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STRATEGIC ANALYSIS OF TRAIT COMMERCIALIZATION IN GENETICALLY MODIFIED (GM) GRAINS: THE CASE OF GM WHEAT

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Abstract

The prospective commercialization of GM traits leads to several strategic questions for agbiotechnology and seed firms. Important issues addressed in this study include the method of trait commercialization by agbiotechnology firms and variety production decisions by seed firms. Specifically, agbiotechnology firms must decide whether to license their traits to seed firms, to purchase a seed firm, or to not license or release their traits. These issues are highly strategic. The purpose of this study was to determine equilibrium strategies of agbiotechnology and seed firms regarding the prospective commercialization of two GM traits. Two game theory models were developed to examine equilibrium strategies in two different scenarios. In the first model, both agbiotechnology firms had commercialization strategies of licensing and not licensing. In the second model, the first moving agbiotechnology firm was allowed to have a strategic option to purchase a seed firm as a commercialization strategy. The second agbiotechnology firm remained with two strategies, licensing and not licensing. These models were applied to the case of Roundup Ready® (RR) and fusarium resistant (FR) HRS wheat, although the general structure of the models could be used to analyze other crops and traits. Studies on trait commercialization and stacking are lacking the public literature. This study uses game theory models to develop likely situations that may occur regarding the prospective commercialization of GM traits.

Keywords: genetically modified grains, wheat

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Scott R. Huso and William W. Wilson*

Introduction

Commercialization of genetically modified (GM) traits in grains and oilseeds began in 1996. The prospect and demand for stacked traits in varieties has led to important strategic questions for agbiotechnology and seed producing firms. Agbiotechnology firms are confronted with how to commercially introduce a trait. If two or more GM traits are commercialized for the same grain, seed firms face decisions of which traits to incorporate into their variety development portfolio and whether to stack two traits in one variety. These decisions are highly strategic. The agbiotechnology firm's decision depends on expected actions of the seed firm and vice versa. A related decision for an agbiotechnology firm is whether to commercialize its GM trait through a license to seed firms or to purchase a seed firm and release it through their own varieties. These strategic questions are motivated by the fact that mergers and acquisitions have changed the structure of the seed industry which is evolving from "seeds" to "seeds and traits" (Fernandez-Cornejo, 2004).

The Roundup Ready® (RR) and fusarium resistant (FR) traits in wheat are the focus in this study, though other traits in wheat are at various stages of development. Commercialization of GM traits in wheat is slow because of consumer, government, and environmental concerns. RR wheat was under review by the United States and Canadian governments but Monsanto made a highly strategic decision to defer further commercialization. Reasons for the deferment include the decline in spring wheat acreage in the United States, a lack of widespread need for superior weed control in the wheat market, and the success of other varieties in Monsanto's research portfolio (Monsanto, 2004). Monsanto's deferment does not indicate that Roundup Ready® wheat will never be commercialized, but more likely in stacked variety.

The purpose of this study is to analyze equilibrium strategies of agbiotechnology and seed firms when deciding amongst strategies of trait commercialization along with variety production decisions. Specific objectives are to determine payoffs to agbiotechnology firms and analyzing the HRS wheat seed industry in North Dakota and the geographical adoption rates of RRW, GM FRW, stacked, and conventional varieties. Using these parameters, we developed a game theory model of trait-stacking to evaluate equilibrium strategies of agbiotechnology and seed firms. The model is applied to the case of HRS wheat, but could be generalized to other crops and traits. Economic analysis of licensing and trait-stacking strategies is non-existent in public literature despite these being critical in industry analysis. This paper contributes to the literature by providing a framework for modeling trait commercialization and trait-stacking strategies. Although the analysis focuses on one crop and two traits, the game framework provides guidance for possible strategies as GM traits in wheat near commercialization and can be applied in other grains and traits.

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Elements of the Problem and Background Information

In this section, we examine development in GM wheat, the role of intellectual property rights (IPRs) and licensing in agbiotechnology, and the strategic interactions of agbiotechnology and seed firms when engaging in trait commercialization.

Trait Demand and the Status of GM Wheat

Adoption of GM traits depends on several key factors. In some areas, the use of RR soybean and heat tolerant (HT) canola have cleaned up weeds in cropping systems, and thus reduced the need for a RR wheat variety. Also, infestation levels of pests play an integral role in the demand for certain traits by farmers. For example, two types of GM traits are currently available in corn, herbicide tolerant (HT) and insect resistant (IR). If farmers in the Corn Belt have significant weed problems combined with low insect pressure, they prefer HT corn to remedy this problem. If, on the other hand, the farmers have high insect pressure but few weed problems they are likely to prefer the IR variety. Finally, if the farmers have both high weed pressure and susceptibility to the European corn borer, they would have demand both traits, which is available in a seed that contains stacked traits.

