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Vertical and Horizontal Coordination in the Agro-biotechnology Industry: Evidence and Implications

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ABSTRACT

Agro-biotechnology is evolving from a pre-commerical phase dominated by basic research science to a commercial phase oriented around marketing products. In pursuing innovation rents in the commercial phase, firms are reorienting their strategies around complementary marketing and distribution assets. This is impacting vertical and horizontal industry structure. Conversely, industry structure is also impacting firm strategies. Horizontal alliances and consolidation continue from the pre-commercial phase into the commercial phase, while vertical coordination and integration strategies are accelerating rapidly. Interplay between firm strategy and industry structure is too complex for firms to anticipate early in the pre-commercial phase for long-term strategy formulation.

Key Words: acquisitions, agricultural biotechnology, firm strategy, industry consolidation, industry structure, mergers.

Since the development of gene transfer and cell fusion techniques in the mid-1970s, agro-biotechnology has promised fundamental change in food production, processing, and distribution systems (Molnar and Kinnucan; Organization of Economic Cooperation and Development). Agro-biotechnologies with commercial potential range from transgenic plants, animals, and fish with improved production and quality characteristics to enhanced systems for pest control, animal health care, and waste management (Office of Technology Assessment). Admittedly, the rate of product introduction has been slower than originally thought possible. Agro-biotechnology has been gradually approaching the marketplace in recent years, however. Although attention has concentrated on a few products, such as Bovine Somatotropin, the FlavrSavr® tomato, Roundup Ready® soybeans, and Bacillus thuringiensis (Bt)-corn and -cotton, over 50 commercial agro-biotechnology products are currently in the market and twice as many are expected to enter the market within the next two to three years.

Much has been written about the potential reception of agro-biotechnology by farmers and consumers (Lesser, Magrath, and Kalter; Lacy, Busch, and Lacy; Zepeda) and its potential impacts on farm structure (Kaiser and Tauer; Lemieux and Wohlgenant; Marion and Wills). Other favorite topics of social scientists have involved intellectual property rights (Acharya), food safety (Doyle and Marth; Juskevich and Guyer), regulation (Larson and Knudson), and ethics (Thompson). Yet, little attention has been directed toward the dynamics of innovation, firm strategy, and industry structure. Indeed, agro-biotechnological inno-

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vation, by and large, has been treated exogenously and its relationship with the structure of agricultural industries has been almost overlooked. While studies by Just and Hueth, and Goldburg et al. are exceptions, their hypotheses remained untested.

This omission has parallels in the general innovation literature. As Cohen and Levin pointed out, "Theorists and empiricists alike have devoted too little attention to the dynamics of innovation and market structure, the Schumpeterian process of creative destruction" (p. 1098). Yet, important contributions exist, allowing significant understanding of the dynamics of innovation and industry structure.

Responding to developments in agro-biotechnology, several agricultural and food industries have shown a marked change in their structure. Firm incentives and strategies have interacted with the nature of the technology to drive firm mergers, acquisitions, strategic alliances, and joint ventures. Such actions, in turn, may have affected the rate and direction of agro-biotechnology innovation. This paper is devoted to the relationship of agro-industrial structures and biotechnological innovation and its important implications for both competitive firm strategy and policy analysis.

Technological Discontinuities and Firm Strategies

Abernathy and Utterback described the basic characteristics of innovation cycles which are initiated through technological discontinuities or new technological paradigms. A new technology paradigm is defined as a set of new models for solving selected technological problems using specific principles from natural sciences and material technologies (Dosi). During the first stage of the innovation cycle, firms engage in product innovation bringing forward new technical know-how and product concepts. Over time, specific new product concepts become the standard through broad market acceptance. Then product innovation subsides in favor of process innovation which attempts to improve on production and distribution processes (Abernathy and Utterback; Utterback).

