeds can differ according to the institutional setup of providers. Over the last twenty years, the US soybean seed industry has experienced a rapid shift from public sector breeding to private

[2] We define a "biotech seed" as a seed with identifiable biotech traits (genes), which are often inserted in the seed through genetic modification.

sector breeding. The acreage share of publicly developed varieties decreased from over 70% in 1980 to 10% in the mid-1990s (Fernandez-Cornejo, 2004), and is 0.5% in 2007 according to our data.[3] Such changes were caused in large part by advances in breeding technology (including biotechnology) and changes in the intellectual property protection of life forms since the 1980s. At this point, the implications of theses institutional changes for seed 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 vertical integrated structure are priced higher than those through licensing, but only for bundled seeds. In addition, we fail to reject component pricing under licensing. But we strongly reject component pricing under vertical integration, where the evidence points to sub-additive pricing.

The paper is organized as follows. Section 2 presents a conceptual framework of multiproduct pricing under imperfect competition. It develops a Cournot model introducing the VHHIs capturing the effects of imperfect competition in both vertical and horizontal markets. Section 3 provides an overview of the US soybean seed market. Section 4 presents our econometric model of seed pricing, where the VHHIs reflect the exercise of market power. The

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

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.

1. 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, $k \in \mathbf{K}$, $n \in \mathbf{N}$, $\tau \in \mathbf{V} \equiv \{1, \ldots, V\}$. We assume that the vertical structures can support price discrimination schemes. In other words, through different labeling or packaging, prices for a given product are allowed to vary across vertical structures. In this context, the price-dependent demand for the k-th output under the τ-th vertical structure is $p_{k\tau}(\sum_{n \in N} y^n)$.

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

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

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

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

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

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). This is important in our analysis. 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 $C_n(y^n) = F_n(\mathbf{S}_n) + \sum_{k\in\mathbf{K}} \sum_{\tau\in\mathbf{V}} c_{k\tau} y^n_{k\tau}$ + $0.5\sum_{k,m\in\mathbf{K}} \sum_{\tau,u\in\mathbf{V}} c_{mk,u\tau} y^n_{mu} y^n_{k\tau}$, where $\mathbf{S}_n = \{(j, \tau)\text{: } y^n_{j\tau} > 0, j\in\mathbf{K}, \tau\in\mathbf{V}\}$ is the set of positive outputs produced by the *n*-th firm. Here, $F_n(\mathbf{S}_n) \geq 0$ 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 cost (where $F_n(\mathbf{S}_n) > 0$ for $\mathbf{S}_n \neq \varnothing$) implies increasing returns to scale. In this situation, marginal cost pricing would imply negative profit and any sustainable equilibrium must be associated with departures from marginal cost pricing. Note that the fixed cost $F_n(\mathbf{S}_n)$ 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 either case, recovering the fixed cost would require departures from marginal cost pricing.

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 $F_n(\mathbf{S}_n)$ satisfy $F_n(\mathbf{S}^a) + F_n(\mathbf{S}^b) > F_n(\mathbf{S}^a \cup \mathbf{S}^b)$ for some $\mathbf{S}^a \subset \mathbf{K}\cup\mathbf{V}$ and $\mathbf{S}^b \subset \mathbf{K}\cup\mathbf{V}$, i.e. when the joint provision of $y^a = \{y^n_{ju} : ((j, \tau) \in \mathbf{S}^a\}$ and $y^b = \{y^n_{ju} : ((j, \tau) \in \mathbf{S}^b\}$ reduces fixed cost (Baumol et al., 1982, p. 75). This can apply to in 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., 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

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

which can be alternatively written as

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

where $H_{mk,u\tau} = \sum_{n \in \mathbf{N}} s_{mu}^{n} s_{k\tau}^{n}$, 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

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

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 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, $M_{k\tau}$ in (4) provides a convenient measure of the exercise of market power and its effects on pricing. We will make extensive of (3) and (4) in our analysis below.

Equation (4) provides useful information on the structural determinants $M_{k\tau}$. 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 $c_{11,11} \geq 0$ and $\alpha_{11,11} < 0$, equations (3)-(4) indicate that an increase in the HHI $H_{11,11}$ (simulating an increase in market power) is associated with an increase in 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).