There are currently no GM wheat varieties commercially available. However, several GM traits for wheat are currently being developed. At the forefront in North America are the RR trait by Monsanto and the FHB resistant trait by Syngenta (Wilson et al., 2003). With the prospective commercialization of these traits in wheat, farmers may be able to choose the trait which best suits their production needs. Farmers will likely demand FHB resistant GM wheat if their region is highly susceptible to scab and RRW if their land has high weed pressure. However, forecasting farmer adoption of such traits poses a challenge for agbiotechnology and seed firms which in turn affects whether they should license, develop, and sell traits individually or as a stacked trait variety.

At the farmer level, the RR trait may have significant value. During growth, the wheat plant is at competition with weeds for moisture, nutrients, and sunlight. Chemicals are used to kill or stunt weeds and allow the wheat plant to compete and survive. However, conventional chemicals are limited to specific weeds that a particular chemical can eliminate. Also, combinations of hard-to-kill weeds may limit the producer to target certain weeds and allow others to remain. These factors, combined with the possibility of multiple applications of chemicals, affect producers' demand for the Roundup Ready® technology in wheat.

Another technology that may be highly sought after by farmers is the fusarium resistant trait in wheat. Fusarium head blight is a fungus disease that can occur on all small grain crops, but is most commonly seen in North Dakota in spring wheat, durum, and barley (McMullen and Stack, 1999). Certain conventional wheat varieties have been labeled "moderately resistant" to FHB, such as Alsen from North Dakota State University (Ransom and Sorenson, 2003). Currently, most producers use a fungicide (e.g., Folicur® - Bayer) to reduce the susceptibility of the plant to the disease. Fungicide is typically applied at the onset of flowering; however, the window of application is small and for this reason is not 100% effective. Besides yield reduction, FHB causes reduction in quality, which results in market price discounts. This quality concern is shared by elevators, food processors, and consumers. Fusarium resistant technology would eliminate uncertainty about fungicide application and also the quality concerns related to this disease.

Intellectual Property Rights in Agbiotechnology

Property rights were established to promote incentives to invest in research of a new process or product. Debates on the economics of property rights began in the mid-19th century. Supporters of property rights shared the idea "that stressed that intellectual property rights are both ethical and fair, and that they encourage innovation and foster social goals" (Giddings and Schneider, 1999, p. 3). Critics of intellectual property rights (IPRs) emphasize the high cost of protection, the hindrance of competition, and asserted that IPRs limited the diffusion of knowledge and new technology. Demand for free trade of all goods by some and property rights by others continued through the 1800s. By the early 1900s, most countries had some form of intellectual property rights (Giddings and Schneider, 1999).

Duration and scope determine the optimal intellectual property protection. If an IPR were to exist for a short period of time, the innovator may not be able to recover their costs of research and development. Giddings and Schneider (1999) indicate that, the optimal duration of a patent may be a function of the type of product or industry itself. In the United States, patent length has increased from 17 years to 20 years from date of issue.

The scope of a patent is more loosely defined in that it encompasses fringe developments, improvements, and applications that become barriers to entry resulting in changes in the economic environment. Previous studies surmise that the stronger the protection (or, broader the scope) of the patent, the weaker the competition and the greater the benefits to the innovator. The weaker the protection, the stronger the competition, and the innovator may not be able to recover research and development costs.

Once an innovator acquires an IPR, the invention may be commercialized in some way in order for the innovator to gain rents from the invention. The firm can choose to produce the invention on its own or to license it for a licensing fee, or royalty. Oster (1999) provides reasons for licensing: "Innovators may license innovations to rivals who are expected to be more efficient in the exploitation of that innovation due to the presence of complementary assets. Licensing may increase the speed with which the innovation enters the market" (p. 323).

Trait Stacking

If traits are licensed to seed firms, a licensing agreement must be agreed upon by the agbiotechnology and seed firms. Once licensed, the trait can then be incorporated into the seed firm's variety portfolio. If the seed firm enters licensing agreements to acquire two different traits and stacks them into one variety, the seed firm has engaged in vertical product differentiation. For example, adding the traits for herbicide tolerance and fusarium resistance to a wheat variety should be preferred by all producers to adding only one or neither of the traits into the same variety. However, the farmer's willingness-to-pay for the improved technology may prevent farmers from adopting it. Traits are typically stacked when farmers' willingness-to-pay for the new technology is sufficient to warrant the stacked trait variety.

Typically, a stacked variety contains two traits. For example, the four crops with commercial value in biotech varieties as of 2004 were corn, soybean, cotton, and canola (Runge and Ryan, 2003). The two traits that have been commercialized for these crops are B_t, or insect resistant (IR), and herbicide-tolerant (HT). In some varieties, these two traits are stacked. Use of HT and insect resistant (IR) stacked traits in corn and cotton has increased since their commercialization in 2000. Cotton varieties with stacked traits comprised 27% of total U.S. cotton acres in 2003. Monsanto has recently announced the first offering of a 3-trait stacked variety. This GM corn variety contains YieldGard® (two traits to control corn borer and rootworm) as well as Roundup Ready® Corn 2 ("YieldGard Plus," 2004).