Given that agro-biotechnology is still at its early developmental stages, our interest concentrates on the dynamics of product innovation. We propose that for technological innovations that involve long gestation periods of research and development (R&D) before marketable products are developed, Abernathy and Utterback's product innovation stage be separated into two sequential phases: (*a*) a pre-commercial technology development phase, and (*b*) a commercial phase. The pre-commercial phase involves basic and applied research which may or may not have a direct commercial target. The commercial phase represents applications of science and technology to product development with commercial targets. As explained later, the significance of this distinction is that firms face different external conditions and incentives with resultant strategy effects.

Firm Strategies in the Pre-Commercial Phase

Following a technological discontinuity, technological barriers to entry are lowered and newcomers gain easier entry into affected industries. They bring forward new scientific and product concepts and aspire to capture rents from their innovation, often by integrating forward. Established firms may also join in and participate in the innovation process. Incumbent firms choose from a variety of technology development strategies. They may develop technological know-how through in-house R&D. They may develop new technology jointly with other firms through research contracts, strategic alliances, and joint ventures where they can leverage their technological, financial, and market assets. They may acquire technology through mergers and acquisitions, through licensing of intellectual property, or through supply agreements (Pisano 1991). Finally, they may adopt a wait-and-see (imitation) strategy which seeks to time entry into the innovation race after dominant product concepts have become discernible and market risks reduced (Bozeman and Link). Minority investments in new entrants may be used to monitor new technological developments and provide a platform for sharing innovation rents captured by newcomers (Pisano 1988).

In general, collaborative R&D plays an important role in many high technology industries (Mowery 1983, 1988). In the presence of complex and fast changing science, firms find it increasingly difficult to internalize all R&D necessary to take new technical know-how all the way to the market. Here, collaborative R&D becomes important. Widening geographic and organizational diversity of new sources of technology provide further incentives (Mowery 1988).

Firm Strategies in the Commercial Phase

As the science base begins to stabilize and commercialization opportunities become increasingly apparent, product formulation, scale-up, and other forms of product development innovation intensify. Complementary assets (e.g., manufacturing capability, scale-up experience, marketing, and distribution networks) become increasingly important. Newcomers and incumbents alike decide their commercialization strategies based on the appropriability of innovation rents and their access to complementary assets (Teece 1987).

A firm's ability to appropriate the profits from its innovation is decided principally by two factors. The first is the degree of innovation tacitness and the resultant ease of imitation (Teece 1987). A variety of determinants may contribute to the tacit nature of technical know-how. Accumulated knowledge and management experience in research, regulatory compliance, scaling up, partnership formation, procurement, and production are significant to performance. These are difficult to imitate and difficult to learn. If the technology is not tacit and can be easily codified and copied, imitators could appropriate a significant share of the profits from innovation.

The second appropriability factor is the strength of intellectual property rights available to the technology (Teece 1987). Firms use a variety of intellectual property rights, including patents and trade secrets, to protect their technology from imitators. Intellectual property rights that are not strongly defensible lead to weak appropriability.

If innovations are strongly appropriable, and if the complementary assets required for commercialization are not specialized, then the innovator ordinarily can contract or make open-market transactions for these assets' services while capturing its innovation rents. If innovation is only weakly appropriable and if the complementary assets are specialized to a narrow range of potential uses, however, then the owners of complementary assets may capture a large portion of the innovation rents. In this case, innovators must contract or vertically integrate to gain control of such assets or lose innovation rents to an outside supplier. There are numerous market procurement and coordinating strategies between these two extremes which may conform to varying degrees of innovation appropriability and control of complementary assets.

Pre-commercial and commercial phase strategies require coordination. Firm strategies during the pre-commercial phase collectively define the appropriability of technological innovation and condition strategic choices in the commercialization phase. For example, research contracts and collaborative R&D may facilitate entry of new competitors and expedite the diffusion of know-how. This diminishes the tacitness and, hence, appropriability of the new technology. Similarly, in research agreements with downstream firms, it may seem inconsequential during the pre-commercial phase that they own complementary assets. But later in the commercial phase this can have fundamental impacts on the innovators' ability to profit. This endogenous appropriability contrasts with Abernathy and Utterback's as well as Teece's framework of exogenous appropriability determined by institutional arrangements and technological parameters.

