Biotechnology, Intellectual Property and Value Differentiation in Agriculture

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Over the past decade, the structure of the plant breeding and agricultural biotechnology industries has been radically transformed. Through dozens of mergers, acquisitions and strategic alliances, there has been a rapid and dramatic concentration of control over value-generating assets, particularly intellectual property. This restructuring follows a significant strengthening of the intellectual property rights of plant breeders due to the Supreme Court ruling Diamond v. Chakrabarty (447 U.S. 303 (1980)), and advances in biological sciences. Over the same time period, there has been a broader pro-patent movement in American industry (Hall and Ziedonis, Kortum and Lerner).

We explore the relationships among scientific innovation, intellectual property rights, and industrial restructuring in plant agriculture. Our goal is to shed light on the history of consolidation in agricultural biotechnology. Figure 1 presents the frequency of corporate mergers and acquisitions in agricultural biotechnology from January, 1984, through April, 2000.[1] The purposes served by consolidation could also be served by vertical integration and/or contracting. Why, then, has the frequency of organizational consolidations been so high in recent years in agricultural biotechnology?

One concern is that this trend may reflect a relentless quest for market power. Other, less sinister motivations for consolidation include the mitigation of contractual hazards and the exploitation of asset complementarities. Our specific concern regards the role, if any, that intellectual property has played in the restructuring of the U.S. agricultural biotechnology industry.

One obvious question that arises is whether the evolution of patent ownership mirrors the changing structure of the industry. As shown in Figure 2, the concentration of agricultural patent holding fell from the mid-1980s through the mid-1990s. There is a trough in the mid-1990s, and since that time the concentration of patent holdings has risen, consistent with the merger and acquisition frequencies in Figure 1. Patent data provides an accurate picture of the consolidation of intellectual property rights, since patent data is publicly available for both public and private firms.

We develop a theoretical explanation of the reorganization of firms and the consolidation of intellectual property rights that is based on the transition of agriculture from a commodity system toward a differentiated product system and the development of improved intellectual property rights in agriculture. We demonstrate that the combination of these two factors can explain the consolidation in firm ownership and intellectual property observed in Figures 1 and 2. However, neither factor alone is sufficient to influence the incentives to integrate, nor the choice of integration method.

Analytical Framework

The goal of our analysis is to determine whether the nature of the product system and the intellectual property regime influence the incentives for vertical integration or the choice of integration form. We consider a two stage production chain: the first stage is trait development, which provides an input for the second stage, seed production. We assume that there are two seed producers, and at least two trait developers. Seed producers may sell either a basic seed, which has a perfectly elastic demand function, or an augmented seed containing a trait developed by the trait developer, which has a downward-sloping demand function.

We model two product systems: a commodity system, where the demand for the augmented seed is invariant to the actions of the seed producer, and a differentiated product system, where the demand for the augmented seed is influenced by the actions of the seed producer. We model two intellectual property regimes: one in which intellectual property rights are clearly articulated, the *IP*-regime, and one in which they are not, the *NIP*-regime.[2] In order to evaluate the effects of these factors on the incentives to vertically integrate, we compare returns under non-exclusive licensing and under exclusive licensing. In order to evaluate the effects of these factors on the choice of the method of vertical integration, we compare returns under exclusive licensing and under consolidation through a merger or acquisition.

In each product system, markets are open for two periods. In the first period, a single agent develops an R&D product called a *trait*, incurring a fixed cost and zero marginal cost. The developer holds a monopoly over his trait for that period, and can choose whether to license non-exclusively, license exclusively, or consolidate with a seed producer. What happens in the second period depends on the intellectual property rights regime. Under the *IP*-regime, the trait developer attains a patent and retains his monopolistic status in the second period. Under the *NIP*-regime, other suppliers will imitate the trait developer's product in the second period, and price competition will drive the equilibrium price of licenses, and hence equilibrium profits for the innovating trait developer, to zero.

Commodity System: IP-*regime versus* NIP-*regime*

In this section, we develop the formal model specification and evaluate the implications of the intellectual property regime under a commodity system.

Period 1 Equilibrium, Non-Exclusive Licensing. Two agents produce *seed* according to the inverse supply function $s_1 q$, where $s_1 > 0$.[3] This product is sold directly to a large number of competitive growers, either as *augmented seed*, which has the trait inserted, or as *basic seed*, which does not. Demand for basic seed is perfectly elastic at a price of $\bar{p}^{\mathcal{B}} > 0$. Each producer who supplies this market earns a profit of $\bar{\pi}^{\mathcal{B}}_{\mathsf{sd}} = (\bar{p}^{\mathcal{B}})^2/(2s_1)$ per period.

In order to sell augmented seed, suppliers must obtain a license from the trait developer. Non-exclusive licenses are available on the same terms to all seed suppliers. As is the current practice in the industry, we assume that the per-unit license fee, ℓ, is passed on directly to growers. That is, the inverse supply function for augmented seed is $\ell + s_1 q$. The demand for augmented seed is given by $\tilde{d}_0 - d_1 p^{\mathcal{A}}$, where $d_1, \tilde{d}_0 > 0$.