Mechanisms of Licensing Agreements

Licensing agreements are used between agbiotechnology and seed firms to facilitate research and commercialization of GM traits. A research agreement gives a seed firm the right to use a particular trait in its variety development portfolio. Once a variety is ready to be commercialized, the seed firm enters a commercial licensing agreement with the agbiotechnology firm, through which the agbiotechnology firm receives royalties from the sale of their traits by the seed firm. Because of the significant cost of agbiotechnology research and development, few large firms lead the industry in research and development of new traits. Licensing agreements between firms who own the traits and seed firms that sell to farmers via various seed market channels provide a mechanism that allows traits to reach producers.

The relationship between the agbiotechnology and seed firms allow the seed firm to view the portfolio of traits offered by the agbiotechnology firm and choose those that best fits its needs[1]. Seed firms choose traits and enter research agreements with agbiotechnology firms that give the right to incorporate that trait into their own research and development program. This research agreement does not allow the seed firm to mass produce and sell seed commercially. In order to commercialize a GM variety, the seed firm then enters a commercialization agreement with the agbiotechnology firm. Typically, the commercialization agreement states that the agbiotechnology firm will receive a royalty for each unit (bag, acre, etc.) sold.

The North Dakota State University (NDSU) Research Foundation recently formed a commercial seed firm called Roughrider Genetics, which is a "trademarked brand name established solely for the marketing of licensed or proprietary varieties owned and managed by the NDSU Research Foundation" (Roughrider Genetics, n.d., para. 1). Roughrider Genetics currently has two commercially available RR soybean varieties. In the early 1990s, the NDSU Research Foundation entered a research agreement with Monsanto to use the RR trait in the research and development of RR soybean varieties. This research agreement was renewed at least once, indicating that the NDSU Research Foundation must adhere to guidelines set by

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[1] Material in this section is taken from interviews with J. Schuler, D. Zetocha, and S. Joehl in March/April 2004.

Monsanto in order to continue using the trait in variety research. Once NDSU had a variety ready for commercialization, Roughrider Genetics entered a commercialization agreement with Monsanto. Through this commercialization agreement, Monsanto charges a royalty for each unit of the RR soybean sold. In this case, the royalty is directly seen in the retail price of the seed, and Roughrider Genetics acts as a collector of the royalties for Monsanto.

Mechanisms involved in stacking traits vary. Traits are licensed individually to seed firms, not as a stacked bundle. If RR and B_t traits are stacked, the seed firm may purchase these traits from Monsanto. If another HT trait (such as Liberty Link from Bayer) is stacked with the B_t trait, the seed firm would enter separate licensing agreements with the two agbiotechnology firms and pay royalties to each. The amount of royalty demanded by the agbiotechnology firm depends on the use of the trait (individual or stacked), if the stacked traits are purchased from the same agbiotechnology firm, the performance of the product, and other factors.

Typically, the seed firm would select traits that best complement their varieties. GM traits are incorporated into varieties that sell, or have a potential of performance for the seed firm. Also, most seed firms have different GM varieties on hand to satisfy different needs of farmers. It is not uncommon for a seed firm to have a portfolio that contains conventional HT, IR, and HT/IR stacked corn varieties. Licensing agreements vary among agbiotechnology firms; the amount of royalties charged varies among products; and stacked traits may be treated differently than individual traits.

Agbiotechnology firms use a number of criteria in determining the royalty charged for a particular trait. First, market research is used to determine the price elasticity of the trait. If the price elasticity of demand for the trait is high, the agbiotechnology firm may use a margin strategy; whereas if the price elasticity is low, it may choose to use a share or volume strategy. Second, the impact of royalty pricing on the company's portfolio of products is evaluated, since most agbiotechnology firms sell many other products such as pesticides. The agbiotechnology firm must determine how the royalty affects sales of other products in the firm's portfolio. Finally, concern is given to the prospective reaction of key stakeholders (e.g., American Soybean Association and National Corn Growers Association). The royalty for a particular trait does not vary by hybrid or variety, but may vary by region. Market research helps determine the farmer's willingness-to-pay for traits in different regions[2].

Agbiotechnology firms use the above methods to determine the royalty for a particular trait. 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 the price for the traits is additive. In the case of stacked traits, the agbiotechnology firm can offer royalty rebates to the seed company if the price elasticity for the stacked trait favors a discounted stacked price. When traits are from two separate tech providers and stacked in one variety by a seed firm, there are typically no agreements between the agbiotechnology firms. Each agbiotechnology firm stills requires the royalty for their respective trait.

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[2] For example, producers in Louisiana spray their cotton acres more times for boll weevil than producers in Arkansas. Therefore, Monsanto charges a higher royalty for BollGard® cotton in Louisiana than in Arkansas.

