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Trait Stacking, Licensing, and Seed Firm Acquisitions in Genetically Modified Grains: A Strategic Analysis

William W. Wilson and Scott R. Huso

Commercialization of genetically modified (GM) traits leads to interesting strategic questions for agbiotechnology and seed firms. The purpose of this study is to evaluate equilibrium strategies of agbiotechnology and seed firms regarding commercialization of GM traits. Two game theory models were developed to examine equilibrium strategies. In the first, both agbiotechnology firms have commercialization strategies of licensing or not. In the second, the agbiotechnology firm also has the strategic option to purchase a seed firm as a commercialization strategy. Results indicate that the equilibrium strategy would be for each of the agbiotechnology firms to license their traits, and the seed firm would release a stacked trait. However, order of play matters and impacts the equilibrium. Finally, in the second game, the equilibrium is for the agbiotechnolgy company to purchase a seed firm. Each of these decisions is highly strategic and reflects the current strategic challenges in the agbiotechnology industry.

Key words: acquisition, game theory, genetically modified, licensing, trait commercialization, trait stacking

Introduction

Agbiotechnology firms confront major strategy questions concerning how to commercialize genetically modified (GM) traits, including through a license to seed firms or to purchase a seed firm and release traits through their own varieties. In practice, we observe both strategies. Seed firms face decisions about which traits to incorporate into their variety portfolio and whether to stack multiple GM traits. For agbiotechnology firms, these are highly strategic decisions and depend on expected actions of the seed firm and vice versa. The prospect and demand for multiple traits stacked in varieties has led to important strategic alternatives for agbiotechnology and seed firms. These strategic questions are motivated by the fact that the seed industry is evolving from "seeds" to "seeds and traits" (Fernandez-Cornejo, 2004).

Roundup Ready® wheat (RRW) and fusarium-resistant wheat (FRW) traits are the focus in this study, though other traits in wheat are at various stages of development (Wilson, Janzen, and Dahl, 2003), such as recent developments of a drought-tolerant trait

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in Australia (Kyodo News International, 2008). Commercialization of GM traits in wheat is slow for various reasons—in particular, consumer concerns. Yet there has been a recent resurgence of grower interest in commercializing GM traits (National Association of Wheat Growers, 2006). The FRW trait is currently under development by Syngenta. RRW was under review in the United States and Canada, but in 2004, Monsanto made a strategic decision to defer further commercialization (Monsanto, 2004a).

The purpose of this study is to evaluate equilibrium strategies of agbiotechnology and seed firms for trait commercialization and variety production decisions. A game theory model of trait stacking and commercialization was developed to evaluate equilibrium strategies. The model is applied to the case of hard red spring (HRS) wheat, but could be generalized to other crops and traits. Strategic analysis of licensing and trait stacking has not been addressed in the literature despite being critical to firms in the industry. This article contributes to the agbiotechnology literature by developing a trait commercialization and trait stacking game for modeling strategies. Although the analysis focuses on one crop and two traits, the game offers guidance for possible strategies for new GM traits in wheat near commercialization and can be applied to other GM grains and traits. It also provides a logical explanation for recent observed strategies by firms in this industry and their actions associated with wheat in particular.

Background

There is extensive literature investigating GM crops. Some of these analyses are summarized in Kalaitzandonakes (2003) and in Santaniel, Evenson, and Zilberman (2002). Recent studies have explored welfare considering intellectual property protection regimes using a model that simultaneously determines equilibrium in seeds, research, and final product (Lence et al., 2005), and examining differentiation and identity preservation in the case of corn (Lence and Hayes, 2005). Lavoie and Sheldon (2000) evaluated the dynamics of the structure of the agbiotechnology industry using real options. Few studies have explicitly modeled trait commercialization strategies—i.e., whether to license a trait to other firms and/or whether to acquire a seed firm and market the trait through own-varieties. These include a recent study in the biopharmaceutical sector which investigated commercialization strategies through use of a survey (Kollmer and Dowling, 2004), a survey of Argentine cotton growers to analyze technology price (Qaim and deJanvry, 2003), and an assessment of the impact of piracy on protection of intellectual property in seeds (Burton et al., 2005).

Several related studies have been conducted with focus on the case of GM wheat. Some recent studies have quantified the prospective welfare distribution of introducing a GM trait in wheat (Wilson et al., 2008; Berwald, Carter, and Gruère, 2006; Furtan, Gray, and Holzman, 2005; Johnson, Lin, and Vocke, 2005). Assumptions about technology prices varied across investigations and, with the exception of Furtan, Gray, and Holzman, the studies assumed these as exogenous.

Our study differs and extends the literature. We specifically analyze firms' strategies about commercializing traits. These encompass licensing and seed firm acquisition by agbiotechnology firms and stacking decisions by seed firms. Once an innovator acquires an intellectual property right (IPR) for an invention, it can be commercialized in several ways. Alternatives include choosing to produce it internally through acquisition of a seed firm or to license it for a fee or royalty.

Licensing and Trait Stacking

Licensing agreements are used between agbiotechnology and seed firms and organizations to facilitate research and commercialization of GM traits. A research agreement gives a seed firm the right to use a trait in its variety development portfolio, but does not allow the seed firm to produce and sell the seed and trait commercially. Once a trait is ready to be commercialized, the agbiotechnology firm enters a commercial licensing agreement (normally referred to as a commercialization agreement) with seed firms (or organizations) and receives royalties from the sale of its traits by seed firms. Licensing agreements are the mechanisms for executing commercialization. There are no regulations or generic legal provisions that impact decisions of firms' stacking traits. These would all be governed by contract law embedded in the licensing agreement.

Trait stacking involves inserting multiple GM traits into a single variety. Companies may choose to stack their own traits into their own varieties (if they own a seed firm) and/or to license them out (out-license) to other seed firms or to other agbiotechnology companies.[1] It is common for traits of one firm to be stacked by a seed company with traits of another agbiotechnology firm. Numerous examples illustrating trait stacking can be observed. For instance, Pioneer HiBred International currently in-licenses the RR trait licensed from Monsanto and Herculex from Dow; Mycogen Seeds has a new "quad stack corn hybrid" that includes Heculex, RR, and LibertyLink,[2] and a recent agreement allows stacking of RR and Herculex by Dow.[3] Other seed companies do this as well (personal communication with Syngenta). A recent example is DuPont and Syngenta who formed a venture to "out-license seed genetics and biotech traits."[4]

Any restrictions applicable to stacking traits would occur through the licensing agreement. Two companies may have an agreement to share traits, and in such an agreement it would be typical to stipulate that they be the only licensees. Restrictions placed on stacking by a seed company are not common, due primarily to the fact that biotechnology companies have more value in making their traits broadly available. As an example, each of the major biotechnology companies puts their traits in their own germplasm, but also out-licenses them to other seed companies.