If both seed producers participate in the market for augmented seed, they will compete-by-price and the equilibrium in this market will coincide with the competitive equilibrium.[4] The competitive equilibrium price of the augmented product, given that non-exclusive licenses are priced at ℓ, is $p^{\mathcal{A}}(\ell) = \frac{\tilde{d}_0 s_1 + 2\ell}{2+d_1 s_1}$. Each seed producer earns profits of $\bar{\pi}^{\mathcal{A}}_{\mathsf{sd}}(\ell) = \frac{s_1}{2}\left(\frac{\tilde{d}_0 - d_1\ell}{2+d_1 s_1}\right)^2$.

We restrict attention to the case where $\tilde{d}_0$ is sufficiently large that if the price of licenses is sufficiently low, it is more profitable to sell augmented seed than basic seed. (The necessary and sufficient condition for this case to apply is derived in Lemma 1 in the appendix). Define $\ell^* > 0$ by the condition that $\bar{\pi}^{\mathcal{A}}_{\mathsf{sd}}(\ell^*) = \bar{\pi}^{\mathcal{B}}_{\mathsf{sd}}$. At a license price of ℓ^*, the seed producer is indifferent between selling basic seed and selling augmented seed. Substituting and rearranging, $\ell^* = \frac{\tilde{d}_0}{d_1} - \bar{p}^{\mathcal{B}}\left(1 + \frac{2}{d_1 s_1}\right)$. It will be more profitable to produce for the augmented market than the basic market if and only if $\ell < \ell^*$.[5] Thus, the derived demand schedule for the trait, $x^d(\ell)$, is zero if $\ell > \ell^*$. Otherwise, $x^d(\ell) = q^{\mathcal{A}}(\ell) = \frac{\tilde{d}_0 - d_1\ell}{2+d_1 s_1}$ for each seed producer, so that the market demand for the trait is $2x^d(\ell)$. The sole trait developer is a monopolistic supplier of licenses, and sets the license price at $\bar{\ell}^{\mathcal{A}} = \min\left[\frac{\tilde{d}_0}{2d_1}, \ell^*\right]$.[6] We focus on the case where the seed suppliers' outside option is binding, defined in Lemma 2 in the appendix. In this case, each seed provider earns profits of $\bar{\pi}^{\mathcal{A}}_{\mathsf{sd}}(\ell^*) = \frac{(\bar{p}^{\mathcal{B}})^2}{2s_1}$. The trait developer's profit from selling non-exclusive licenses is $\bar{\pi}^{\mathcal{A}}_{\mathsf{tr}} = 2\bar{\ell}^{\mathcal{A}} q^{\mathcal{A}}(\bar{\ell}^{\mathcal{A}}) - \tilde{F} = \frac{2\bar{p}^{\mathcal{B}}}{d_1(s_1)^2}\left(\tilde{d}_0 s_1 - \bar{p}^{\mathcal{B}}(2 + s_1 d_1)\right) - \tilde{F}$

Period One Equilibrim, Exclusive Licensing. We consider the conditions under which the trait developer will choose to exclusively license his innovation in period one to a single seed producer.[7] We assume that under an exclusive agreement, the monopoly outcome holds. The two parties determine the price and output levels that maximize their joint profits, $\tilde{\pi}^{\mathcal{M}}_{\Sigma}$. In a commodity system, the joint monopoly price for the augmented product is $\tilde{p}^{\mathcal{M}} = \frac{\tilde{d}_0(1+d_1 s_1)}{d_1(2+d_1 s_1)}$. Joint monopoly output is $\tilde{q}^{\mathcal{M}} = \frac{\tilde{d}_0}{2+d_1 s_1}$ and joint monopoly profits are $\tilde{\pi}^{\mathcal{M}}_{\Sigma} = \frac{\tilde{d}_0^2}{2d_1(2+d_1 s_1)} - \tilde{F}$. An agreement will be negotiated if and only if there is a division of profits, $(\lambda_{\mathsf{tr}}\tilde{\pi}^{\mathcal{M}}_{\Sigma}, \lambda_{\mathsf{sd}}\tilde{\pi}^{\mathcal{M}}_{\Sigma})$—where λ_{tr} is the trait developer's share and λ_{sd} is the seed producer's share—such that each party's share exceeds his *reservation share* level. In the present perfect information context, this condition will be satisfied if and only if $\bar{\pi}^{\mathcal{A}}_{\mathsf{sd}} + \bar{\pi}^{\mathcal{A}}_{\mathsf{tr}} \leq \bar{\pi}^{\mathcal{M}}_{\Sigma}$.

The trait developer's reservation share is determined by his profit $\bar{\pi}^{\mathcal{A}}_{\mathsf{tr}}$ from licensing nonexclusively to both seed providers. The seed provider's reservation level is the profit $\bar{\pi}^{\mathcal{B}}_{\mathsf{sd}}$ from supplying the basic (non-augmented) product or, equivalently since $\bar{\pi}^{\mathcal{B}}_{\mathsf{sd}} = \bar{\pi}^{\mathcal{A}}_{\mathsf{sd}}$, his profit in the augmented market under a nonexclusive licensing agreement, when the license fee is set at $\bar{\ell}^{\mathcal{A}}$, defined above (page 4). The necessary and sufficient condition for integration to occur is $1 + \frac{d_1 s_1}{2} \left\{ \frac{\bar{d}_0 s_1}{\bar{p}^{\mathcal{A}}(8+3d_1 s_1) - 4\bar{d}_0 s_1} \right\} > \frac{\bar{p}^{\mathcal{A}}(2+d_1 s_1)}{\bar{d}_0 s_1}$, derived in Lemma 3 in the appendix.