Firm Strategy Within a Transaction Costs and Evolutionary Framework

Given a variety of possible configurations in the ownership of technical know-how and complementary market assets, what are the basic principles guiding the firm strategy decisions in both the pre-commercial and commercial phases of the product innovation cycle? In other words, how do firms choose their organizational boundaries from a range of options between a fully vertically integrated firm with exclusive internal R&D to a concept firm where all R&D, production, and distribution services are procured through contracts and markets?

If markets were efficient in pricing innovation and transacting was costless, specialized R&D firms could emerge to sell know-how and R&D services to downstream firms (Stigler). In the case of real markets, however, intellectual property rights enjoy limited protection, technology transfer costs can be high, specialized assets can be held up by opportunistic contractors, and licensing and intermediate technology markets tend to have limited importance for capturing innovation rents (Joly and deLooze; Teece 1981, 1987; Von Hippel).

Transaction cost theory and evolutionary economics provide guidance for the choice of firm innovation strategies (Pisano 1991). Transaction cost theory suggests that, assuming constant production costs, firms draw their boundaries so that they minimize the transaction costs of governing economic activity (Williamson). Two broad categories of transaction costs exist: (*a*) coordination costs for transferring information and coordinating complex activities across firm boundaries, and (*b*) motivation costs arising from informational asymmetries between transacting parties or from imperfect commitment to a binding agreement (Milgrom and Roberts). Imperfect commitment and informational asymmetries lead to incomplete contracts and invite post-contractual opportunistic behavior. This raises the cost of monitoring and enforcing the agreement.

Coordination costs increase with the complexity and tacitness of the technical information exchanged. Transfer of scientifically complex and not easily codified technical know-how between firms typically incurs high coordination costs. Higher coordination costs discourage outsourcing and make firms more likely to internalize R&D activities.

Motivation costs increase with the specificity of the required investment. Thus, contracting for the service of specialized assets creates motivation problems. As the specificity increases, contracting efficiency decreases because asset specificity transforms the market into an ex post bilateral trading relation that is exposed to opportunistic behavior. The irreversible investment in specialized assets creates quasi-rents for the owner that can be opportunistically extracted by the other party. Asset specificity would not pose problems if comprehensive contracting were feasible, since this would anticipate all contingencies. However, bounded rationality precludes this (Klein, Crawford, and Alchian). R&D contractual agreements are inherently vague since technical outcomes and intellectual property rights are difficult to predict and specify ex ante. When motivation costs are high, firms are more likely to internalize R&D.

While transaction cost theory provides insights on a firm's motivation to develop new technical know-how internally or through external procurement, evolutionary theory focuses on a firm's ability to develop such know-how (internally or externally) under conditions of rapid change. Evolutionary theory stresses the limits of a firm to change, adapt, and learn in the short run as it is constrained by its own ability to absorb new knowledge and skills (Nelson and Winter). Existing routines that coordinate internal firm activities as well as the specific skill set and capabilities of the firm may define the likelihood of a firm's survival under a new (emerging) technological paradigm.

Transaction cost and evolutionary views are complementary. Applied to product innovation strategies, evolutionary theory suggests that only part of the menu of all possible pre-commercial and commercial strategies is in fact available to firms. Given the firms' separate histories, organizational routines, skills, and capabilities, different subsets of these strategies are effectively available to them. Firms then choose specific strategies from a relevant sub-menu of strategic options that minimize production, coordination, and motivation costs. For R&D that does not require specialized investments and for which expected technical outcomes and intellectual property rights can be delineated ex ante, downstream firms will more likely opt for outsourcing R&D with research specialists, especially when they lack in-house expertise. If such procurements are foreign to the firm's culture and organizational routines, then it may choose to internalize R&D even with a lack of expertise and the implied higher costs. Similarly, firms with organizational routines geared toward outsourcing and licensing of technical know-how may opt for collaborative R&D even when technological outcomes are uncertain, intellectual property rights are vague, or exposure to hold-ups is apparent.