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[1] Material in this section is taken from interviews with Jay Schuler, Director for Seeds 2000, and Dale Zetocha, Executive Director of the North Dakota State University Research Foundation, in March/April 2004, and with attorneys and strategy analysts at each of the different agbiotechnology companies. In addition, see Fraley (2006) and recent annual reports by Monsanto, Syngenta, and others, each of which discuss trait stacking.

[2] See Mycogen Seeds (2006).

[3] See Monsanto (2006a) and National Grain and Feed Association (2006).

[4] Specifically, DuPont and Syngenta formed a joint venture and licensing agreement to out-license genetics by offering corn and soybean breeding material from both companies, and will facilitate licensing their biotech traits. The two companies will cross-license some traits that each company will market independently under its own seed brands. The agreement provides the right to Syngenta to market the Optimum GAT herbicide-tolerant trait that was developed by DuPont. Syngenta also licensed its insect-resistance technology for European corn borer, rootworm, and broad lepidopteran control to DuPont. Through the agreement, DuPont will also provide other seed companies access to its plant genetics. Prior to this agreement, Pioneer (owned by DuPont) only sold through its own name. Though a competitor, both Pioneer and Syngenta had licensing agreements with Monsanto on RRW which allowed them to insert it into their own varieties. Monsanto has gained market share due to its licensing of herbicide and insect-resistant crop genes to other seed companies.

Traditionally, stacked varieties have contained two traits. Use of herbicide-tolerant (HT) and insect-resistant (IR) stacked traits in corn and cotton has increased since their commercialization. Monsanto now offers a triple-trait stacked corn variety containing YieldGard® Plus (two traits to control corn borer and rootworm), as well as Roundup Ready® Corn 2 (*Agweek* staff, 2004). Indeed, Monsanto concluded that stacking traits is a critical element of its commercial strategies (Monsanto, 2006b) and, as stated in Monsanto's 2004 annual report, the company is "offering more stacked-trait products this year than ever before" (Monsanto, 2004b, p. 2). More recently, Monsanto has announced "Smart Stacks" which would contain eight traits and would be the new platform for commercialization commencing in 2010.

There are numerous issues that impact these relationships. Most important are distinctions between a company that stacks traits in its own germplasm versus out-licensing (examples of each exist), inter-agbiotechnology firm agreements allowing stacking, and whether the traits are complementary versus competitive. While it would be rare for restrictions to be placed on complementary traits, restrictions on competing traits are more common. Traits are licensed individually to seed firms, not as a stacked bundle. Mechanisms involved in stacking traits vary. It is up to the seed firm to determine if the value of a variety stacked with two separately owned traits is sufficient, given that prices for traits are additive.

Seed firms select traits that best complement their varieties. Most seed firms have different GM varieties under development. It is not uncommon for a seed firm to have corn available in conventional, HT, IR, and HT/IR stacked varieties. Agbiotechnology firms have typically not restricted stacking of traits with those from rival providers (at least to our knowledge), since the purpose is to promote the adoption of the trait as widely as possible.

Finally, in the case of wheat, the issue is also about public varieties developed at universities, which control the vast majority of germplasm. Moreover, the RRW and FRW traits, although produced by competing agbiotechnology firms, would be complementary—due in part to the positive correlation between weed pressures and pressures from the vomitoxin disease (about 0.45). In this case, it would be unlikely that an agbiotechnology company would want to restrict the complementary trait. Further, each of the companies has indicated they would license their traits to breeding organizations (mostly public) and have not imposed any such restriction (Sears, 2006). A drought-tolerant trait is currently under development and would also be a prospective candidate to be stacked with other traits.

Mergers and Acquisitions in Agbiotechnology

The vertical relationship between seed and agbiotechnology firms and the process by which GM technology can be transferred from the innovator to downstream firms is important (Lemarie and Ramani, 2003). The agbiotechnology firm can commercialize a trait by issuing an exclusive license to one downstream seed firm or by issuing a nonexclusive license to numerous downstream firms. Because traits need to be transferred into varieties in order to be sold, the success of agbiotechnology firms hinges on seed firms' decisions. For these reasons, a wave of mergers and acquisitions occurred in the U.S. crop seed sector in the second half of the 1990s, resulting in a major change in the structure of these industries. Rausser, Scotchmer, and Simon (1999) identified motivations associated with mergers in the crop seed sector, including to exploit complementarities of assets, to internalize spillovers, or to circumvent the impossibility of issuing complete and contingent contracts. Lemarie and Ramani (2003) focused on the first of these motivations and found that the final form of vertical control accompanying commercialization of GM seeds is greatly influenced by final market demand.

Agbiotechnology firms began purchasing seed firms because of the presumed need to own a seed firm as a mechanism for the sale of trait innovations (Chataway and Tait, 2000). Coinciding with the first GM traits, agbiotechnology firms purchased seed firms that were leaders in corn and soybean sales, but acquisitions of seed firms did not stop agbiotechnology firms from further licensing their GM traits to independent seed firms. For example, Monsanto acquired Dekalb Genetics Corporation (Cargill's international seed business) and Plant Breeding International Cambridge, Ltd., while still licensing its traits to independent seed firms such as Pioneer and Golden Harvest (Chataway and Tait, 2000; Lemarie and Ramani, 2003); DuPont purchased Pioneer Hi-Bred; Monsanto also acquired Asgrow (Kalaitzandonakes and Hayenga, 2000; Fernandez-Cornejo, 2004), Channel Bio Corporation (owner of two Iowa seed companies), Seminis, Inc. (Monsanto, 2005), and Emergent (the third largest cotton seed company in the United States with two brands in India), thereby allowing Monsanto to model its brands and licensing strategy in cotton similar to its strategies for corn and soybeans (Howie, 2005). A listing (selected) of Monsanto's acquisitions is contained in Bell and Shelman (2006, p. 23). Monsanto claims that it pioneered the "seeds and trait" evolution, which has been a pillar for its strategy and is now being adapted by rivals (Monsanto, 2004b, p. 1).

Of direct interest in this study is that Syngenta and Fox Paine purchased Advanta BV (Syngenta, 2004). Through this acquisition, Syngenta obtained Advanta's North American corn and soybean business (trading under the Garst brand name) and AgriPro Wheat, the largest private-sector wheat-breeding firm in North America. This acquisition gives Syngenta potential commercialization strategies for its GM corn, soybeans, and, possibly, wheat traits.

Strategic Games for Commercializing GM Wheat Traits

In industries with few players, actions of one player impact the price and profits of rivals. Consequently, players consider actions of other players in making strategic decisions. A game theory model was developed in this study to analyze equilibrium strategies about trait commercialization. To do so requires prices for GM traits, but since these traits have not been commercialized, their prices are not available. Thus, we derived prices for the GM traits from an equilibrium model of the input market based on Huso and Wilson (2006). This model was applied to RRW and builds upon an earlier formulation by Lemarie and Marette (2003). In addition to deriving prices for RRW, that model was extended and applied to FRW, which has a different grower utility function. The equilibrium relationships were used, along with data distributions and several assumptions, to derive prices for GM traits. The resulting prices were incorporated as inputs in the game theory model on trait commercialization strategies.