Integration is more profitable as the intercept of the demand curve increases and as the slope of the *inverse* supply curve increases. The effect of an increase in the slope of the demand curve is indeterminate. Intuitively, the incentives to integrate depend on the different components of profits under integration and non-exclusive licensing. These components are illustrated in Figures 3 and 4. In the integrated case, depicted in Figure 3, the integrated firm acts as a monopoly supplier with regard to market demand for the augmented seed. It equates marginal revenue to marginal cost, and price and quantity are determined accordingly. In the non-exclusive case, the two seed suppliers act competitively, and equate price with marginal cost. Each supplier produces half of the total quantity demanded. In this case, the profit of a single supplier is the area above his supply curve and below the price line for the quantity he produces, as depicted in Figure 4.

Holding other parameters constant, a steeper inverse supply curve reduces the quantity produced and seed supplier profits in the non-integrated case. The profit of the trait developer is equal to the license fee, ℓ, multiplied by the total quantity produced. As s_1, the slope of the inverse supply curve, increases, the optimal license fee increases. However, the total quantity produced decreases, and it is the latter effect that determines the net effect on trait developer profits.

In the integrated monopoly case, in contrast, the endogeneity of the output price partially offsets the negative effect on an increase in the slope of the inverse supply curve. A larger demand intercept increases the profits obtained in the integrated monopoly case, holding other parameters constant. The endogeneity of the output price enhances this effect, relative to the effect in the non-exclusive license case.

Period Two Equilibrium. The returns to non-exclusive licensing and the returns to vertical integation through exclusive licensing in period two are affected by the intellectual propery regime. In the *IP*-regime, the analysis of non-exclusive licensing in the second period will be exactly the same as in the analysis of the first period in the preceding subsection. In particular, the supplier will earn profits of $\bar{\pi}_{tr}^{A}$ in each period, if he sells licenses on a non-exclusive basis. In the *NIP*-regime, other suppliers will imitate the trait developer's product in the second period, and price competition will drive the equilibrium price of licenses (and equilibrium profits for the trait developer) to zero. since trait development is assumed to have only an initial fixed cost and zero variable costs. Second period imitators do not incur the initial fixed costs.

As an alternative to marketing its product nonexclusively, the trait developer can negotiate an exclusive arrangement with one of the seed providers. Regardless of the intellectual property regime, in the first period augmented seed will be monopolistically supplied in the final market. In the *NIP*-regime, other suppliers will imitate the trait developer's product in the second period, so that an exclusive license can not be maintained. As in the case of non-exclusive licensing, the price of licenses, and trait developer profits, will be driven to zero. In the *IP*-regime, augmented seed will be monopolistically supplied in the final market under an exclusive license in both periods.

Proposition 1. *In a commodity system, the incentive to integrate is not a function of the intellectual property regime.*

Proof. In the *NIP*-regime, an exclusive licensing agreement can be sustained only in the first period; in the second period, competition between trait developers will dissipate monopoly rents. In the *IP*-regime, the exclusive arrangement can be maintained for both periods. However, the second period replicates the first. The trait developer will weakly prefer an exclusive arrangement in the first period if and only if it prefers it in both periods. □

Since the incentive to integrate is not a function of the intellectual property regime, we can address whether the form of vertical integration matters in a commodity system independently of the intellectual property regime.

Proposition 2. *In a commodity system, integration via consolidation and integration via exclusive licensing yield identical outcomes.*

Proof. By construction, if the trait developer merges with one of the seed producers, the two parties can exactly duplicate the outcome and sharing arrangement obtained under the exclusive licensing arrangement. Similarly, the division of returns from joint profit maximization under a merger can be duplicated under an exclusive licensing agreement. □

Differentiated Product System

We now consider a system in which augmented seed is viewed as a differentiated product, rather than a commodity. We use these terms in a highly specific way. For our purposes, the sole distinction is that in the latter, the demand for, and the technology for providing, the product is exogenously fixed, while in the former, both demand and technology are to some extent dependent on the actions taken by producers. For a commodity, such as Number 2 Red Winter Wheat (Debreu's example of a commodity in the *Theory of Value*) a well-defined demand schedule is already in place. There is no need to develop a marketing plan for Number 2 Red Winter Wheat, since demand does not respond to efforts by individual market participants to change it.

For a differentiated product, however, significant resources must be devoted to "developing a market for" or "capturing the value of" the product. It is not enough simply to supply the product; one must also create a demand for it. By the same token, for a commodity, the fixed operating costs that a producer faces are truly fixed, while for a differentiated product, the magnitude of these fixed costs can be modified by management effort. In particular, in the production of augmented seed, there are production complementaries that may or may not be exploited, depending on the nature of the relationship between the trait developer and the seed provider and the expertise of the managers that oversee the relationship.

To formalize these ideas, we replace the commodity system's exogenously specified demand intercept $\tilde{d}_0$ and fixed cost parameter $\tilde{F}$ with the variable intercept $\hat{d}_0(\theta; t)$ and variable fixed cost $\hat{F}(\theta; t)$, where $\theta \in [0, 1]$ is a random variable measuring *management quality* and $t \in \{1, 2\}$ indicates the period. The two parameters vary with θ only in period two. That is, for all θ, $\hat{d}_0(\theta; 1) = \tilde{d}_0$ and $\hat{F}(\theta; 1) = \tilde{F}$. On the other hand, we assume that $\hat{d}_0'(\cdot, 2) > 0$ and $\hat{F}'(\cdot, 2) < 0$. That is, higher quality management of the integrated operation can do a better job of "creating a market" for augmented seed, and can better exploit synergies and complementarities in its production. These benefits, however, take time to materialize, and are realized only in period two.