Based on the development in the two previous sections, we now specify the firm's product innovation decision process. We propose that during the pre-commercial phase, firms maximize technological outcomes and the degree of appropriability from a given stream of R&D investments, restricted to a subset of options defined by their organizational routines. During the commercial phase, firms maximize intertemporal net profits from any additional investment in R&D or complementary assets. Their strategy is conditioned on their technology and their appropriability position secured during the pre-commercial phase. Organizational routines remain determinant. The significance of separability between the two phases is that firms' choices in the commercial phase are constrained by those in the pre-commercial phase, and that their technological bases are sunk costs as firms approach the market.

Innovation Strategies and Industry Structure

The number, relative size, and concentration of suppliers of technical know-how and complementary assets, as well as their degree of vertical integration into downstream or upstream industries, affect the transaction costs of strategic interactions among firms and their bargaining power. Hence, industry structure has a fundamental impact on firm strategy formation in both the pre-commercial and commercial phases.

In the early part of the pre-commercial phase, technical barriers to entry are low and many specialized technology firms with similar technical expertise may enter the innovation cycle. Given their low technical differentiation, their bargaining power may be weak in selling R&D services to contracting buyers. Ex ante, their bargaining power is reduced through competitive bidding. Ex post, power is limited through exposure to potential hold-up tactics whereby buyers could terminate the relationship in favor of a new supplier.

The bargaining power of technology firms could be enhanced as time goes by and as specialized desirable technical expertise is developed. The technology firm's bargaining position may be further strengthened if buyers must make specialized investments in order to incorporate the purchased technology into their own operations and product development. As their bargaining power increases, technology firms can increase the prices of their R&D services or appropriate a greater portion of the technology they develop. If buyers are exposed to hold-ups, however, and if there are few other suppliers to resort to, then market or contract purchases of technology may fail. Buyers may be forced to turn to internal R&D, acquisition of a technology firm, or a joint venture or strategic alliance where both transacting parties make irreversible investments.

Firm size and imperfections in capital markets may also drive technology strategies toward vertical integration. Long investment periods required for research and the development of commercial products often deplete the capital resources of specialized startup technology firms. If capital markets were perfect, then they could assess firm prospects and efficiently allocate capital to firms with a high present value of expected future profits. But the technology is often relatively difficult to assess, and much of the firm's value lies in the tacit knowledge held collectively by employees. This drives many of these firms to develop relations with larger firms that are better able to evaluate their prospects than are capital markets. Large firms receive technology in exchange for capital investments if not outright acquisition. Thus, a concentrated technology industry structure and failure in technology and capital markets can motivate firm strategies that lead to a more vertically integrated sector.

As product innovation approaches its commercial phase, access to marketing and distribution assets becomes increasingly important. Strategy emphasis shifts toward the structure of downstream industries. If downstream industries are characterized by a large number of firms operating in competitive markets, then simple market transactions should be adequate for technology firms to appropriate innovation rents. If the new technology is weakly appropriable, or specialized to or dependent on complementary marketing and distribution assets, then the bargaining power of technology firms is reduced and a large portion of innovation rents may be appropriated by downstream firms. The bargaining power of downstream industries increases further as they become increasingly concentrated. Under such conditions, the technology firms may pursue forward integration, as long as capital resources allow it and barriers to entry are not too high.

Based on the above discussion, industry structure and transaction costs influence strategy. Conversely, firm strategies also influence industry structure by means of firm coordination and integration. Hence, there is an intimate interplay between industrial structure and firm strategies fueled by the pursuit of innovation rents. This interplay defines the process of creative destruction and shapes innovation cycles.