Below, we first describe the input model used to derive equilibrium trait prices, and then we specify the logic and data of the game theory model in the section to follow.

Input Trait Market

The input pricing models were used to obtain trait prices for each of the two GM traits proposed in wheat.[5] The logic of the input pricing equilibrium is as follows. The biotechnology firm develops a trait and determines a profit-maximizing technology fee for its GM trait. Inputs include market size, idiosyncratic characteristics of growers, efficiency gains from the trait, and market structure (number of agbiotechnology firms and firms producing conventional treatments). In period 1, the biotechnology firm determines the license price; and in period 2, firm(s) producing conventional chemicals and agbiotechnology firm(s) that bundle GM seed and chemical sales identify the quantities to produce assuming Cournot competition. In period 3, farmers determine quantities of these inputs to purchase. Once these input firms (conventional chemical supplier and agbiotechnology firms) commit to a quantity, these firms set the price to clear the market. Because price depends on production of both input firms, quantity produced by one depends on how much it expects its competitor to produce, and vice versa.

In the input market model, weed control can employ conventional post-emergent herbicides or a bundle or RRW seed plus burndown herbicides. Similarly, fusarium head blight (which was not modeled in Huso and Wilson) is a disease that can be controlled using a fungicide spray or GM FRW seeds. The price of the technology fee (sometimes referred to as a license fee, or royalty) is the instrument by which technology firms are compensated for their investment in the research and development.

Technology choices are indexed by i; $i = 0$ refers to a conventional plant protection solution and $i = 1$ refers to a GM plant protection solution. Technology choice i is supplied by n_i firm(s) which compete(s) on quantity. For each technology, the marginal production cost is c_i and the price is p_i (both expressed in \$/lb.). Conventional and GM inputs are both assumed to be produced with a constant unit cost ($c_0 = c_1$). This assumption aids in explicitly modeling innovations that take the form of vertically differentiated inputs (e.g., a more productive seed variety). Since we don't observe these costs, for simplicity we assume these to be nil, as is common in other studies in this sector (e.g., Lapan and Moschini, 2000).[6]

In the RR seed technology, the farmer pays both the price of the burndown herbicide (p_1) and the royalty for GM seed (p_{LRR}). In the FR case, the farmer pays the GM seed premium (p_{LFR}) only. The royalty is decided by the agbiotechnology firm, which is assumed to have a monopoly for the GM trait.

The farmer's choice between the different plant protection solutions is made on a per acre basis. The efficiency for technology choice i is x_i, with $x_1 > x_0$. Farmers are assumed heterogeneous, and each has a willingness to pay equal to θx_i for technology choice i, where θ represents individual pesticide demand or the intensity of production problems for each farmer, and θ is assumed uniformly distributed between 0 and 1. For the RR technology, a farmer with highly intensive weed pressures corresponds to a θ close to 1, while those with less weed pressure correspond to a θ close to 0. Use of technology choice i (at the required per acre dosage of each technology choice, a_i) provides an indirect utility of u_i. The indirect utilities are written as:

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[5] The complete model specification is shown in the appendix, and a more thorough derivation is given in Huso and Wilson (2005).

[6] Specifically, Lapan and Moschini (2000, footnote 6) indicate this assumption simplifies the analysis.

$$(1)\qquad \begin{cases} u_0 = \theta x_0 - a_0 p_0, \\ u_1 = \theta x_1 - a_1 p_1 - p_{LRR}. \end{cases}$$

The farmer selects the technology with the highest indirect utility (i.e., GM will be adopted if $u_1 > u_0$). If the indirect utility for all choices is negative for a given θ, then no product is purchased. The total number of farmers by acreage is denoted by N.

The model is solved for two competing plant protection solutions—conventional and GM. The price of the GM technology includes a seed price p_L (for simplicity we will refer to p_{LRR} as p_L) plus the cost of a GM-chemical combination, represented by $p_L + p_1$. A farmer who is indifferent (i.e., receives the same utility) between the technology choices 0 and 1 is denoted by $\tilde{\theta}$. Technology choice 1 is used by a farmer with $\theta > \tilde{\theta}$, while technology choice 0 is used by the farmer with θ such that $\hat{\theta} < \theta < \tilde{\theta}$. Because θ is assumed $U[0, 1]$, the demand functions for technology choices 0 and 1 are expressed as:

$$(2)\qquad Q_0 = Na_0(\tilde{\theta} - \hat{\theta})$$

and

$$(3)\qquad Q_1 = Na_1(1 - \tilde{\theta}).$$

Since $\tilde{\theta}$ denotes a farmer who has equal utility from either product ($u_0 = u_1$), then

$$(4)\qquad \tilde{\theta} = \frac{a_1 p_1 + p_L - a_0 p_0}{x_1 - x_0}.$$

These relations are solved for the inverse demand functions for the two technology choices. Substituting the inverse demand functions into a profit function and maximizing profit for the n_0 and n_1 sellers under a symmetric Cournot-Nash equilibrium leads to first-order conditions. These can be solved to determine equilibrium quantities and prices for each technology choice. Equation (5) is the equilibrium price of the complementary pesticide needed in technology choice 1:

$$(5)\qquad p_1^*(p_L) = \frac{\left\{ \begin{array}{c} x_1\big(x_1 + a_0 c_0 n_0 - x_0 n_0 + x_1 n_0\big) \\ -a_1\big(p_L x_1 (n_0 + 1) - c_1 (x_1 - x_0 n_0 + x_1 n_0) n_1\big) \end{array} \right\}}{a_1\big(-x_0 n_0 n_1 + x_1 (n_0 + 1)(n_1 + 1)\big)}.$$

If two companies supply technology choice 1 ($n_1 = 2$), one firm is the agbiotechnology firm providing the GM trait while selling the complementary pesticide, and the other only sells a competitive complementary pesticide. The firm selling only the complementary pesticide does not gain profit from the GM trait itself, but only from the sale of the complementary pesticide.