The costs and benefits of creating value through shifting the demand intercept will vary depending on market structure. In particular, management's incentives to create value will be sharply diminished under a non-exclusive licensing agreement, since in this case the benefits of each seed producer's efforts will partially accrue to the other seed producer. Opportunities to exploit production synergies will similarly be diminished unless integration occurs, because the degree of cooperation required to develop these synergies would be difficult to maintain without exclusive arrangements. We model these effects of integration in a simple binary fashion. We assume that in the absence of integration, the demand intercept and fixed cost parameter remain constant at $\tilde{d}_0$ and $\tilde{F}$. The modifications described above apply only if integration occurs. either through consolidation or exclusive licensing. Obviously, like any other input, management effort is costly. For simplicity. we ignore these costs.

Party i's beliefs about θ when party j controls the management are given by the probability distribution $g_{ij}(\theta)$. We initially assume homogeneous beliefs. Under *homogeneous beliefs*, $g_{ij}(\cdot) = g_{jj}(\cdot)$, i.e.. both parties agree on the (random) quality of party j's management ability. We will assume that in this case, the common belief is that management can improve matters on average, so that $E^2_{ii}\hat{d}_0 = \int_{[0,1]} \hat{d}_0(\theta;2)g_{ii}(\theta)d\theta > \tilde{d}_0$ and $E^2_{ii}\hat{F} = \int_{[0,1]} \hat{F}(\theta;2)g_{ii}(\theta)d\theta < \tilde{F}$. We assume that all parties are risk-neutral expected profit maximizers.

Integration Incentives under the NIP*-regime.* If the trait developer cannot obtain a patent for its product, then the distinction between the commodity system and the differentiated product system evaporates. In the absence of intellectual property protection in period two, intellectual property considerations do not affect the incentives to integrate. Further, in the absence of intellectual property protection, integration through consolidation and integration through an exclusive license yield identical outcomes. These findings suggest that the transition of agriculture from a commodity to a differentiated product system alone can not explain the reorganization of the agricultural biotechnology sector.

Proposition 3. *In the* NIP*-regime, the differentiated product system yields exactly the same conclusions as the commodity system. In particular, the incentive to integrate is not a function of the intellectual property system. Moreover, integration via consolidation and integration via exclusive licensing yield identical outcomes.*

Proof. In the second period competitition between the original producer of the trait and its imitators will drive license fees to zero. since there are no variable costs associated with producing a developed trait. Neither an exclusive licensing agreement nor consolidation will extend market power into the second period, since each seed provider can integrate with a different trait developer. Hence whether or not integration occurs will depend only on first period market considerations. □

Integration Incentives under the IP*-regime.* When management quality affects market performance in the second period, intellectual property *may* affect the decision to integrate or not integrate. However. as in the commodity case, the effect of integration is the same, whether it occurs through consolidation or contracting. This finding demonstrates that intellectual property protection in conjunction with the transition of agriculture from a commodity system to a differentiated product system may explain the reorganization of the agricultural input sector. These two forces, however. can not explain why this reorganization has occurred through mergers and other forms of consolidation, rather than through exclusive licensing.

Proposition 4. *In a differentiated product system, there are parameter values for which integration is feasible in the* IP*-regime but not in the* NIP*-regime. The effect of integration through consolidation or through contracting is the same.*

Proof. By assumption, management efforts both increase demand and lower fixed costs on average. Hence, expected second period profits will exceed first period profits. provided that integration occurs. (If integration does not occur, then expected second period profits will equal first period profits.) Thus, there is a range of parameter values for which the necessary conditions for integration will not be satisfied based on first-period considerations alone, but when the additional second-period benefits of integration are taken into account, an exclusive arrangement will prove feasible. These improved second period profits can be secured only if intellectual property rights extend the trait developer's status as the unique supplier into the second period. Hence we have established that in the differentiated commodity system, intellectual property rights may drive integration.

The equivalence of integration through consolidation and integration through exclusive licensing may be seen in the equivalence of expected monopoly profits. Specifically, in either case, expected monopoly profits are $E\hat{\pi}_{\Sigma}^{\mathcal{M}} = \frac{\tilde{d}_0^2 + E_{ii}^2 \hat{d}_0^2}{2d_1(2+d_1 s_1)} - \left(\tilde{F} + E_{ii}^2 \hat{F}\right)$. □

The proof clearly relies upon our binary definition of the roles of management with and without integration. However, the same result would apply if management incentives to create value and exploit synergies were merely diminished, rather than extinguished, in the absence of integration, although for a narrower range of parameters.

Intellectual Property Regime and Vertical Integration Incentives: Summary

Within a commodity system, the intellectual property regime does not affect the incentives to vertically integrate or the choice of integration form. Within a differentiated product system, the incentives to integrate *are* affected by the intellectual property regime. In the absence of intellectual property protection, the differentiated product system generates the same incentives to integrate as the commodity system does. Under intellectual property protection, the incentive to vertically integrate is increased relative to the case of no intellectual property rights, and relative to the commodity system case. Thus, the combination of increased intellectual property protection and increased product differentiation can explain the tendency toward increased integration in the agricultural seed market. However, as Proposition 4 states, these two factors can not explain the tendency of this integration to occur through consolidation, rather than exclusive licensing. In the following subsection, we introduce an explanation for this tendency.