It is now apparent why it is necessary to separate product innovation into pre-commercial and commercial phases. In the beginning of a new technological paradigm with long R&D investment horizons, it is impossible for firms to predict (*a*) relevant technological outcomes, (*b*) competitors' future intellectual property rights positions, or (*c*) the future structure of downstream industries. Hence, in the beginning of a product cycle it is unlikely that firms can formulate a strategy that effectively maximizes innovation rents because key parameters are unknown. Firms begin to shape strategies for the commercial phase only after technological expertise and intellectual property rights positions of competitors are clarified, downstream industry structures appear stable, and R&D outcomes become predictable. These strategies must be tailored to the firm's idiosyncratic technology and complementary asset position in order to maximize innovation profits from additional R&D investment and complementary asset acquisition.

Innovation Strategies in Agro-biotechnology

We have described a dynamic interplay among innovation, firm strategy, and industry structure relevant to complex new science and technology with long R&D gestation lags. How much of this description, however, is relevant to agro-biotechnology? Should we expect that agro-biotechnology innovation cycles follow predictable patterns? If so, what are the implications for competitive strategies and industry structure? To shed some light on these questions, we analyzed some 1,600 collaborative agreements, joint ventures, mergers, partial and total acquisitions, licensing agreements, and equity investments related to technology development and commercialization in the area of agro-biotechnology over the period 1980 to 1996. This information was collected from a variety of trade magazines, on-line databases, company annual reports and news releases, and books and journals related to agro-biotechnology.

The development of genetic engineering techniques in the mid-1970s provided the technological discontinuity that initiated the agro-biotechnology innovation cycle. The new science permitted new product concepts and processes for a variety of traditional agri-food industries (e.g., pesticide, seed, animal health, and food processing). Numerous new research-oriented firms entered these industries in pursuit of these concepts and the associated innovation rents (figure 1). Under these conditions, agri-food industries were soon characterized by

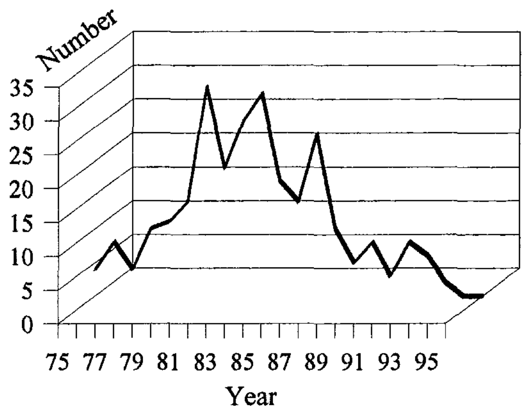

Figure 1. Number of new agro-biotechnology firms

Table 1. Numbers of Inter-Firm Activities in the Agro-biotechnology Industry

Activity	Period 1981–85	1986–90	1991–96	Total 1981–96
Mergers and Acquisitions	19	115	274	408
Equity Investment	24	41	47	112
R&D Agreements	84	244	147	475
Joint Ventures	24	77	81	182
Licensing Agreements	6	78	122	206
Distribution Agreements	9	66	109	184
Production Agreements	1	3	21	25
Total	167	624	801	1,592

a bi-modal structure of technology startups and traditional established firms. This environment created opportunities for R&D collaboration between established firms that needed new technology, and startups that needed capital resources to finance costly R&D.

Collaborating to Compete

Table 1 shows that in the 1980s, R&D agreements grew at significant rates. Approximately 90% of all R&D agreements included in our sample were between large established firms and technology startups. Collaborative agreements involving complementary market assets (e.g., manufacturing, distribution, and marketing services) also grew as time progressed. Most of the growth in these agreements occurred in the 1990s, implying the maturation of the technology and its approach to the market. Figure 2 illustrates the temporal progression of strategic alliances in R&D and complementary assets agreements. This progression maps the pre-commercial and commercial phases of agro-biotechnology product innovation. R&D agreements are important during the pre-commercial phase of product innovation. As product concepts approach the market, agreements that marshal the necessary complementary assets for commercialization become important. Figure 2 shows the transition from the pre-commercial to the commercial phase in the case of agro-biotechnology.