Equilibrium prices and quantities determine firm profits, calculated as:

$$(6)\qquad \pi_1^*(p_L) = \frac{N x_1\big(x_1 + a_0 c_0 n_0 - x_0 n_0 + x_1 n_0 - a_1 (c_1 + p_L)(n_0 + 1)\big)^2}{\big(x_0 n_0 n_1 - x_1 (n_0 + 1)(n_1 + 1)\big)^2}.$$

The agbiotechnology firm gains profit from both the sale of complementary pesticides to its GM traits, and from the license price received from the sale of GM seeds, p_L. Profit maximization for the agbiotechnology firm with respect to p_L gives the equilibrium royalty p_L^* in equation (7) which depends on the efficiency of each technology choice (x_0 and x_1), among others:

$$p_L^* = \frac{\left\{ \begin{array}{l} \left(x_1 + a_0c_0n_0 - x_0n_0 + x_1n_0 - a_1c_1(n_0+1)\right) \\ \times\left(-x_0n_0n_1^2 + x_1(n_0+1)(-2+n_1+n_1^2)\right) \end{array} \right\}}{2a_1(n_0+1)\left(-x_0n_0n_1^2 + x_1(n_0+1)(-1+n_1+n_1^2)\right)}. \tag{7}$$

The Huso and Wilson (2006) model was extended to account for a trait in which a complementary pesticide is not required as in FRW. In this case, a farmer purchasing technology choice 1 pays only the royalty, p_{LFR}, and the growers' indirect utilities are:

$$\begin{cases} u_0 = \theta x_0 - a_0p_0, \\ u_1 = \theta x_1 - p_{LFR}, \end{cases} \tag{8}$$

which differ because a complementary product is not needed. Equilibrium quantities, prices (hereafter referred to as p_L), and profits are derived similarly, yielding the following equilibrium royalty for the technology:

$$p_L^* = \frac{x_1^2(n_0+1) - c_1x_0n_0n_1 + x_1(a_0c_0n_0 - x_0n_0 + c_1n_1 + c_1n_0n_1)}{\left(-x_0n_0n_1 + x_1(n_0+1)(n_1+1)\right)}. \tag{9}$$

The price of technology choice 1 is now only the royalty. The equilibrium prices used to derive payoffs in our game theory model below are those in equations (7) and (9) for RRW and FRW, respectively.

Data Distributions and Assumptions

Adoption rates were approximated using data on geographical weed pressure and fusarium head blight (FHB) infestations. Specifically, adoption rates for each variety were determined based on geographical weed and FHB infestations relative to economic thresholds (as suggested by Extension weed and disease specialists, respectively). Two statewide weed surveys in North Dakota (ND) were conducted in 2000 by Zollinger, Ries, and Hammond (2003) to determine the population and distribution of weed species. "Weed frequency" was defined as "the percentage of fields surveyed that contained the weed in one or more of the ten 0.25 m^2 sample quadrants" (p. 2). Wild oats and buckwheat were selected as problem weeds, meaning that between the two weeds, the higher frequency assumed the number of acres in the county that would potentially adopt the RRW variety. FHB infestation data were taken from Nganje et al. (2001). Yield loss due to FHB was estimated for each county within the Crop Reporting District. For either weed frequency or FHB, if the loss exceeded the economic threshold, it was assumed treatment would be applied. If a county was a candidate for both RRW and GM FRW adoption, the lower of the two values was assumed to be the adoption level of a stacked variety. This method was applied to each county to determine RRW, GM FRW, stacked, and conventional acres. We then summed over counties to obtain the total number of acres planted to each technology from which geographical adoption rates were derived.

Table 1. Base Case Assumptions: Payoffs and Adoption Rates

A. Payoffs for Agbiotechnology and Seed Firm

	N (millions)	$p_{L(A)}$ (\$/acre)	$p_{L(B)} + p_1$ (\$/acre)	p_S (\$/acre)	Payoff (\$ millions)
π_A	6.65	12.35			82
π_B	6.65		11.33		75
π_S	6.65			9.54	63

B. Equilibrium Adoption Rates on HRS Acres Under Different Market Regimes

Available Varieties	Conventional	RRW	GM FRW	Stacked
Conventional Only	100%	NA	NA	NA
Conventional + RRW	50%	50%	NA	NA
Conventional + GM FRW	35%	NA	65%	NA
Conventional, RRW, GM FRW, Stacked	15%	20%	34%	31%

Source: Derived from Huso and Wilson (2005).

Using the above formulae for the trait prices and the above data, payoffs were defined for each player. Payoffs for technology firm A producing GM FRW are $\pi_A = N*P_{LFR}$, where N is the number of HRS acres planted in ND, and P_{LFR} is the per acre technology fee for GM FRW. Similarly, for firms producing GM RRW, firm B, the payoffs are given by $\pi_B = N*(P_{LRR} + P_1)$, where P_{LRR} is the per acre tech fee for RRW and p_1 is the \$/lb. of the complementary glyphosate herbicide (assuming an application rate of 1 lb./acre). Payoffs for the seed firm or organization were determined by $\pi_S = N*p_S$, where p_S is the average price of HRS seed per acre. Per acre values were derived using results from equations (7) and (9), respectively, for RRW and FRW, along with the assumptions below. The average per acre HRS seed cost was taken from Fernandez-Cornejo (2004). Average HRS acres in ND were derived from the USDA's National Agricultural Statistics Service (NASS) (2004). The resulting values were calibrated and consistent with those suggested by the biotech industry during negotiations and discussions with grower groups. Payoffs and adoption rates are shown in table 1.

Game Theory Model of Trait and Commercialization Strategies

A game theory model was specified to analyze equilibrium strategies about trait commercialization decisions. Players are agbiotechnology firms, seed companies, and growers. Another player, "nature," was included to account for uncertainty on adoption rates, which is a function, in part, of market acceptance. When outcomes are uncertain, nature determines the probability of each outcome. This type of game has a mixed strategy equilibrium where "a mixed strategy for a player is the act of selecting a strategy according to a probability distribution" (Watson, 2002, p. 38). A mixed strategy means that the player may choose one pure strategy with probability γ, and the other with probability $1-\gamma$. In the trait commercialization game, a mixed strategy may exist because of uncertainties related to farmer adoption and market acceptance. The uncertainty in a mixed strategy is evaluated by weighing the payoffs of each pure strategy by the probability with which that strategy is played (Dutta, 1999).

This is interpreted as a sequential move game in which players make their strategy decisions sequentially. Order of play is important in that one player can impact or change the other player's preferred strategy. In order for an advantage to exist, there must be a credible commitment by the player with the advantage. Specifically, the first mover must make a credible threat to alter its payoffs in order to induce the second player to choose a strategy that is more desirable for the first player.

A seed firm or organization that enters licensing agreements with two different traits and stacks them into one variety is engaged in vertical differentiation. Two models are used to illustrate potential strategic issues in trait commercialization. Both include trait commercialization decisions by each agbiotechnology firm and a variety release decision by the seed firm. The first game allows licensing to seed firms. The second game additionally allows the agbiotechnology firm to purchase a seed breeding firm. *Gambit* was used to determine the equilibrium because of its ability to incorporate uncertainty and derive mixed strategy equilibriums (McKelvey, McLennan, and Turocy, 2004).

■ Model I. Entry via Licensing Only

In model I, two agbiotechnology firms, A and B, seek to determine if they should license their GM traits to seed firms. Firms A and B own the GM FRW and RRW traits, respectively. Because of Monsanto's decision to defer RRW, the order of play is clear. Firm A moves first and decides whether or not to license the GM FRW trait to seed firms or organizations. Firm B observes A's decision and chooses whether or not to license the RRW trait to seed firms. Based on the decisions of the agbiotechnology firms and the potential adoption rates by farmers, the seed firm then determines which variety(ies) to produce.