Equation (4) extends the HHI to a multi-product context (when $K > 1$) and under various vertical structures (when $V > 1$). It defines $H_{mk,u\tau}$ 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 $M_{k\tau}$ if $[c_{mk,\tau\tau} - \alpha_{mk,\tau\tau}] > 0$ (< 0). This indicates that, under vertical structure τ, the sign of $[c_{mk,\tau\tau} - \alpha_{mk,\tau\tau}]$ affects the nature and magnitude of departure from competitive conditions. Since $\alpha_{mk,\tau\tau} = \frac{\partial p_{m\tau}}{\partial y^n_{k\tau}}$ and following Hicks (1939), note that $\alpha_{mk,\tau\tau} < 0$ (> 0) when products m and k are substitutes (complements) on the demand side, corresponding to situations where increasing $y^n_{k\tau}$ tends to decrease (increase) the marginal value of $y^n_{m\tau}$. Similarly, $c_{mk,\tau\tau} = \frac{\partial^2 C_n(y^n)}{\partial y^n_{m\tau} \partial y^n_{k\tau}} > 0$ (< 0) when products m and k are substitutes (complements) on the supply side, corresponding to situations where increasing $y^n_{k\tau}$ tends to increase (decrease) the marginal cost of $y^n_{m\tau}$. Note that the complementary case (where $c_{mk,\tau\tau} < 0$) generates economies of scope (Baumol et al. 1982, p. 75), where multi-output production contributes to reducing cost. It follows that the term $[c_{mk,\tau\tau} - \alpha_{mk,\tau\tau}]$ would be positive when $y^n_{m\tau}$ and $y^n_{k\tau}$ behave as substitutes on both the supply and demand side. And it would be negative when $y^n_{m\tau}$ and $y^n_{k\tau}$ behave as complements on both the supply and demand side. From equations (3) and (4), it follows that the qualitative effects of the market concentration terms $\{H_{mk,\tau\tau}\}$ on $M_{k\tau}$ and on price $p_{k\tau}$ depend on the nature of substitution or complementarity among outputs (through the terms $[c_{mk,\tau\tau} - \alpha_{mk,\tau\tau}]$).[5] It means that a rise in $H_{mk,\tau\tau}$ would contribute to an increase (a decrease) in $M_{k\tau}$ when $y_{k\tau}$ and $y_{m\tau}$ are substitutes (complements).

Of special interest here are the effects of vertical structures on pricing. Consider the case where $u \neq \tau$ and $k = m$. Then, equations (3) and (4) also show how vertical structures influence prices. They show that a rise in VHHI $H_{kk,u\tau}$ would be associated with an increase (a decrease) in $M_{k\tau}$ if $[c_{kk,u\tau} - \alpha_{kk,u\tau}] > 0$ (< 0).[6] This indicates that, for a given product k, the sign of $[c_{kk,u\tau} - \alpha_{kk,u\tau}]$ affects the nature and magnitude of departure from competitive pricing. As just discussed, we expect $[c_{kk,u\tau} - \alpha_{kk,u\tau}] > 0$ (< 0) when product k exhibits substitution (complementarity) across vertical structures u and τ. Thus the terms $H_{kk,u\tau}$'s in equations (3)-(4) show how the nature of substitution or complementarity across vertical structures influences the 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 y_{ku} and $y_{k\tau}$ are substitutes (complements).[7]

Are there conditions under which vertical structures would have no effect on prices? As shown below, this would occur if products were perfect substitutes across vertical structures on the demand side as well as on the supply side. Perfect substitution on the supply side corresponds to situations where the cost function takes the form $C_n(y^n) = C_n(\sum_{\tau\in \mathbf{V}} y^n_{1\tau}, \ldots, \sum_{\tau\in \mathbf{V}} y^n_{K\tau})$,

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

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

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

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-end 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

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

and

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

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.[8] 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 VHHI's $H_{mk,u\tau}$ provide the relevant information to assess the role of market power in a vertical sector. As just discussed, this applies in the presence of product differentiation where products are not perfect substitutes across vertical structures. 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 vertical structures in the US soybean seed industry. In this application, the upstream firm develops the seed production technology (e.g., a biotech firm developing patented seeds by inserting genetic material in the basic seed germplasm), and the downstream firm uses the upstream technology to produce and sell the seeds to farmers. In this context, we will investigate the pricing implications of vertical ownership versus licensing in the US soybean seed industry.