The substantial number of strategic alliances in both R&D and market activities suggests that expected synergies exceeded expected transaction costs enough to encourage contractual arrangements without full integration. Thus alliances were struck among a variety of firms interested in the new technology. The large number of technology startups with high but weakly differentiated technical capability indicates that the possibility of holdups was small or their bargaining power limited. Such conditions apparently encouraged large established firms to outsource initial efforts to engage with the new technology rather than investing large sums for building internal technical capability.

As the complexity of the new science became increasingly apparent and R&D cycles were elongated, investment capital for re-

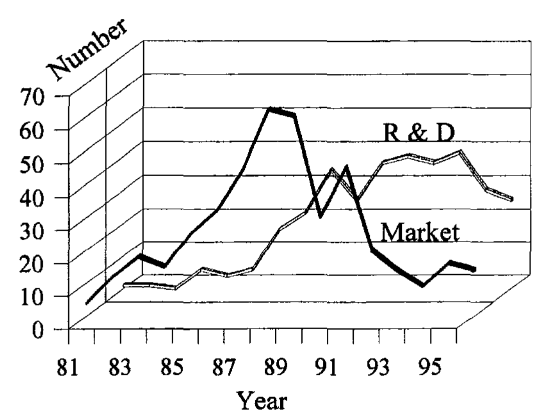

Figure 2. Strategic alliances in agro-biotechnology

search became a binding constraint for most startups. These capital constraints further weakened the bargaining position of technology startups and further encouraged their collaboration with well-capitalized established firms. Following the stock market crash of 1987, venture capital and investor capital resources seeking technology startups were reduced. This encouraged collaborative agreements as an alternative means of financing R&D and commercialization (figure 2). Hence, financing constraints at the end of the 1980s may have speeded the transition of agro-biotechnology to its commercial phase.

Internalizing Technological Capability

Mergers and acquisitions (M&As) have grown significantly since the mid-1980s, but the bulk of these have occurred during the 1990s. Unlike strategic alliances and licensing agreements which encourage technology transfer, however, growth in M&As marked the beginning of the internalization of technological capabilities by firms and the consolidation of the agro-biotechnology industry. Almost 60% of the M&As we have counted were carried out by technology firms attempting to create sufficient financial and technological resources to integrate forward. Selective partial and total acquisitions of technology assets by established downstream firms were also an important part of the observed M&A activity.

Increased integration has occurred primarily during the commercial phase of agro-biotechnology product innovation. Low innovation appropriability may be a primary motivating factor because technology firms may integrate forward to capture their innovation rents. Conversely, firms established in downstream industries may integrate backwards to increase the value of their assets by internalizing R&D and associated innovation rents. The profitability of integrating backwards improves when their bargaining power relative to technology firms increases.

While the degree of innovation appropriability is best assessed at the firm level on a case-by-case basis, we provide an initial general appraisal with some informative indicators. As the number of firms with expertise or intellectual property rights on a particular technology increases, the degree of appropriability of the technology will tend to decrease. Table 2 reports the number of firms experimenting with specific agro-biotechnologies with commercial outlook and the number of firms owning related patents. It is apparent that no firm has exclusive claims or expertise on most agro-biotechnologies with commercial potential. A number of firms seem to have staked a technological position. Further, agro-biotechnology applications tend to be weakly differentiated. Most differentiation actually comes from relevant complementary downstream assets (e.g., brand name of pesticide with which the seed is tolerant, or brand name of the seed). Under such conditions, appropriability of the technology innovation is weakened.