Heterogeneous Beliefs: Consolidation versus Exclusive Licensing

A differentiated product system imposes a multitude of demands on management that simply do not arise in a commodity system. In particular, to compete in a differentiated product system, firms' managers must acquire. interpret and respond strategically to massive amounts of information regarding their customers. products and suppliers. All this takes time and effort. and intellectual property protection is required in order to justify the investment in both. Different management teams may tend to have widely divergent views about their abilities, to meet these challenges, relative to their perception of the abilities of their competitors. This suggests that our assumption of homogeneous beliefs may be overly restrictive.

Party i (either the trait developer or the seed producer) may be unwilling to cede control over his component of the joint product (i.e., augmented seed) to party j through a licensing agreement, because he lacks faith that j will be able to "capture the value" inherent in the joint relationship. If party j is to manage the production and marketing process, party i's subjective expectation of its royalty revenues may be sufficiently pessimistic that no licensing agreement will be feasible. If i is absorbed by j through a merger. on the other hand, then i's expectations about j's management skills will no longer matter. Party i's compensation will be based on j's confidence about j's own abilities: i may not believe that the performance of the consolidated company will live up to j's expectations, but i will no longer care about performance, since he will have been compensated already.

We formalize heterogeneous beliefs in the following fashion: Recall that party i's beliefs about θ when party j controls the management are given by the probability distribution $g_{ij}(\theta)$. Under *heterogeneous beliefs*, we presume that each party has greater confidence in its own management team than in the other party's, so that for each i. $E^2_{ii}\hat{d}_0 > E^2_{ij}\hat{d}_0$ while $E^2_{ii}\hat{F} < E^2_{ij}\hat{F}$.

Incentives for Integration. Up to this point in the analysis, there has been nothing in our model that distinguishes the incentives for integration via consolidation from the incentives for integration via exclusive licensing. Once heterogeneous beliefs regarding management ability are introduced, the equivalence between the two forms of integration breaks down, due to the differences in control. Under an exclusive licensing agreement, both parties maintain a stake in the performance of the company. If neither party has sufficient faith in the other's ability to deliver the requisite management skills, the subjectively evaluated surplus may be insufficient to warrant integration. For *consolidation* to occur, however, it is not necessary that both parties share an optimistic assessment of the acquiring party's management skills. Provided that at least one party has sufficient faith in his own management abilities to warrant consolidation, the other will be willing to cede control through a merger or acquisition: compensation that does not depend on the subsequent performance of the integrated enterprise.

Proposition 5. *In a differentiated product system, there are parameter values in the* IP*-regime for which integration via consolidation is feasible, but integration via exclusive licensing is not.*

Proof. First, consider the case of integration via exclusive licensing. For $j = \mathsf{tr}, \mathsf{sd}$, suppose that j obtains a license from i to produce the augmented product. Now for $r = \mathsf{tr}, \mathsf{sd}$, define $\hat{\lambda}^{\ell}_{rj}$ by $\hat{\lambda}^{\ell}_{rj} E^2_{rj} \hat{\pi}^{\mathcal{M}}_{\Sigma} = \bar{\pi}^{\mathcal{A}}_r$. Since r is risk neutral, it will be willing to consider a contract in which j obtains a license from i, provided that r's share of expected joint profits weakly exceeds $\hat{\lambda}^{\ell}_{rj}$. Hence a necessary condition for an exclusive licensing agreement to emerge is that $\hat{\lambda}^{\ell}_{\mathsf{sd},j} + \hat{\lambda}^{\ell}_{\mathsf{tr},j} \leq 1$.

Now consider the case of consoildation through integration. Suppose there is a consolidation proposal which leaves j in control. In this case, for $j, r = \mathsf{tr}, \mathsf{sd}$ define the threshold shares $\hat{\lambda}^{m}_{rj}$ by $\hat{\lambda}^{m}_{rj} E^2_{jj} \hat{\pi}^{\mathcal{M}}_{\Sigma} = \bar{\pi}^{\mathcal{A}}_r$. The key distinction here is that for $i \neq j$,

$$\hat{\lambda}^{\ell}_{ij} \quad = \quad \frac{\bar{\pi}^{\mathcal{A}}_i}{E^2_{ij} \hat{\pi}^{\mathcal{M}}_{\Sigma}} \quad > \quad \frac{\bar{\pi}^{\mathcal{A}}_i}{E^2_{jj} \hat{\pi}^{\mathcal{M}}_{\Sigma}} \quad = \quad \hat{\lambda}^{m}_{ij}$$

while

$$\hat{\lambda}^{\ell}_{jj} = \frac{\bar{\bar{\pi}}^{\mathcal{A}}_{i}}{E^{2}_{jj}\,\hat{\bar{\pi}}^{\mathcal{M}}_{\Sigma}} = \hat{\lambda}^{m}_{ij}$$

That is, the requirement that threshold shares sum to at most unity is strictly more onerous for licensing than for consolidation. □