The base case assumes the profit-maximizing technology fees from the input equilibrium model described above. Payoffs for the sale of its GM trait or seed and the base case adoption rates account for uncertainty in the firm's expected payoffs (see table 1). If a conventional variety is released, only the seed firm would realize payoffs. If a GM variety is released, the agbiotechnology firm receives payoffs from the sale of its trait, and the seed firm receives payoffs from the sale of the seed. The value of the seed, in addition to the value of the GM trait, is constant across conventional and GM varieties.

Figure 1 shows the game tree. Firm A decides whether or not to license, and firm B makes a similar decision. Depending on the licensing decisions of the agbiotechnology firms, the seed firm decides which varieties to release. The final move is by "nature," which determines the probabilities of adoption (from table 1).

The equilibrium consists of pure and mixed strategies for the agbiotechnology and seed firms, resulting in a mixed strategy sequential equilibrium as summarized in table 2. Interpretation of the equilibrium is as follows. Firm A's strategy is to license GM FRW to seed firms with probability 1.0, and B licenses RRW with probability 0.96. If B licenses, the seed firm's strategy is to sell a stacked variety with probability 0.17 and sell a GM FRW variety with probability 0.83; however, if B does not license, the seed firm's strategy is to sell a GM FRW variety with probability 1.0. The mixed strategy sequential equilibrium is a result of the uncertainty in adoption by farmers based on geographic distribution of weeds and FHB. GM FRW and stacked varieties are the only two produced by seed firms because of the high payoffs due to higher adoption rates—34% and 31%, respectively. RRW and conventional varieties have adoption rates of 20%

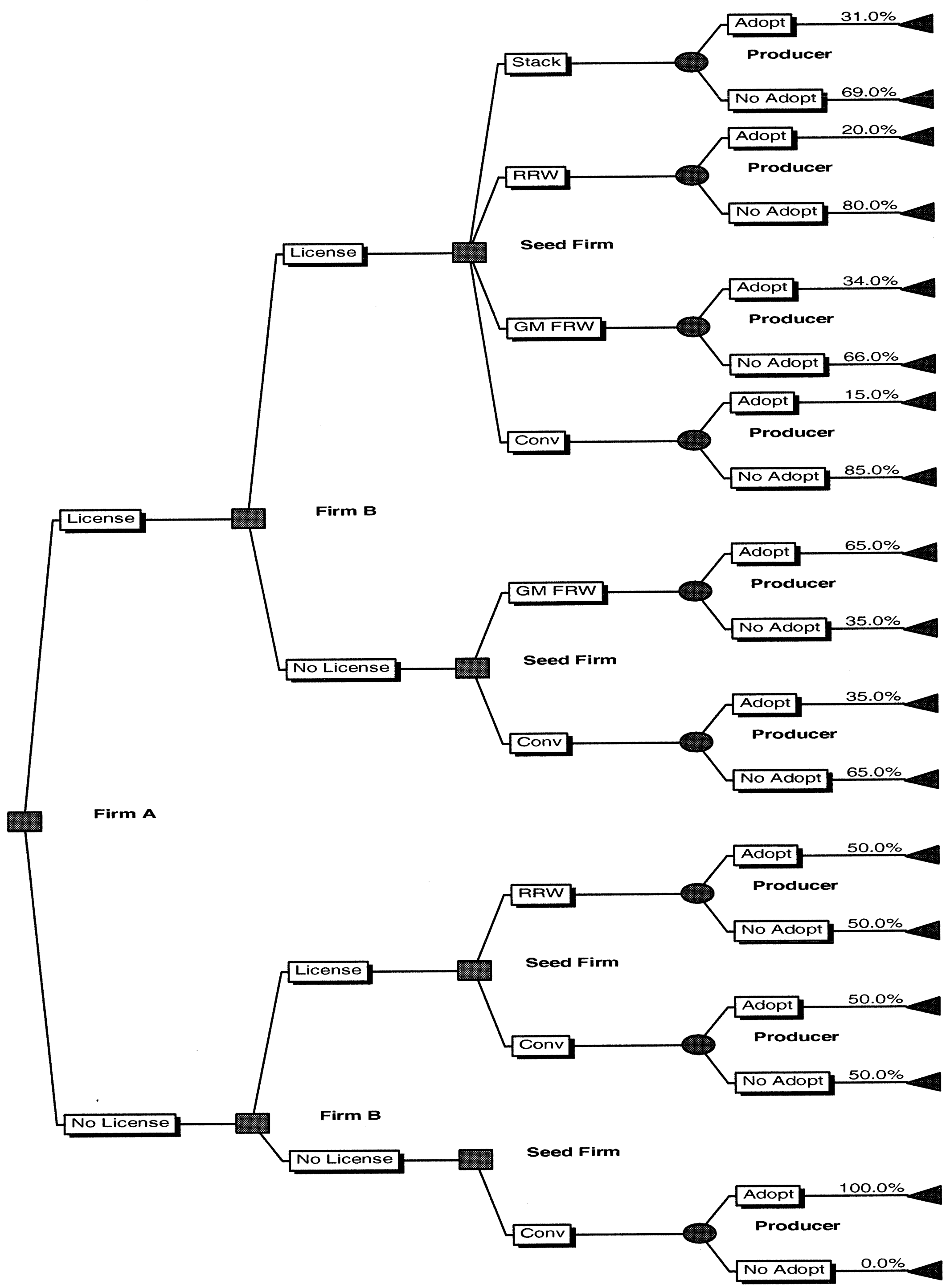

Figure 1. Model I: GM wheat trait-stacking/licensing game

Table 2. Model I: Base Case Results

	Firm A Strategy		Firm B Strategy		Seed Firm Strategy			
	License	No License	License	No License	Conv	RRW	GM FRW	Stacked
Base Case: *A moves first*	1.00		0.96	0.04			0.83	0.17
Change in the Order of Play: *B moves first*	1.00		0.50	0.50			1.00	

and 15%, respectively. Seed firms choose to produce the combination of varieties with the highest payoffs which are determined in part by adoption rates.

The base case assumes firm A has the first play with GM FRW because of Monsanto's announcement of deferring the commercialization of RRW until another agbiotechnology firm commercializes a GM wheat trait. To illustrate the strategic impacts of this play sequence, the order of play was changed so that firm B moved first, followed by A. The resulting equilibrium strategy is as follows. Firm B would license its RRW trait with probability 0.50, A's pure strategy is to license regardless of B's move, and the seed firm chooses to produce the GM FRW variety irrespective of B's strategy. The seed firm chooses to produce GM FRW if the trait is licensed because of the higher percentage of adoption of GM FRW. Firm A chooses to license its GM FRW technology. Because of the seed firm's strategy of producing GM FRW, B is indifferent between licensing and not licensing.