2. Data

Our analysis relies on a large, extensive data set providing detailed information on the US soybean seed market. The data were collected by **dmr**kynetec [hereafter dmrk], St. Louis, MO. The dmrk data come from a stratified sample of US soybean farmers surveyed annually from

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

2000 to 2007.[9] 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, our analysis defines the "local market" at the Crop Reporting District (CRD)[10] level. To guarantee reliable measurement of market concentrations, our analysis focus 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.[11] 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.[12]

Currently the only available gene/trait technology in the biotech soybean seed market is the herbicide tolerance (*HT*) designed to reduce yield reductions from competing plants (weeds). There are two major types, labeled here as type 1 (*HT*1) and type 2 (*HT*2). These traits are owned by different biotech companies, which also own subsidiary soybean seed companies. Some biotech seeds contain only one of these traits, while some are bundled and contain 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] The survey is stratified to over-sample producers with large acreage.

[10] 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.

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

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

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

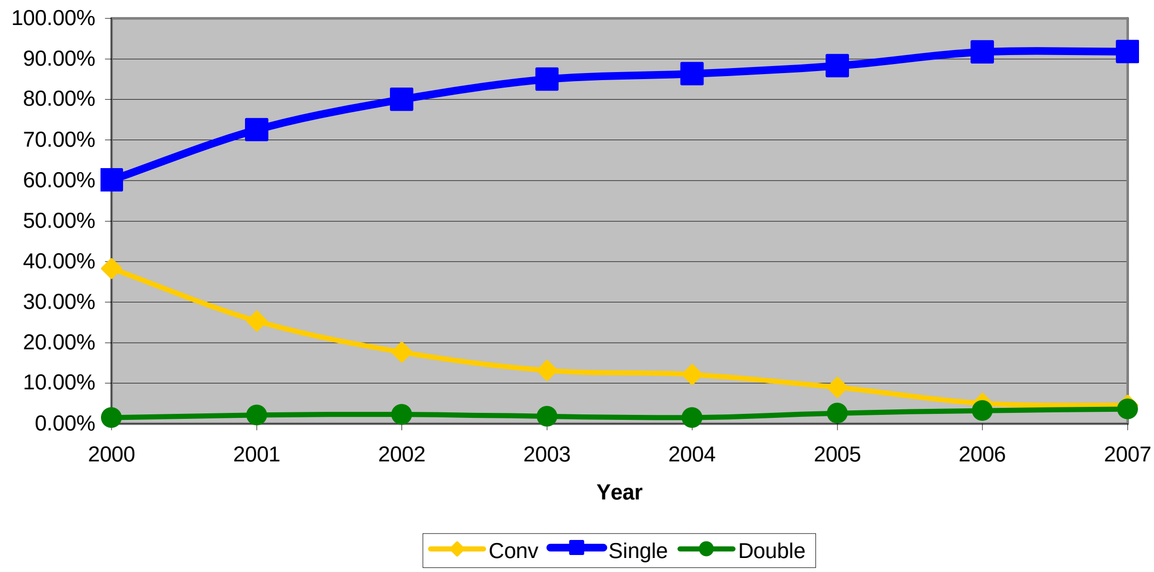


Table 1 shows the number of seed companies distributing different type of seeds from 2000 to 2007. The total number of companies active in the soybean seed market declined from 211 in 2000 to 172 in 2007. The decrease comes mostly from the conventional seed market and *HT*2 seed market, while the number of companies selling *HT*1 seed remains stable over the years, and more companies now carry double stacking seeds.