The intuition behind the proposition can be illustrated by a simple numerical example. The example is completely symmetric: each agent has the same reservation profit level and the same beliefs about expected performance, depending whether or not the agent himself is in control. For $i = 1, 2$, suppose that party i believes that expected annual profits will be \$9m per year if i itself controls the management of the joint enterprise, but only \$6m per annum if $j \neq i$ is in control. Suppose also that i's reservation profit level is \$4m. In this case i will be willing to cede control of the joint process to j in exchange for royalty revenues only if he can negotiate a sharing arrangement in which i receives at least 2/3 of every dollar of profit earned. In this case, i will earn at least 2/3 of \$6m p.a., which is at least i's reservation profit level of \$4m p.a.. This leaves 1/3 of every dollar earned for j. Even though j expects the much higher annual profit of \$9m per year, 1/3 of this amount (\$3m) is an insufficient incentive for j to accept the agreement. In sum, because i is so pessimistic about j's ability to deliver, the minimal *share* of profits that i will accept is so great that the residual share is insufficient to satisfy j, even given j's more optimistic assessment of the future. Hence, a royalty arrangement will not be consummated.

Now consider a consolidation in which i cedes control over his asset in exchange for an up-front, lump-sum payment. Any payment over \$4m will be sufficient to induce i to sell, while j will be willing to pay up to \$5m in order to acquire i. In this case, the necessary conditions for an agreement to emerge are satisfied. Thus, the difference between royalty and buy-out agreements is that for royalties what matters to each i is i's own evaluation of how well j can perform. For buyouts, i's own evaluation of how well j can perform is irrelevant.

The proposition demonstrates that when parties have heterogeneous beliefs regarding their management abilities, there are cases where consolidation is feasible, but an exclusive licensing agreement is not. Any such heterogeneity of beliefs can explain the tendency of the reoganization of the agricultural biotechnology sector to occur through mergers and acquisitions, rather than through exclusive licenses.

Conclusion

The goal of this paper has been to investigate the relationship among three historical developments in agriculture: the striking pattern of the consolidation of ownership of intellectual property related to plant biotechnology, the evolution of more clearly articulated intellectual property rights to key agricultural biotechnology assets, and the unfolding transformation of agriculture from a commodity business to a differentiated product business. The paper examines two questions regarding these three developments: (a) how do they affect the incentives of firms to integrate vertically? and (b) how do they affect the relative attractiveness of integration via contracting versus consolidation?

We demonstrate that the strength of intellectual property rights does affect incentives to vertically integrate, either via consolidation or contracting, in a differentiated products system, but does not in a commodity system. However, neither a differentiated product system nor intellectual property protection alone is sufficient to affect the incentives to vertically integrate. Moreover, the combination of these two forces does not explain the tendency of firms in this sector to integrate through consolidation, rather than through exclusive licensing or other forms of contracting. We show that heterogeneous beliefs across agents may explain this tendency. Specifically, provided that agents have heterogeneous beliefs about future values of the endogenous parameters that determine industry profitability, there is a range of parameter values for which integration via consolidation will be profitable, but integration via contracting will not be.

Appendix: Proofs of Lemma 1-3

Lemma 1: $\bar{\pi}^{\mathcal{A}}_{\mathsf{sd}}(0) > \bar{\pi}^{\mathcal{B}}_{\mathsf{sd}}$ *if and only if* $\tilde{d}_0 > \bar{p}^{\mathcal{B}}(d_1 + \frac{2}{s_1})$.

Proof. If $\bar{\pi}^{\mathcal{A}}_{\mathsf{sd}}(0) > \bar{\pi}^{\mathcal{B}}_{\mathsf{sd}}$, then $\frac{s_1}{2}(\frac{(\tilde{d}_0)^2}{(2+d_1 s_1)^2} > \frac{(\bar{p}^{\mathcal{B}})^2}{2s_1}$. Multiplying both expressions by $\frac{2}{s_1}$ and taking their square roots results in the inequality $\frac{\tilde{d}_0}{(2+d_1 s_1)} > \frac{\bar{p}^{\mathcal{B}}}{s_1}$. Rearranging this inequality results in the inequality in the lemma.

The expression $\tilde{d}_0 > \bar{p}^{\mathcal{B}}(d_1 + \frac{2}{s_1})$ may be rearranged as $\frac{\tilde{d}_0}{(2+d_1 s_1)} > \frac{\bar{p}^{\mathcal{B}}}{s_1}$. Multiplying both sides by $\frac{s_1}{2}$ and squaring the results leads to the inequality $\frac{s_1}{2}(\frac{(\tilde{d}_0)^2}{(2+d_1 s_1)^2} > \frac{(\bar{p}^{\mathcal{B}})^2}{2s_1}$. Using the definitions of $\bar{\pi}^{\mathcal{A}}_{\mathsf{sd}}(0)$ and $\bar{\pi}^{\mathcal{B}}_{\mathsf{sd}}$, this may be rewritten as $\bar{\pi}^{\mathcal{A}}_{\mathsf{sd}}(0) > \bar{\pi}^{\mathcal{B}}_{\mathsf{sd}}$. □

Lemma 2: The seed suppliers' outside option of supplying the basic market will be binding ($\ell^* < \frac{\tilde{d}_0}{2d_1}$) if and only if $2\bar{p}^{\mathcal{B}}(d_1 + 2/s_1) \geq \tilde{d}_0$.