Mergers and Acquisitions in Agbiotechnology

A major strategic decision confronting agbiotechnology firms is whether to license their traits or to commercialize them through their own (to be acquired) seed firm. In fact, one of the major structural changes in these industries has been the multitude of mergers that have occurred. Lemarie and Ramani (2003) describe the vertical relationship between seed and agbiotechnology firms and outline scenarios by which GM technology can be transferred from the innovator to the downstream firms. The agbiotechnology firm can commercialize a trait by issuing an exclusive license to one downstream seed firm or by issuing a non-exclusive license to numerous downstream firms. Agbiotechnology firms supply seed firms with grains of plants containing the GM trait. The seed firm then crosses these grains with existing varieties to develop the new GM varieties. Because of the much more rapid pace of trait development compared to plant breeding, the technology from agbiotechnology firms becomes increasingly used to create new varieties (Lemarie and Ramani, 2003). Therefore, agbiotechnology firms are needed by seed firms. Conversely, because the traits need to be transferred into high performance varieties in order to be sold, the success of agbiotechnology firms hinges on seed firms' decisions. For this reason, a wave of mergers and acquisitions occurred in the U.S. crop seed sector in the second half of the 1990s (Lemarie and Ramani, 2003).

Because of the presumed need to own a seed firm in order to provide an avenue of sale for trait innovations, agbiotechnology firms began purchasing seed firms at very high prices (Chataway and Tait, 2000). Coinciding with the first GM traits developed, agbiotechnology firms purchased seed firms that were leaders in corn and soybean sales. But, the acquisitions of seed firms did not stop agbiotechnology firms from further licensing their GM traits to independent seed firms (Lemarie and Ramani, 2003). For example, Monsanto acquired Dekalb Genetics Corp., Cargill's international seed business, and Plant Breeding International Cambridge Ltd., while still licensing their GM traits to independent seed firms such as Pioneer and Golden Harvest (Chataway and Tait, 2000; Lemarie and Ramani 2003).

Through mergers and acquisitions, DuPont and Monsanto have become leaders in the soybean and corn seed markets. Kalaitzandonakes and Hayenga (2000) report that, in 1998 Monsanto and DuPont/Pioneer Hi-Bred had market shares of 15% and 39%, respectively, of the U.S. seed corn market, and 24% and 17% of the soybean seed market. In achieving such levels, DuPont purchased seed giant Pioneer Hi-Bred at a cost of $9.4 billion and Monsanto purchased Dekalb and Asgrow at an approximate cost of $2.54 billion (Kalaitzandonakes and Hayenga, 2000; Fernandez-Cornejo, 2004). In recent transactions, Monsanto acquired Channel Bio Corporation, which holds two Iowa seed companies. Monsanto is attempting to increase its share of the multibillion-dollar corn industry, and may be developing another method for commercializing its GM corn traits ("Monsanto purchase," 2004). Also of interest in this study is that Syngenta and Fox Paine purchased Advanta BV (Syngenta, 2004). Through this acquisition, Syngenta gained Advanta's North American corn and soybean business which trades under the Garst brand name. As a part of this transaction, Syngenta also acquired AgriPro Wheat, the largest private sector wheat breeding firm in North America. This acquisition gives Syngenta possible commercialization strategies for its GM corn, soybean, and, possibly, wheat traits.

Rausser, Scotchmer, and Simon (1999) conducted a survey of mergers and acquisitions in the crop seed sector and propose three possible motivations. The mergers could have been motivated in order to exploit complementarities of assets, to internalize spillovers, or to circumvent the impossibility of issuing complete and contingent contracts. Lemarie and Ramani (2003) focus on the first explanation. They found that final form of vertical control accompanying the commercialization of GM seeds is greatly influenced by final market demand. When the substitutability between the GM and conventional seed is high, mergers are preferred. Generalization of the model developed by Lemarie and Ramani (2003) indicates that any demand enhancing innovation gives rise to an incentive for a merger.

Game Theory – Essential Elements

In an industry with a few major players (such as agbiotechnology), actions of one player impact the market price and, ultimately, profits of each player. Thus, players consider actions of other players in making strategic decisions. The complexity of such interactions is illustrated by Besanko et al. (2004) in that, "…your rivals' optimal choices will often depend on their expectations of what you intend to do, which, in turn, depend on their assessments of your assessments about them" (p. 36). Game theory provides a method to analyze optimal decision making when all decision makers are presumed to be rational, and each player is attempting to anticipate the actions and reactions of its competitors. In sequential move games, players make their strategy decisions sequentially; one firm plays first, another follows, and so on.

Order of play is important in that one player can impact or change the other player's preferred strategy. However, in order for an advantage to exist, there must be a credible commitment by the player with the advantage. This means that the player with the advantage (e.g., first-mover advantage) must make a credible threat to alter its own payoffs in order to induce the second player to choose a strategy that is more desirable for the first player.

"Nature" is a player that accounts for random events or uncertainty. When outcomes are uncertain, nature's decision node incorporates the probability of each outcome, which allows the equilibrium strategies to be reached while considering uncertainty. This type of game has a mixed strategy equilibrium. Watson (2002) describes that "a mixed strategy for a player is the act of selecting a strategy according to a probability distribution" (p. 38). More specifically, a mixed strategy means that the player may choose one strategy with probability, γ, and the other with probability, $1-\gamma$. In the context of the GM wheat trait commercialization game, the possibility of a mixed strategy exists because of the uncertainties related to farmer adoption and market acceptance. The probabilities of adoption of each wheat variety are used to determine the expected value of the representative strategy. Thus, a mixed strategy is realistic.