The results differ from the base case in that firm B is indifferent between licensing and not licensing because it is unable to observe the move by firm A. The reason for B's indifference is the lower projected adoption rate of RRW relative to GM FRW. Because of the uncertainty of whether B will license, the seed firm produces GM FRW with probability 1.0 because of higher expected payoffs. These results may explain why Monsanto deferred commercialization of RRW. Because of the higher expected payoffs, the seed firm chooses to sell GM FRW, thereby reducing the incentive to commercialize RRW. However, if GM FRW were released prior to Monsanto's decision, the seed firm would sell a combination of GM FRW and stacked varieties, making it more appealing for Monsanto to release RRW.

■ Model II. Purchasing a Seed Firm for Trait Commercialization

A strategy alternative is the acquisition of a seed firm through which traits can be commercialized. In our case, we want to explore the prospect of one of the agbiotechnology companies acquiring a seed firm. Of interest is Syngenta's purchase of AgriPro through its acquisition of Advanta BV (Syngenta, 2004), the largest private-sector wheat-breeding firm in North America. This gives Syngenta strategic options for its commercialization strategy which was incorporated into the game theory model. Firm A now has the option to release its GM trait through a license to an independent seed company and/or through its own firm due to the purchase of a seed firm. In fact, Syngenta has since indicated it would out-license to outside seed firms and organizations if it chooses to license or not license (Sears, 2006).

Firm A's payoffs are the same as those defined in model I. If it chooses to purchase a seed firm, its payoffs change. Firm A benefits not only from the sale of its GM FRW

Table 3. Payoffs to Agbiotechnology and Seed Firms ($ millions)

	Conventional	GM FRW	RRW	Stacked
π_A	8	144	62	144
π_B			75	75
π_S	63	63	63	63

trait, but also from the sale of conventional wheat varieties. B's payoffs remain unchanged from the first model. If A purchases a seed firm, B's decision to license means that it licenses the RRW trait to all seed firms, but only A's seed firm will be able to produce a stacked variety. Thus, if A purchases a seed firm, it has a monopoly position with respect to the sale of GM FRW and stacked varieties. It does not license its GM FRW technology to other seed firms when purchasing a seed firm. The possibility of simultaneous strategies of purchasing and licensing was not considered because of the high uncertainty regarding competition and share of seed sales.

Detailed financial data on acquisition costs of seed firms are not publicly available. Hence, these were approximated from data garnered through conversations with seed industry representatives. Total annual cost of operating a seed firm was assumed uniformly distributed between $400,000 and $500,000, and revenues were uniformly distributed between $1 and $1.5 million. A private variety is typically priced $1.00 to $1.50/bushel higher than public varieties and, assuming 15% of total HRS wheat acres planted were a privately bred variety, total revenue from the sale of private HRS wheat varieties was between $1 and $1.5 million. Average total seed cost was $9.54/acre; however, much of this revenue covers the production cost of bulk seed producers, while the private breeding firm receives the royalty as revenue. Using these values and assuming a discount rate of 7%, the net present value of a seed firm was determined to be $11.5 million. Thus, the value to A of a seed firm for the purposes of commercializing a GM HRS wheat trait was $11.5 million, implying an opportunity cost of capital (evaluated at 10 years and 7%) of $1.6 million per year. Payoffs under the new strategy of A are reported in table 3.

If a conventional variety were released, firm A gains 15% of the HRS wheat seed revenue less the annual cost of operating a seed firm. The payoff to the seed firm does not change because A is now in the seed industry. If a GM FRW variety were released, firm A's payoff includes the revenue from the technology fee, along with the revenue from seed sales, less the cost of purchasing a seed firm. If A purchases a seed firm, the only mode of commercialization for GM FRW and stacked varieties is through A. Hence, firm A gains the potential revenue from seed sales if the variety is GM.

The payoff to the seed firm remains constant, but A now has a share of the seed industry. If RRW or conventional varieties were released, A's payoff reflects 15% of seed sales, less the cost of purchasing the seed firm. Firm B's payoff is the total potential revenue from the technology fee, plus the herbicide cost. Again, the seed firm's payoff is constant. Finally, a stacked variety yields a payoff to A that includes the total potential seed value and the technology fee, less the cost of purchasing the seed firm. The stacked variety also provides a payoff for B that includes revenue from its technology fee, plus the herbicide cost.

Table 4. Model II: Base Case Results

Firm A Strategy			Firm B Strategy			Seed Firm Strategy		
Purchase Seed Firm	License	No License	License	No License	Conventional	RRW	GM FRW	Stacked
1.00			0.96	0.04		0.01	0.70	0.29

The base case of model II encompasses model I and a third strategy for A of purchasing a seed firm. If A purchases a seed firm, B has the choice to license or not license its RRW technology. If B licenses, A's seed firm can release GM FRW, RRW, or a stacked variety. Other seed firms are able to produce an RRW variety. Also, firm A, as well as other seed firms in the industry, can release a conventional variety. Other seed firms cannot produce a stacked or GM FRW variety because they do not receive a license from A for the GM FRW technology. If B chooses not to license, A (acting as the sole seed provider) can produce GM FRW or can produce a conventional variety along with all other wheat seed firms.

The mixed strategy sequential equilibrium (table 4) is described as follows. Firm A would purchase a seed firm with probability 1.00; B would license its RRW trait with probability 0.96 and not license with probability 0.04. If B licenses its trait, A would use its seed firm to produce GM FRW with probability 0.70 and stacked RRW/GM FRW with probability 0.29. The seed industry would produce an RRW variety with probability 0.01. If firm B does not license, A would produce the GM FRW variety with probability 1.00.

Firm A has three plays (license, no license, and purchase a seed firm) and chooses to purchase a seed firm rather than license its GM FRW technology because of its increased payoffs resulting from owning a seed firm. With this strategy, A now gains payoffs from the sale of the seed, along with its GM FRW technology. The combination of higher adoption rates for GM FRW and stacked varieties, along with the low annual cost of owning a seed firm, also contributes to A's equilibrium strategy of GM trait introduction by purchasing the seed firm.

In model I, firm A chose to license its technology to seed firms because its two strategies were to license or not license. The inclusion of the third strategy of purchasing a seed firm gives A more options. In model II, the cost of owning the seed firm makes it conducive for A to choose this as its equilibrium strategy. This difference illustrates that purchasing a seed firm may be more attractive than licensing a GM trait, given a lower cost of operating the seed firm.

Because of the lack of historical data relating to trait stacking and licensing of GM wheat varieties, data from the input price equilibrium model and surveys on weed and FHB infestations, along with industry averages, were used to develop a likely situation as represented in the base case. Since this is highly stylistic, sensitivities were conducted on the cost of owning a seed firm to illustrate different possible scenarios and the equilibrium strategies resulting from each.

The base case used an annual opportunity cost of operating a seed firm of $1.6 million per year. Sensitivities were conducted on this value to evaluate changes in equilibrium strategies as the costs of owning a seed firm change. As the cost of the seed firm increases from $5 million to $30 million per year, A's equilibrium strategy moves from purchasing a seed firm to licensing its GM FRW technology to other seed firms (see figure 2).