Proof. Substituting in the definition of ℓ^* into the inequality $\ell^* < \frac{\tilde{d}_0}{2d_1}$, we obtain $\frac{\tilde{d}_0}{d_1} - \bar{p}^{\mathcal{B}}\left(1 + \frac{2}{d_1 s_1}\right) < \frac{\tilde{d}_0}{2d_1}$. Multiplying both sides of the inequality by $2d_1$, we obtain the condition in the lemma: $2\bar{p}^{\mathcal{B}}(d_1 + 2/s_1) \geq \tilde{d}_0$. Beginning with this condition, we divide both sides of the inequality by $2d_1$, and substitute ℓ^* for its definition to obtain $\ell^* < \frac{\tilde{d}_0}{2d_1}$. □

Lemma 3: A necessary and sufficient condition for integration to occur is

$$1 + \frac{d_1 s_1}{2}\left\{\frac{\tilde{d}_0 s_1}{\bar{p}^{\mathcal{A}}(8 + 3d_1 s_1) - 4\tilde{d}_0 s_1}\right\} > \frac{\bar{p}^{\mathcal{A}}(2 + d_1 s_1)}{\tilde{d}_0 s_1}.$$

Proof. We combine the expression for $\tilde{\pi}_{\Sigma}^{\mathcal{M}}$ with the expressions for $\tilde{\pi}_{\mathsf{sd}}^{\mathcal{A}}$ and $\tilde{\pi}_{\mathsf{tr}}^{\mathcal{A}}$ on page 4, in order to obtain the following:

$$\tilde{\pi}_{\Sigma}^{\mathcal{M}} - (\tilde{\pi}_{\mathsf{sd}}^{\mathcal{A}} + \tilde{\pi}_{\mathsf{tr}}^{\mathcal{A}}) = \frac{(x-y)(3x-y) + 2(\bar{p}^{\mathcal{A}})^2(2+d_1s_1)}{(2d_1(s_1^2)(2+d_1s_1)}$$

$$\text{where } x = \bar{p}^{\mathcal{A}}(2+d_1s_1) \text{ and } y = \tilde{d}_0s_1.$$

When this expression is positive, integration will be more profitable than non-exclusive licensing. The common denominator is positive, so in order to determine the sign of the expression we may restrict attention to the numerator. The numerator may be rewritten as

$$\bar{p}^{\mathcal{A}}(2+d_1s_1)\left\{\bar{p}^{\mathcal{A}}(8+3d_1s_1) - 4\tilde{d}_0s_1\right\} + (\tilde{d}_0s_1)^2$$

Substituting in $\bar{p}^{\mathcal{A}} = \frac{\tilde{d}_0}{d_1} - \frac{2\bar{p}^{\mathcal{B}}}{d_1s_1}$,

$$1 + \frac{d_1s_1}{2}\left\{\frac{\tilde{d}_0s_1}{\bar{p}^{\mathcal{A}}(8+3d_1s_1) - 4\tilde{d}_0s_1}\right\} - \frac{\bar{p}^{\mathcal{B}}(2+d_1s_1)}{\tilde{d}_0s_1} = \tilde{\pi}_{\Sigma}^{\mathcal{M}} - (\tilde{\pi}_{\mathsf{sd}}^{\mathcal{A}} + \tilde{\pi}_{\mathsf{tr}}^{\mathcal{A}})$$

If the expression $1 + \frac{d_1s_1}{2}\left\{\frac{\tilde{d}_0s_1}{p^{\mathcal{A}}Bar(8+3d_1s_1)-4\tilde{d}_0s_1}\right\} - \frac{\bar{p}^{\mathcal{B}}(2+d_1s_1)}{\tilde{d}_0s_1}$ is positive, then integration is more profitable than non-exclusive licensing. We omit the parallel proof of sufficiency. □

References

Debreu, G. *Theory of Value.* New Haven: Cowles Foundation, 1959.

Dubey, P. "Price-Quantity Strategic Market Games." *Econometrica.* 50(1982):111-126.

Graff, G., G. Rausser and A. Small. "Agricultural Biotechnology's Complementary Intellectual Assets." *Rev. Econ. Stat.* Forthcoming.

Hall, B. and R. H. Ziedonis. "The Patent Paradox Revisited: An Empirical Study of Patenting in the U.S. Semiconductor Industry, 1979-1995." *RAND J. Econ.* 32(2001):101-128.

Kortum, S. and J. Lerner. "Stronger Protection or Technological Revolution: What is Behind the Recent Surge in Patenting?" Carnegie-Rochester Conference Series on Public Policy, no. 48.

Simon, L. "Bertrand, the Cournot Paradigm and the Theory of Perfect Competition." *Rev. Econ. Stud.* LI(1984):209-230.