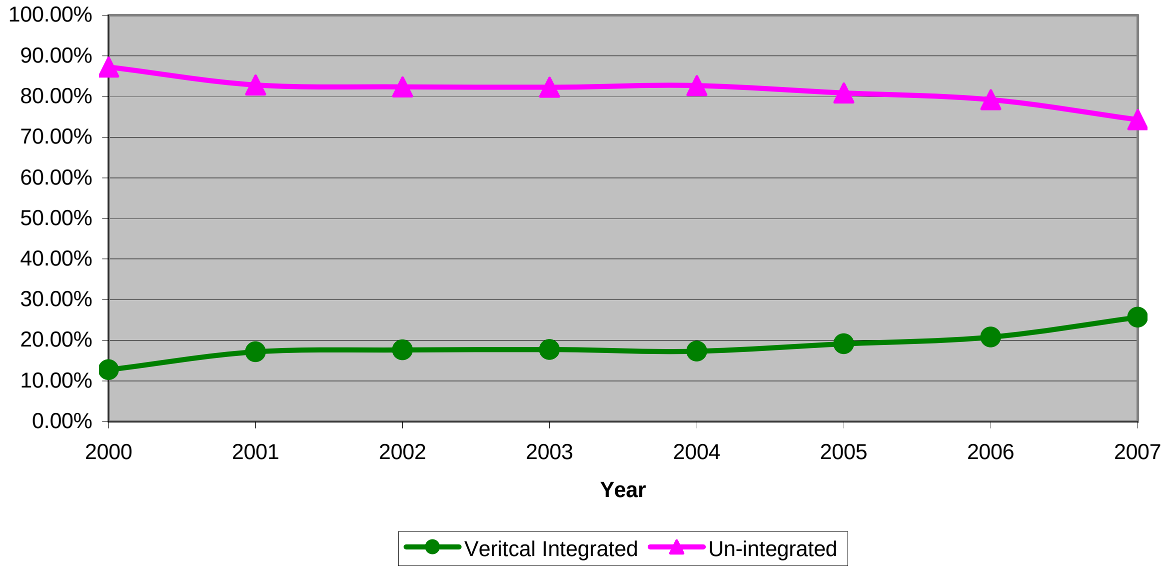
Table 1. Number of seed companies operating in different markets, 2000-2007

Year	Total	Conventional	*HT*1	*HT*2	Double stacking *HT*1&*HT*2	Total acreage (million acres)
2000	211	172	176	66	4	63.5
2001	196	137	178	51	8	64.4
2002	198	131	178	40	12	62.3
2003	182	102	163	28	13	62.7
2004	187	99	179	25	13	62.9
2005	180	89	169	27	24	60.7
2006	178	57	173	24	27	62.7
2007	172	54	167	15	30	53.2

While the biotech companies who own each trait also have subsidiary seed companies, both affiliated and non-affiliated seed companies typically distribute the biotech seeds. 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 case where the seed companies are affiliated. We consider the case of two vertical structures where $\mathbf{V} = \{v, \ell\}$, v corresponding to *vertical integration* (where the company selling seeds to farmers is owned by a 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).

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 a significant number of farmers have the option of choosing which vertical structure they buy from.

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



3. 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. We focus our attention on the case of two vertical structures: *vertical integration* v and *licensing* ℓ. And we consider seeds exhibiting K different genetic characteristics, represented by 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, $k \in \mathbf{K} = \{1, \ldots, K\}$, with $\sum_{k=1}^{K} T_k = 1$. And 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 v, R&D fixed cost can be recovered directly by the integrated firm but the biotech firm may possibly face higher cost of integration. Under licensing

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

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

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

where $\mathbf{X}$ is a vector of other relevant covariates, and $\varepsilon_{K\tau}$ 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. As discussed in section 2, when $k = m$ and $u = \tau$, $H_{mk,u\tau}$ reduces to the Herfindahl index commonly used in the economic evaluation of market concentration. And when $k \neq m$ and $u \neq \tau$, $H_{mk,u\tau}$ provides a measure of cross-market concentration across product types m and k and across vertical structures u and τ. Also, since $H_{mk,u\tau} = 0$ under competitive conditions, it follows from (5b) that that the exercise of market power in (5a)-(5b) is given by

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

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

Our analysis is based on four seed types ($K = 4$): conventional ($T_1 = 1$), single trait $HT1$ ($T_2 = 1$), single trait $HT2$ ($T_3 = 1$), and bundling/stacking of $HT1$ and $HT2$ ($T_4 = 1$). And we distinguish between two vertical structures ($V = 2$): vertically integrated (v) and licensed (ℓ). Moreover, since the conventional seed does not need to add any additional biotech trait, we assume 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

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

And for $HT1$ seed ($T_2 = 1$), the price equations for licensed and integrated seeds are, respectively,

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

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

Similar equations can be written $HT2$ 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 VHHI's. 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 H terms are calculated at that level. Each purchase observation is at the farm-variety level. The price p in equation (5a) is 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 effects related to farm size.