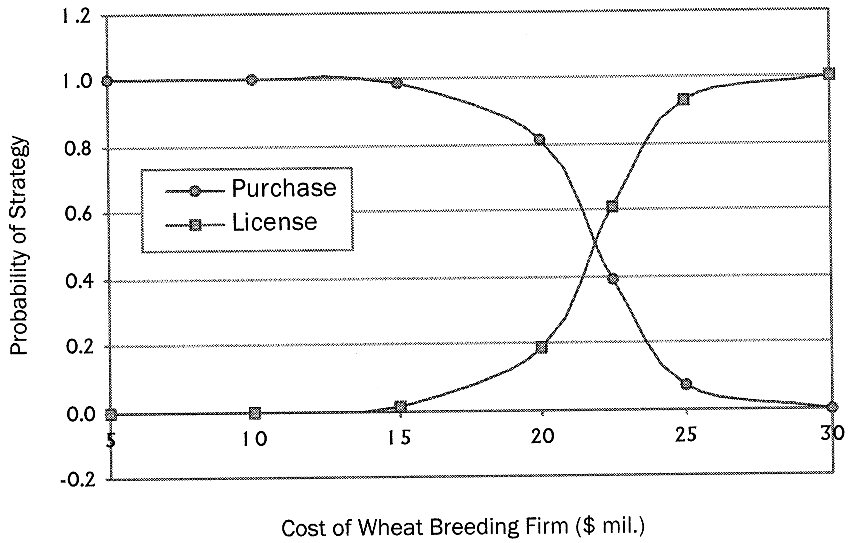

Figure 2. Change in firm A's entry strategy as the cost of purchasing a seed firm increases

At a cost of $15 million, A's strategy is to purchase a seed firm with probability 0.99 and license its technology with probability 0.01. At a cost of $20 million, A's strategy is to purchase a seed firm with probability 0.81 and license with probability 0.19. At $22.5 million, A's strategy is to purchase a seed firm with probability 0.39 and to license with probability 0.61. B's payoffs do not change regardless of A's strategy.

As the cost of acquiring the seed firm increases, the production decisions of seed firms also change. If B does not license its RRW technology to A, all seed firms (firm A + other seed firms) continue to produce GM FRW with probability 1.00 as the costs of purchasing a seed firm increase. If B licenses its RRW technology to A, the production mix of HRS wheat varieties changes as the cost of the seed firm increases.

At a cost of $5 million, A's seed firm will produce a GM FRW variety with probability 0.72, a stacked variety with probability 0.27, and an RRW variety with probability 0.01. At a cost of $20 million, A's seed firm will produce a GM FRW variety with probability 0.82 and a stacked variety with probability 0.18. At a cost of $30 million, A's seed firm will produce a GM FRW variety with probability 0.84 and a stacked variety with probability 0.16. The production mix of HRS wheat varieties changes because as the cost of purchasing a seed firm increases, firm A chooses to produce more of the GM FRW, which has a greater adoption rate than RRW or a stacked variety.

Summary

Commercialization of GM traits leads to strategic questions for agbiotechnology and seed firms. These include the mode of trait commercialization—i.e., whether to license their traits to seed firms, and/or whether to purchase a seed firm. Seed firms must decide which traits to acquire and which varieties to produce and sell to farmers. The purpose of this study was to evaluate equilibrium strategies for commercialization of GM traits by agbiotechnology and seed firms. Two game theory models were developed.

In the first, both agbiotechnology firms had commercialization strategies of licensing and not licensing. In the second model, the agbiotechnology firm was allowed to have a strategic option to purchase a seed firm as a commercialization strategy. These decisions are highly strategic. There are few studies examining trait commercialization and stacking in the literature despite the fact that these are becoming essential strategic alternatives in the rapidly changing seeds and traits industry. Our models were applied to the case of RRW and FRW HRS wheat, although the general structure of the models could be used to analyze other crops and traits.

Results are specific to the stylized specification of the games. A few of the results are of particular interest. First, both agbiotechnolgy firms would license their technology, and the seed firm would sell a stacked variety with probability 0.17 and a single trait variety with probability 0.83. The mixed strategy sequential equilibrium is a result of the uncertainty of adoption by farmers based on geographic distribution of weeds and FHB. For these reasons, seed firms choose to produce the combination varieties and traits with the highest payoffs, which are determined in part by adoption rates. Second, changing the order of play affects the equilibrium and can be used to explain why Monsanto deferred commercialization of RRW. Specifically, if Monsanto were a follower, the seed firm would sell a combination of GM FRW and stacked varieties, which would make it more appealing for Monsanto to release RRW. A third result of interest is that allowing the agbiotechnology firm to buy a seed firm provides another strategic option for commercialization. These findings show that purchasing a seed firm may be more attractive than licensing a GM trait, given a lower cost of operating the seed firm. As the cost of owning the seed firm increases, the agbiotechnology firm's strategy changes from a deterministic strategy to a mixed strategy of owning a seed firm and licensing its technology. These decisions are strategic and illustrate that equilibriums depend on the numerical values used in the payoff functions.

This study highlights several implications, in both the private and public sectors. The results illustrate strategic outcomes of agbiotechnology and seed firms involved in the commercialization of GM traits. There are two areas of interest related to strategy in this sector and the resulting impacts on industry structure. One is that trait stacking is facilitated by out-licensing, and the other is whether agbiotechnology firms should acquire seed firms. Indeed, we are observing both scenarios in this rapidly changing industry. It is for this reason these industries are evolving from "seeds" to "seeds and traits." Finally, though these results reveal reasons for commercialization through acquisition of seed firms (which has actually occurred for one of the players), the bigger challenge in the case of wheat is that most of the germplasm is controlled by public institutions. In fact, each firm has indicated they would license their traits to breeding organizations (mostly public). In this case, the two traits are complementary, which has an impact on the results. It would be unlikely that an agbiotechnology company would want to restrict the complementary trait.

This article contributes to the agbiotechnology literature by developing a trait commercialization and trait stacking game for modeling strategies. Although the analysis focuses on one crop and two traits, the game provides guidance for possible strategies for new GM traits in wheat near commercialization and can be applied to other GM grains and traits. It also provides a logical explanation for recent observed strategies by firms in this industry and their actions related to wheat in particular. There is a limitation which is a motivation for an extension of this research. It may be of interest to allow three strategies inclusive of licensing (as in model I), purchasing a seed firm (as in model II), and/or to commercialize by both licensing and releasing through the firm's own varieties. We do not have data and information necessary to determine the share of seed sales by variety, inclusive of GM traits, and hence would be unable to derive firm payoffs. For these reasons, our representation in model II is limited but is retained for illustration of the strategic interpretation.