Strategic Games for Commercializing GM Wheat Traits

Two models are developed to illustrate potential strategic issues. Both models include a GM trait commercialization decision by each agbiotechnology firm and a variety release decision by the seed firm. The first model is limited in that the only mode of GM trait introduction by either agbiotechnology firm is by licensing to the seed firm. The second model is expanded to allow for agbiotechnology Firm A (with GM FRW) to purchase a wheat seed breeding firm. The two models are presented independently, with base case results, sensitivities, and conclusions being discussed for each.

Solution Algorithm

Gambit is a type of game theory analytical software that can be used in code form or in graphical user interface (McKelvey, McLennan, and Turocy, 2004). The 2004 version of *Gambit* provides graphical displays of the game structure, along with several algorithms with which the software can determine equilibrium strategies of the game. *Gambit* was used in this study because of its ability to incorporate nature and display mixed strategy equilibriums.

Methods and Data

This study focuses on North Dakota (ND), which is the largest producer of hard red spring (HRS) wheat in the United States (USDA NASS, 2004). Variables include

π_A = total potential payoff to Firm A (GM FRW trait),
π_B = total potential payoff to Firm B (RRW trait + glyphosate herbicide), and
π_S = total potential payoff to ND HRS wheat seed firms (conventional variety).

Payoffs for Firm A are $\pi_A = N * p_{L(A)}$, where N is the number of HRS acres planted in ND, and $p_{L(A)}$ is the per acre tech fee for GM FRW. Similarly for Firm B, $\pi_B = N * \left(p_{L(B)} + p_1\right)$, where $p_{L(B)}$ 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 were determined by $\pi_S = N * p_S$, where p_S is the average price of HRS per acre. Payoffs are shown in Table 1. Per acre prices for the GM FRW and RRW traits were taken from Huso and Wilson (2005), which estimates the optimum prices for each trait based on an input price equilibrium model and parameters reflecting those in North Dakota. The average per acre HRS seed cost from 1990 to 1996 was taken from Fernandez-Cornejo (2004). Average HRS acres in ND were from the National Agricultural Statistics Service (USDA NASS, 2004).

Adoption rates for each variety are important in determining equilibrium strategies but they are a source of uncertainty. Adoption rates for each variety were determined based on geographical weed and fusarium head blight (FHB) infestations. Two state-wide weed surveys in 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” (Zollinger et al., 2003, p. 2) and was determined for each of the 53 counties. Wild oats and buckwheat were used as problem weeds, meaning that between the two weeds, the higher frequency assumed the number of acres in that county that would potentially adopt the RRW variety. FHB infestation data was taken from Nganje et al. (2001). Yield loss due to FHB was reported for each crop reporting district (CRD) in ND. These yield losses were assigned to each county within the CRD. It was assumed that if a county had a yield loss due to FHB greater than zero, all HRS acres in that county would potentially adopt the GM FRW variety. If a county was

Table 1. Payoffs for Agbiotechnology Firms and Seed Firm

	N	$p_{L(A)}$	$p_{L(B)} + p_1$	p_S	Payoff
π_A	6.65 M	$12.35/acre			$82.13 M
π_B	6.65 M		$11.33/acre		$75.34 M
π_S	6.65 M			$9.54/acre	$63.44 M

Source: Derived from Huso and Wilson (2005)

a candidate for both RRW and GM FRW adoption, the lower of the two values was assumed to be the adoption level of stacked variety[3].

This method was applied to each county to determine RRW, GM FRW, stacked, and conventional acres, and then summing over counties gave the total number of acres planted to each variety in ND. Dividing by total planted acres gave the geographical adoption rates of each variety. Assumptions were made to limit the number of varieties available due to the possibility of GM traits not being licensed. Derived adoption rates, based on weed and FHB infestation, are shown in Table 2.

Table 2. Adoption Rates on HRS Acres under Different Market Structures

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

Model I: Entry via Licensing Only

In Model I, two agbiotechnology firms, Firm A and Firm B, are seeking to determine if they should license their GM traits to seed firms. Firm A owns a GM FRW trait and Firm B owns a RRW trait. Because of recent developments in the GM wheat industry (i.e., the deferment of RRW), Firm A moves first and decides whether to license the GM FRW trait to seed firms. Firm B observes Firm A's decision and decides whether to license the RRW trait to

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[3] As an example, in Cass County, wild oat frequency was 26%, and buckwheat frequency was 45%. Average planted HRS wheat acres in Cass County was 325,000; so, 45% of planted acres or 146,900 acres would adopt RRW. Average yield loss due to FHB was 5.16 bu/acre; therefore, all acres in Cass County would adopt GM FRW. Since there is an overlap of 146,900 acres, it is assumed that those acres would adopt a stacked variety while the remainder would adopt GM FRW (325,000-146,900=178,100) and no acres would be planted to a conventional variety.

seed firms. Based on the decisions of the two agbiotechnology firms and the potential adoption rates of farmers, the seed firm then decides which variety(s) to produce.