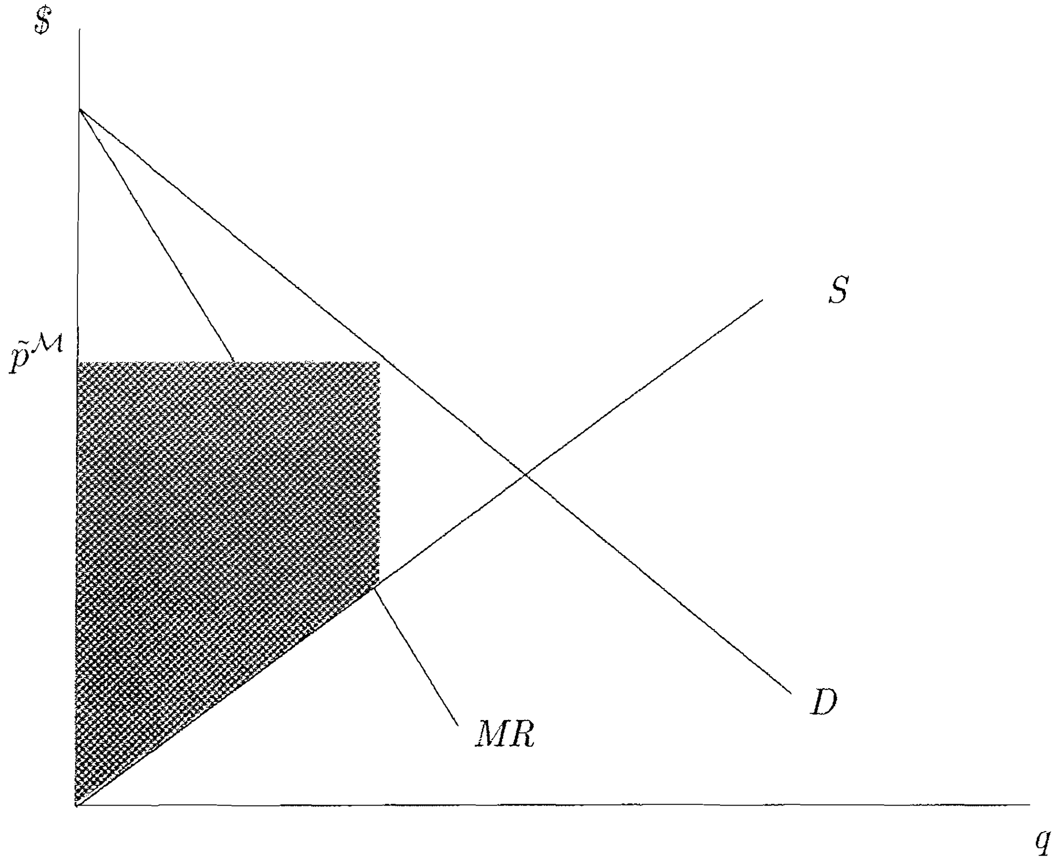

FIGURE 3. Exclusive Contract Profits

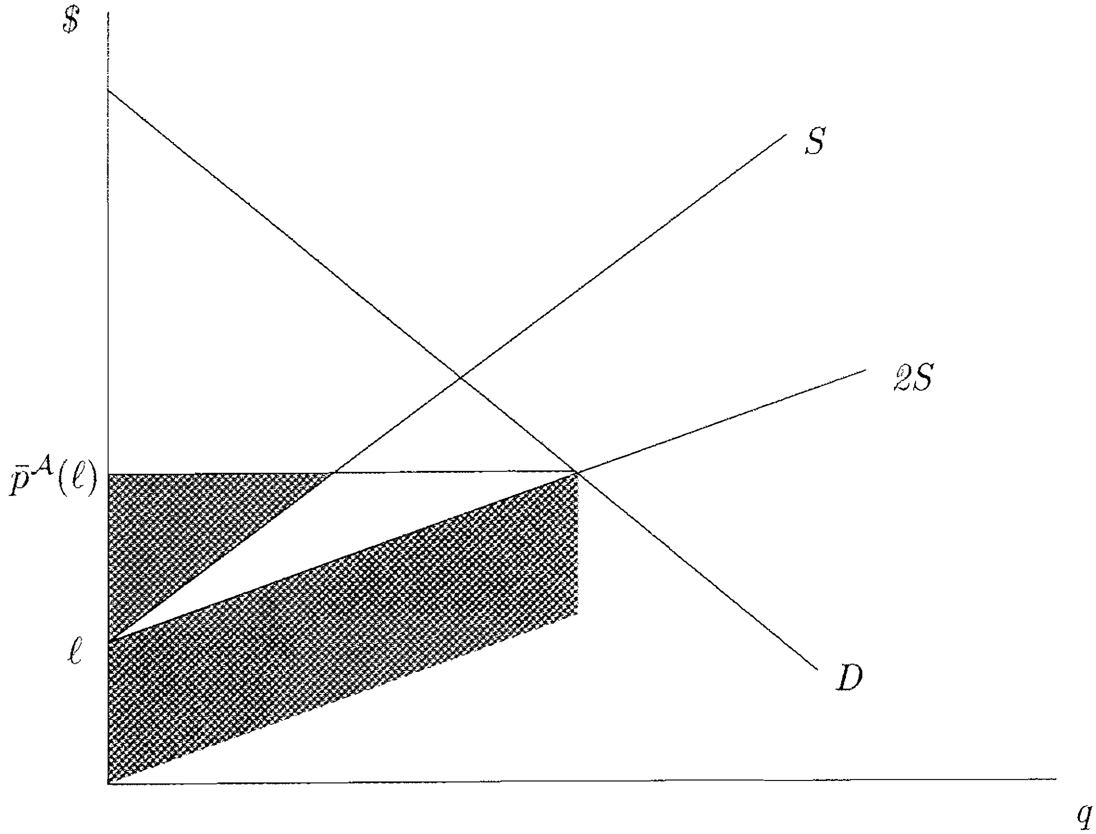

FIGURE 4. Non-Exclusive Contract Profits