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Appendix: Mathematical Derivation of Essential Equations

This appendix shows the market equilibrium with two competing plant protection solutions and using variable abbreviations from the text unless otherwise noted. First we show the equilibrium for a GM trait requiring a complementary product (as in RRW) and then one not requiring a complementary input (as would apply to FRW).[7]

The price for selecting GM seeds that do not require a complementary pesticide is p_L, and the price of a GM-chemical combination is $p_L + p_1$. A farmer who is indifferent (i.e., receives the same utility) between the technology choices 0 and 1 is denoted by $\tilde{\theta}$. Technology choice 1 is used by a farmer with $\theta > \tilde{\theta}$, while technology choice 0 is used by the farmer with θ such that $\hat{\theta} < \theta < \tilde{\theta}$. Because θ is assumed $U[0, 1]$, the demand functions for technology choices 0 and 1 are:

(A1) $$Q_0 = Na_0(\tilde{\theta} - \hat{\theta})$$

and

(A2) $$Q_1 = Na_1(1 - \tilde{\theta}).$$

Demand functions for the two technology choices are:

(A3) $$Q_0(p_0, p_1, p_L) = Na_0\left(\frac{a_1p_1 + p_L - a_0p_0}{x_1 - x_0} - \frac{a_0p_0}{x_0}\right)$$

and

(A4) $$Q_1(p_0, p_1, p_L) = Na_1\left(1 - \frac{a_1p_1 + p_L - a_0p_0}{x_1 - x_0}\right).$$

Multiplying these by the amount applied per acre (a_0 and a_1, respectively) and N gives the total demand for technology choice 1.

Simultaneously solving these technology choice demand functions for p_0 and p_1 results in the following inverse demand functions:

(A5) $$p_0(Q_0, Q_1, p_L) = \frac{x_0}{a_0}\left(1 - \frac{Q_0}{Na_0} - \frac{Q_1}{Na_1}\right)$$

and

(A6) $$p_1(Q_0, Q_1, p_L) = \frac{x_1}{a_1}\left(1 - \frac{Q_0}{Na_0} \times \frac{x_0}{x_1} - \frac{Q_1}{Na_1}\right) - p_L.$$

Since p_1 represents only the price for the complementary herbicide, the license price for the GM trait (p_L) must be subtracted to determine the price of the herbicide.

Substituting the inverse demand functions into the profit function and maximizing profit for the n_0 and n_1 sellers under a symmetric Cournot-Nash equilibrium leads to the following first-order conditions:

[7] The mathematical equations shown here were solved using *Mathematica* 3.0; a detailed listing of all of the equations and their derivations are shown in Huso and Wilson (2005).

$$\text{(A7)} \qquad \frac{\partial \pi_{0k}}{\partial q_{0k}} = \frac{x_0}{a_0}\left(1 - \frac{(n_0+1)q_0}{Na_0} - \frac{n_1 q_1}{Na_1}\right) - c_0 = 0$$

and

$$\text{(A8)} \qquad \frac{\partial \pi_{1k}}{\partial q_{1k}} = \frac{x_1}{a_1}\left(1 - \frac{n_0 q_0}{Na_0} \times \frac{x_0}{x_1} - \frac{(n_1+1)q_1}{Na_1}\right) - p_L - c_1 = 0,$$

which are solved to obtain equilibrium quantities for sellers of each technology choice. These quantities can then be used to determine the equilibrium prices:

$$\text{(A9)} \qquad p_0^*(p_L) = \frac{a_0 c_0 x_1 n_0 (n_1+1) + x_0\big(x_1 + (a_1 c_1 + a_1 p_L - a_0 c_0 n_0) n_1\big)}{a_0\big(-x_0 n_0 n_1 + x_1(n_0+1)(n_1+1)\big)}$$

and

$$\text{(A10)} \qquad p_1^*(p_L) = \frac{x_1(x_1 + a_0 c_0 n_0 - x_0 n_0 + x_1 n_0) - a_1\big(p_L x_1 (n_0+1) - c_1(x_1 - x_0 n_0 + x_1 n_0) n_1\big)}{a_1\big(-x_0 n_0 n_1 + x_1(n_0+1)(n_1+1)\big)}.$$

Equation (A10) is the equilibrium price of the complementary pesticide needed in technology choice 1.

Equilibrium prices and quantities determine firm profits. Profits for the agbiotechnology firm are calculated as:

$$\text{(A11)} \qquad \pi_1^*(p_L) = \frac{Nx_1\big(x_1 + a_0 c_0 n_0 - x_0 n_0 + x_1 n_0 - a_1(c_1 + p_L)(n_0+1)\big)^2}{\big(x_0 n_0 n_1 - x_1(n_0+1)(n_1+1)\big)^2}.$$

The agbiotechnology firm gains profit from both the sale of complementary pesticides to its GM traits, and from the license price received from the sale of GM seeds, p_L. Profit maximization for the agbiotechnology firm with respect to p_L gives the equilibrium license price p_L^*:

$$\text{(A12)} \qquad p_L^* = \frac{\big(x_1 + a_0 c_0 n_0 - x_0 n_0 + x_1 n_0 - a_1 c_1 (n_0+1)\big)\big(-x_0 n_0 n_1^2 + x_1(n_0+1)(-2 + n_1 + n_1^2)\big)}{2a_1(n_0+1)\big(-x_0 n_0 n_1^2 + x_1(n_0+1)(-1 + n_1 + n_1^2)\big)}.$$

When a complementary pesticide is not required (as in FRW), a farmer purchasing technology choice 1 pays only the license price, p_L. Equilibrium quantities, prices, profits, and surpluses also differ. Equilibrium quantities for each technology choice are defined as:

$$\text{(A13)} \qquad q_0^* = \frac{Na_0\big(a_0 c_0 x_1 (n_1+1) - x_0(x_1 + c_1 n_1)\big)}{x_0\big(x_0 n_0 n_1 - x_1(n_0+1)(n_1+1)\big)}$$

and

$$\text{(A14)} \qquad q_1^* = -\frac{Na_1\big(-x_1 - a_0 c_0 n_0 + x_0 n_0 - x_1 n_0 + c_1(n_0+1)\big)}{-x_0 n_0 n_1 + x_1(n_0+1)(n_1+1)}.$$

Equilibrium prices for each technology choice are derived similarly, and are written as:

$$\text{(A15)} \qquad p_0^* = \frac{a_0 c_0 x_1 n_0 (n_1+1) + x_0(x_1 + c_1 n_1 - a_0 c_0 n_0 n_1)}{a_0\big(-x_0 n_0 n_1 + x_1(n_0+1)(n_1+1)\big)}$$

and

$$\text{(A16)} \qquad p_L^* = \frac{x_1^2(n_0+1) - c_1 x_0 n_0 n_1 + x_1(a_0 c_0 n_0 - x_0 n_0 + c_1 n_1 + c_1 n_0 n_1)}{\big(-x_0 n_0 n_1 + x_1(n_0+1)(n_1+1)\big)}.$$

The price of technology choice 1 is now only the license price.