Payoffs in the base case represent the potential payoff to the respective firm for the sale of its GM trait or seed. The derived adoption rates used in the base case account for uncertainty in the firms achieving the total potential payoff (Table 2). Thus, the adoption rates result in expected payoffs for certain strategies due to uncertainty. If a conventional variety is released, only the seed firm would realize payoffs. If a GM variety is released, the agbiotechnology firm would receive payoffs from the sale of its trait, while the seed firm would receive payoffs from the sale of the seed. It is assumed that the value of the seed, in addition to the value of the GM trait, is constant across conventional and GM varieties.

Figure 1 illustrates the game tree. Firm A decides whether to license. 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 farmers, who choose whether or not to adopt a particular variety. The probabilities of adoption under the possible strategies are taken from Table 2.

Base case results. The equilibrium consists of pure and mixed strategies for the agbiotechnology and seed firms, resulting in a mixed strategy sequential equilibrium (summarized in Table 3). Interpretation of the mixed strategy sequential equilibrium is as follows: Firm A's equilibrium strategy is to license GM FRW to the seed firm with probability 1.0, and Firm B's equilibrium strategy is to license RRW with probability .96 and to not license with probability .04, etc. The seed firm's equilibrium strategy if Firm B licenses is to sell a stacked variety with probability .17 and sell a GM FRW variety with probability .83; and, if Firm B does not license, the seed firm's equilibrium strategy is to sell a GM FRW variety with probability 1.0. The mixed strategy sequential equilibrium is a direct result of the uncertainty in adoption of 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 adoption rates, which are .34 and .31, respectively. RR and conventional varieties have adoption rates of .20 and .15, respectively. Seed firms receive identical payoffs regardless of the variety produced, so they will choose to produce the varieties with the highest adoption rates.

Several assumptions were made in the base case. Adoption rates, tech fees, and the order of play were relaxed to examine impacts on equilibrium strategies. Sensitivities were performed on these variables to determine if and how the equilibrium strategy changes depending on the values of these variables.

Adoption rates. Adoption rates reflect the portion of area adopting each technology solution. These also are reflective of potential rates of market acceptance, which vary across importing and domestic markets. Presumably, market acceptance would be reflected in farmer adoption rates in a mature market. Adoption rates in the base case were determined by considering spatial distribution of weeds and FHB across North Dakota. The base case assumed that the weed frequency percentage in a county represented the number of acres planted to RRW; and if a county experienced any level of yield loss due to FHB, all acres in the county would be planted to GM FRW. The overlap of RRW and GM FRW acres was assumed to be planted to a stacked trait variety.