Table 2. Appropriability of Agro-biotechnology

		No. of Firms Experimenting with:		
Technology	No. of Crops	Single Trait	Multiple Trait	No. of Firms w/ Patents
Herbicide Tolerant:				
Glyphosate	10	28	5	4
Bromoxynil	4	4	3	2
Phosphinothricin	16	30	24	4
Sulfonylurea	6	9	2	2
Product Quality:				
Amino acid content	5	5	3	12
Fruit ripening	10	16	3	10
Oil profile	3	4	1	15
Protein	5	8	1	n/a
Insect Resistant:				
Coleopteran	9	12	8	7
Lepidopteran	15	39	23	9
Viral Resistant:				
Mosaic virus	15	17	14	18
Other	13	18	7	17
Fungal Resistant:				
Phytophthora	4	7	1	2
Rhizoctonia	3	2	2	7
Agronomic Properties:				
Cold tolerant	3	4	0	3
Male sterility	7	15	2	14

Low appropriability for the new technologies is coupled with moderately concentrated downstream industries. For example, the top 20 firms in the chemical, seed, and animal health industries have, respectively, 88%, 47%, and 68% shares of the total global market (Heijbroek, deSchutter, and vanGaasbeek; Watkins). Hence, complementary assets in these industries may be difficult to acquire and rather specialized. Low appropriability, high complementary asset specificity, and downstream industry concentration therefore can provide an adequate explanation of the recent integration and consolidation of the agro-biotechnology industry.

As consolidation decreases the number of technology firms, the motivation of downstream firms to internalize R&D through acquisitions or internal growth increases as well. Hence, the recent patterns of consolidation and integration in the agro-biotechnology industry should be expected to continue.

Implications

Treating agro-biotechnology as a uniform technology, as we have done in this study, is due to analytical convenience in describing concepts, rather than due to a need for realism. Agro-biotechnology is indeed an amalgamation of various applications of a similar science. The developmental stage of various applications is in many cases quite different. Animal biotechnology, for example, is less advanced than plant biotechnology. Thus, although the proposed framework and data apply broadly, one may begin to more effectively analyze the dynamics of innovation, firm strategy, and industry structure by refining the concept of agro-biotechnology and focusing on particular applications. Bearing this in mind, we draw possible implications of the forces and concepts analyzed.

Consolidation

As the rate of product innovation in agro-biotechnology diminishes, industry consolidation will eventually result in a few remaining firms with significant technical and complementary asset positions. During this period of consolidation, the market valuation of key complementary assets is likely to increase. Acquisition price tags—such as the $1 billion paid by the Monsanto Company for Holdens Foundation Seed, or the $750 million paid by German chemical giant AgrEvo for the technology startup Plant Genetic Systems—may be unprecedented but not surprising.

Integration

The speed and pattern of integration of upstream and downstream industries affected by agro-biotechnology will likely vary across subsectors and industries. The degree of concentration and ownership of technology or downstream complementary assets will be important determinants. For example, the animal health industry should anticipate less change since most new technology and complementary assets are in the hands of existing dominant players. This contrasts with the seed industry, which has few dominant firms and hundreds of small regional companies that depend on technology firms for access to agro-biotechnology. This industry could experience significant structural change and consolidation. The likelihood and patterns of such consolidation will depend on the outcomes of current competitive games among key players.

Firm Competitive Position

If our conceptual framework and data are representative of the agro-biotechnology industry, then it is implied that future dominant players already have a presence in the industry. While the basic science and technology are becoming increasingly accessible, the accumulated technology base and complementary assets owned by incumbent firms will increasingly act as barriers to new entrants. It is becoming unlikely that new key players will emerge as product innovation winds down and as complementary marketing and distribution assets are controlled by incumbent networks. New biotechnology startup firms will continue to enter the industry. However, their likely role will be limited to contract R&D for tasks that established firms can easily outsource, especially when intellectual property rights are clear (e.g., gene and protein discovery). Economic rents to this R&D will be minimal. Yet, as process innovation in agro-biotechnology progresses, opportunities for efficient division of labor among established firms and research specialists should expand. Key new technologies, however, will be increasingly developed internally by established firms that have built the necessary technological base for fundamental research and product development. Internalization will increase the appropriability of innovation and will mark a more proprietary era for agro-biotechnology. Their positions could be dominant.

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