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 stays 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 of conventional type. 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).

4. Econometric estimation

Table 2 reports summary statistics of key variables used in the analysis. As discussed above, the *H*'s are evaluated at the CRD level. The mean value of conventional seed HHI, $H_{11,\ell\ell}$, is 0.412, more than twice of the Department of Justice's threshold of 0.18 for identifying "significant market power". Biotech seeds in licensing market exhibit greater competition, with a mean value of $H_{22,\ell\ell}$ at 0.201. We observe significant changes in the *H*'s 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.

One econometric issue in the specification (5a)-(5b) is the endogeneity of the *H*'s. Both market concentrations (as measured by the *H*'s), quantity sold (*Y*'s) and seed pricing are expected to be jointly determined as they both depend on firm strategies in the seed market. To the extent that parts of the determinants of these strategies are unobserved by the econometrician, this would imply that the interaction terms $H \cdot Y$'s 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 (due to endogeneity bias). 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 the *H* and *Y*'s, the *C* statistic is distributed as Chi-square with degrees of freedom equal to the number of variables tested. The test is robust to violations of the conditional homoscedasticity assumption (Hayashi 2000, p. 232).[13] In our case, the *C* statistic is 19.83, showing strong statistical evidence against the null hypothesis of exogeneity.

Table 2. 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: $H_{22,\ell v} = H_{22,v\ell} = 0$. Moreover, $H_{12,\ell\ell} = H_{21,\ell\ell}$ and $H_{12,\ell v} = H_{21,v\ell}$.

The presence of endogeneity motivates the use of an IV estimator. We used the lagged value of each *H* interacting with the lagged *Y* as instruments and conducted a series of tests supporting this choice. 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 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 appear to be good candidates for instruments. On that basis, equation (5a)-(5c) was

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

estimated by two-stage-least-square (2SLS), using one-period lag of the $H{\cdot}Y$'s for instruments. Further evaluation of these instruments is presented below.

A second pretest was to evaluate the model for the effects on prices from unobserved heterogeneity across farms (e.g., unobserved pest populations). A Pagan-Hall test[14] found strong evidence against homoscedasticity of the error term in (5a). On average each farm purchases three different seed varieties. Some large farms actually 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).

Additional tests of the validity of the instruments were conducted.[15] In the presence of heteroscedastic errors, we used the Bound et al. (1995) measures and the Shea (1997) partial R^2 statistic to examine the possible presence of weak instruments. The F-statistics testing for weak instruments were large (i.e., much above 10). Following Staiger and Stock (1997), this means that there is no statistical evidence that our instruments are weak. Finally, The Kleibergen-Paap weak instrument test was conducted (Kleibergen and Paap, 2006),[16] 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.

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[14] 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).

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

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

5. Results

Table 3 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 3, 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 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 verticalintegration are priced higher than those produced and marketed under licensing. Wald tests suggest that such differences between vertical structures are statistically significant for the single-trait biotech seed, but not for the stacked biotech seeds. We investigated empirically the validity of component pricing (where the value of a bundle is just the sum of the value of its components). This is done by comparing the price premium of the stacked seed with the sum of the premiums of the corresponding single trait. Using a Wald test, we find that, under licensing, the premium of the stacked traits is not statistically different from the sum of the premiums of the corresponding biotech traits in the single-trait seeds. In other words, the econometric evidence indicates that standard component pricing holds for licensed seeds.

In the vertically integrated structure, the premium of the stacked seed is higher than that of each the single-trait seed. But it is lower than the sum of the corresponding individual premiums. And the difference is found to be statistically significant at the 5 percent level. This provides evidence that component pricing does not apply under vertical integration. This negative and significant stacking effect indicates sub-additive pricing of soybean seed in their individual components in the vertically integrated structure. Sub-additive pricing in bundling could be driven by price discrimination associated with demand heterogeneity for the components (higher prices being associated with more inelastic demands). However the fact that it occurs only in the vertically integrated structure (and not under licensing) indicates that the subadditivity of pricing is likely driven by supply-side factors. This may 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.