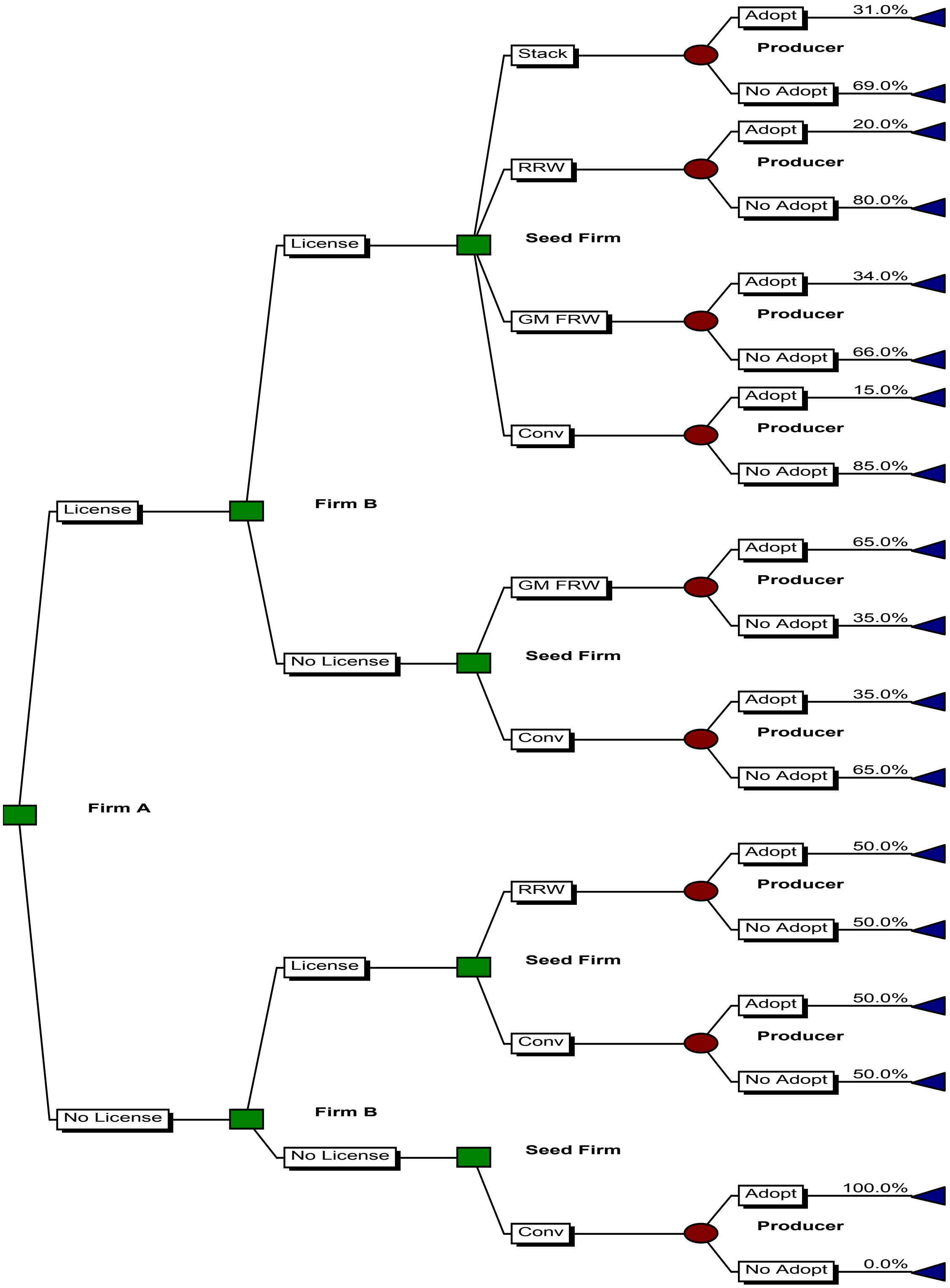

Figure 1. Model I: GM wheat trait-stacking/licensing game.

Table 3. Model Structure I: Base Case Results

Firm A Strategy		**Firm B Strategy**		**Seed Firm Strategy**			
License	*No License*	*License*	*No License*	*Conv*	*RRW*	*GM FRW*	*Stack*
1.0		.96	.04			.83	.17

Farmer adoption rates do not necessarily conform to spatial differences in pest pressure. They could also be affected by input and market prices, cost and benefits, and market acceptance. To examine differences in adoption rates on the equilibrium firm strategies, the percentage of potential acres planted to a GM variety was varied from 0% to 100% of base case values (Table 4). If adoption of all GM varieties was zero, the mixed strategy sequential equilibrium for Firm A is to license with probability .5 and not license with probability .5; under both possible strategies of Firm A, Firm B had similar mixed strategies in that it would license with probability .5 and not license with probability .5. Under each possible combination of strategies of Firms A and B, the seed firm's pure strategy is to sell a conventional variety.

Table 4. Percentage of Potential Adoption on Equilibrium Strategies

Potential Adoption (%)	**Firm A Strategy**		**Firm B Strategy**		**Seed Firm Strategy**			
	License	*No License*	*License*	*No License*	*Conv*	*RRW*	*GM FRW*	*Stack*
0	.5	.5	.5	.5	1.0			
20	.5	.5	.5	.5	1.0			
40	.5	.5	.5	.5	1.0			
60	.5	.5	.5	.5	1.0			
80	.5		.51	.49	.95		.05	
100	.5		.96	.04			.83	.17

As adoption rates increase (and converge toward our base case) due to an increase in percentage of potential acres treated, the mixed strategy sequential equilibrium does not change until the level of adoption reaches 80% of base case adoption. The mixed strategy sequential equilibrium at 80% of base case adoption is for Firm A to license the GM FRW trait with probability 1.0; and Firm B would license with probability .51 and not license with probability .49. If Firm B licenses, the seed firm would produce GM FRW with probability .05 and the conventional variety with probability .95. If Firm B does not license, the seed firm would produce GM FRW with probability .95 and a conventional variety with probability .05. The change in equilibrium strategies is because as adoption levels of stacked and GM FRW varieties increase, the expected payoffs for Firm A when licensing are greater than when not licensing. Similarly, expected payoffs for Firm B and the seed firm change as adoption levels of GM varieties increase. Thus, as adoption levels increase, there is more incentive for agbiotechnology firms to license their GM traits. Practically, the licensing costs of an agbiotechnology firm are small in comparison to the R&D costs for a particular trait. Therefore, commercializing a trait through licensing (as adoption levels increase) results in higher expected payoffs for an agbiotechnology firm than not licensing.

Technology fees and payoffs. The base case used technology fees and input prices from an input price equilibrium model to determine payoffs for Firms A and B. Base case technology fees were $12.35/acre and $5.09/acre for Firm A and B, respectively. Firm B's RRW requires a complementary glyphosate at a price of $6.24/acre (assuming application rate of 1 lb/acre) for a total cost of $11.33/acre for the RRW + glyphosate bundle. Changing the costs of the GM traits changes the payoffs for the agbiotechnology firms and the equilibrium strategy (Table 5).