Market concentration effects and vertical structures

The model incorporates market share information about each seed type in different vertical structures using the vertical Herfindahl indexes $H_{mk,u\tau}$ as given in equations (5a)-(5b). 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 type-m seed in u-th market structure and 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).

Of the three VHHI's 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 $Pub = 1$ and the VHHIs. Again, table 3 shows strong statistical evidence that public sector follows different pricing rules (compared to the private sector). For the private sector, the effect of 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 VHHI between licensed type-2 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 type-1 and type-2 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 type-2 seed and the conventional seed ($H_{21,v\ell}$) for the private and public sectors are not statistically significant.

Of the four VHHI's that may affect the type-2 biotech seed, only the VHHI between licensed type-2 seed and the conventional seed ($H_{12,\ell\ell}$) is statistically significant. The coefficient of $H_{12,\ell\ell}$ affecting the type-2 seed is again negative, consistent with its effects in the conventional seed market. This suggests strong and symmetric complementarity between type-1 and type-2 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 type-2 seeds. Note that the coefficient of the VHHI between integrated type-2 seed and the conventional seed ($H_{12,\ell v}$) is also negative. But it is 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 conventional Herfindahl indexes measuring market concentration in the type-2 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 impact on seed price 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 type 1 and type 2 cross-market concentration effects on the conventional seed are different with different vertical structures in type 2 seed market (hypothesis I). Moreover, the own- and cross-market concentration effects are statistically different on type 2 seed with different vertical structures in type 2 seed market (hypotheses II and III). As discussed in section 2, this provides statistical evidence that vertical organization matters since it affects how the exercise of market power affects pricing.[17]

Other Covariates

Location effects**:** From table 3, soybean seeds are sold at a discount price in the Corn Belt compared to the non-corn belt states. Compared to Illinois, seeds are sold at a premium in Arkansas (\$2.51), Louisiana (\$2.66), Mississippi (\$2.68), and Tennessee (\$1.47). Seeds sold in all the other states in our sample (mostly in the corn belt) are at similar price to Illinois, with a price difference ranging from –\$0.35 to \$0.70. This shows that the main soybean producing states in the Corn Belt charge less for seeds. Seed companies seem to do price discriminate across regions, possibly reflecting spatial differences in elasticities of demand for seeds.

Purchase source effects: Most farmers purchase seed from "Farmer who is a dealer or agent" (27.6%), followed by "Direct from seed company or their representatives" (23.7%), "Myself, I am a dealer for that company" (13.1%), and "Co-Ops" (10.1%). Compared to purchasing from "Farmer who is a dealer or agent", table 3 shows that "buying directly from a seed company or their representative" costs about \$0.24 less, purchasing from "Co-Ops" costs about \$0.34 more, while purchasing from "myself" costs about the same. These results may reflect the effect of farmer's bargaining position, but also possibly the presence of price discrimination across different modes of purchase.

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[17] Since the demand for seed is a derived demand from farmers' profit maximization, the seed price 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.

Other variables: 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.

In table 3, the farm size effect is statistically significant: large farms within each state pay less for soybean seeds. Large farms seem to enjoy a price discount over smaller farms. The farm size variable appears to capture another form of price discrimination used by seed companies in negotiating prices to individual clients. The year dummy effects show a strong rising trend in and after 2004. Compared to the year 2001, the soybean seed price rises by $0.20 per bag in 2002, then drops by $0.66 per bag in 2003, and then jumps up by $2.45 per bag in 2004 and keeps on rising since then. In 2007, soybean seed price is $6.22 per bag higher than in 2001. Given that the mean price is about $22.82, this gives a growth rate higher than the inflation rate over the same time period.[18]

Table 3. IV (2SLS) regression with robust standard errors,[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		
$H_{11,\ell\ell}T_1D_\ell Y_{1\ell}$ (conventional seed)	0.145**	2.08

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

$H_{11,\ell\ell}T_1D_\ell Y_{1\ell}$*_pub* (public-sourced conventional seed)	-0.160*	-1.70
$H_{21,\ell\ell}T_1D_\ell Y_{2\ell}$ (conventional seed)	-0.227***	-3.12
$H_{21,\ell\ell}T_1D_\ell Y_{2\ell}$*_pub* (public-sourced conventional seed)	0.270**	2.40
$H_{21,v\ell}T_1D_\ell Y_{2v}$ (conventional seed)	0.050	0.56
$H_{21,v\ell}T_1D_\ell Y_{2v}$*_pub* (public-sourced conventional seed)	-0.056	-0.37
$H_{12,\ell\ell}T_2D_\ell Y_{1\ell}$ (*HT1* in licensing structure)	-0.265***	-3.04
$H_{22,\ell\ell}T_2D_\ell Y_{2\ell}$ (*HT1* in licensing structure)	0.040	1.53
$H_{12,\ell v}T_2D_v Y_{1\ell}$ (*HT1* in vertically integrated structure)	-0.077	-0.83
$H_{22,vv}T_2D_v Y_{2v}$ (*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.

6. Implications

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

Two sets of results are presented. First, we evaluate the characteristics effects within and across different vertical structures by estimating how stacking influences seed prices in the licensed case and the vertically integrated case. Second, in an evaluation of the 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 where component pricing may not apply (e.g., when demands are heterogeneous). As discussed above, our econometric results strongly reject component pricing (i.e., seeds being priced as the sum of their component values) in the vertically integrated market but not in the licensed market. This raises the question: how do prices vary across bundles within and across different vertical structures? To address this question, we evaluate the effects of bundling/stacking on seed prices using mean values of relevant variables for Illinois in 2004 (including farm size and VHHIs).[19]

Table 4 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. And 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 document significant departures from component pricing in the integrated market but not the licensed market. As discussed above, this provides evidence of sub-additive pricing under vertical integration. For vertical structure comparison, for both type-2 and type-3 biotech seeds, those marketed under licensing are priced statistically significantly lower than those in the vertically integrated

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

channel, at \$0.46 per bag and \$1.77 per bag, respectively. Such differences across vertical structures disappear in the stacked seed market. This indicates tthat sub-additive pricing of stacked seed occurs only under vertical integration.

Table 4. 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	0.00	16.32	0.00	N/A
T_2 (*HT*1 biotech)	23.71	7.39*** (0.13)	24.18	7.85*** (0.16)	-0.46*** (0.13)
T_3 (*HT*2 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.

As discussed earlier, vertical integration involves transaction costs. Licensing also involves transaction costs (mainly negotiation), but most of the technologies in the soybean seed market were introduced in early 1990s and the licensing contracts were well developed during our study period. This suggests the transaction costs under licensing may be less than that under vertical integration. This would help to explain why single trait seeds marketed under licensing are priced lower than in the integrated channel.

As for stacking, the likely presence of economy scope in the integrated channel (but not in the licensed channel) can help explain the observed discount in the integrated case. The research and production of the stacked seed involves two biotech traits and the basic seed germplasm. The integrated firm has already had experience in the R&D of identifying and incorporating the biotech traits. Such prior knowledge facilitates the insertion of additional trait to produce the stacked seed. This suggests that vertically integrated seed companies benefit from economies of scopes in bundling and share with farmers some of the associated efficiency gains.

Estimated Market Power Effects

As discussed in sections 2 and 4, the market power effects can be measured by the term *M* in equations (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 5 reports the estimated market power component *M* for selected seed types for Illinois in 2004. Table 5 also presents the corresponding relative measures $\frac{M}{p}$.[20] The market power measures *M* are statistically significant in the conventional seed market and in the licensed type 2 seed market. The market power measure for the conventional seed is \$0.54 per bag and 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 type-2 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 10% level) of changing market concentration in T_1&T_2 on the price of licensed type-2

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[20] 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.

seeds. This provides empirical evidence that market power 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 direction in the licensed type-2 seed market. These results are due in part to our estimated complementarity effects that tend to 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 5. 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 mean price and the predicted price when the *VHHI*'s are set equal to zero.

7. 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 application to the pricing of US soybean seeds. The econometric analysis involves the estimation of a structural model where our VHHI's capture the effects of imperfect competition across both horizontal and vertical markets. 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. While our empirical application to the US soybean seed industry provides useful insights into the effects of complementarity and imperfect competition in concentrated markets, additional research is needed to investigate these issues in 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.

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): 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): 37-859.

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