Table 5. Impacts of Technology Fees on Equilibrium Strategies

Revenue/acre to agbiotech firms ($)	**Firm A Strategy**		**Firm B Strategy**		**Seed Firm Strategy**			
	License	*No License*	*License*	*No License*	*Conv*	*RRW*	*GM FRW*	*Stack*
Sensitivity on Firm A's per acre revenue (tech fee)								
8	1.0		.5	.5			1.0	
10	1.0		.95	.05			.88	.12
12	1.0		.96	.04			.84	.16
14	1.0		.97	.03			.8	.2
16	1.0		.97	.03			.77	.23
Sensitivity on Firm B's per acre revenue (tech fee + glyphosate)								
8	1.0		.92	.08			.81	.19
10	1.0		.95	.05			.83	.17
12	1.0		.97	.03			.83	.17
14	1.0		.98	.02			.84	.16
16	1.0		.99	.01			.85	.15

At a cost of $8.00/acre for the GM FRW technology, the mixed strategy sequential equilibrium is for Firm A to license with probability 1.0, Firm B to license with probability .5 and not license with probability .5, and the seed firm to produce and sell GM FRW with probability 1.0 (Figure 2). At a cost of $10/acre for the GM FRW technology, the seed firm produces GM FRW with probability .88 and stacked with probability of .12. This increase in the probability of stacked variety production results in Firm B having a probability of licensing its RRW technology of .95. Firm A continues to have a pure strategy of licensing. As the cost of the GM FRW technology increases from $10/acre to $16/acre, the probability of the seed firm selling a stacked variety increases from .12 to .23, and the probability of the seed firm selling the GM FRW variety decreases from .88 to .77. The increase in the probability of the stacked variety increases the probability of Firm B to license its RRW technology, from .95 to .97. This shift in variety production is likely due to diversification by the seed firm. The seed firm

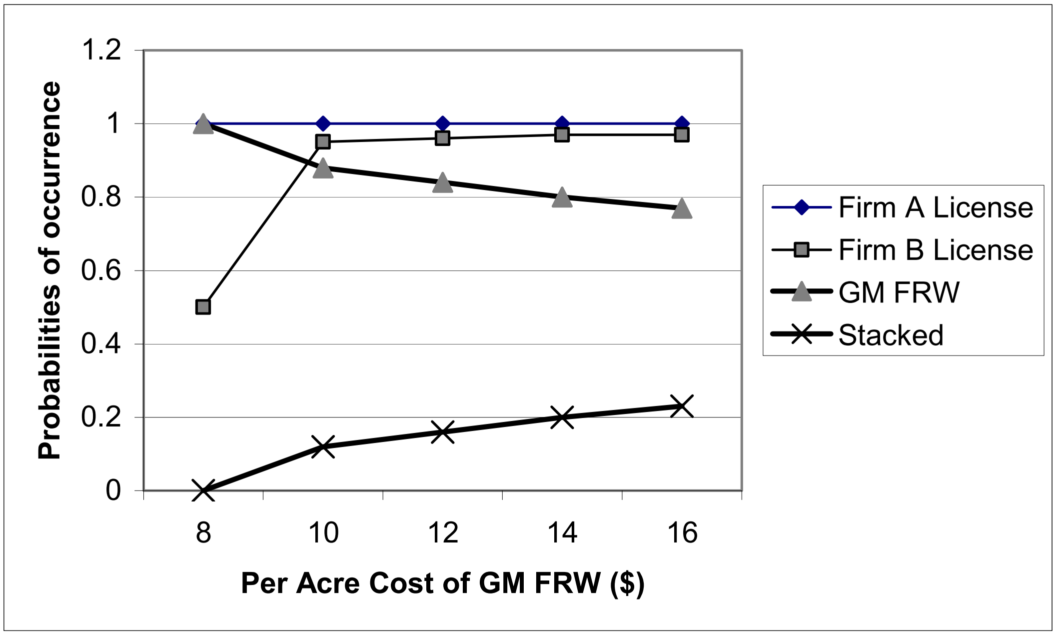

Figure 2. Probabilities of licensing and variety production as cost of GM FRW increases.

strategically examines the payoffs of Firm A and chooses to produce a mix of GM FRW and stacked varieties because of their high adoption rates and payoffs to all players. Because of the production of stacked varieties, Firm B has a high probability of licensing its RRW technology.

As the cost of the RRW bundle increases from $8/acre to $16/acre, the probability of the seed firm producing a stacked variety decreases from .19 to .15, and the probability of the seed firm producing the GM FRW variety increases from .81 to .85. Over the same range, Firm B increases the probability with which it licenses its RRW technology, from .92 to .99. This increase in the probability of licensing is due to increased payoffs as the cost of the RRW technology increases. Firm A has a pure strategy of licensing regardless of changes in Firm B's payoffs.

Order of play. The base case assumed that Firm A had 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. The order of play was changed so that Firm B moved first, followed by Firm A, to examine changes in equilibrium strategies if Firm B decides to undo its deferment of RRW (Figure 3). The resulting mixed equilibrium strategy is as follows: Firm B would license its RRW trait with probability .5 and not license with probability .5; Firm A's pure strategy is to license regardless of Firm B's move; and the seed firm will choose to produce the GM FRW variety no matter what Firm B's strategy is. The seed firm chooses to produce GM FRW if the trait is licensed because of the higher percentage of adoption of GM FRW (Table 2). Firm A chooses to license its GM FRW technology. Because of the seed firm's strategy of producing GM FRW, Firm B is indifferent between licensing and not licensing.

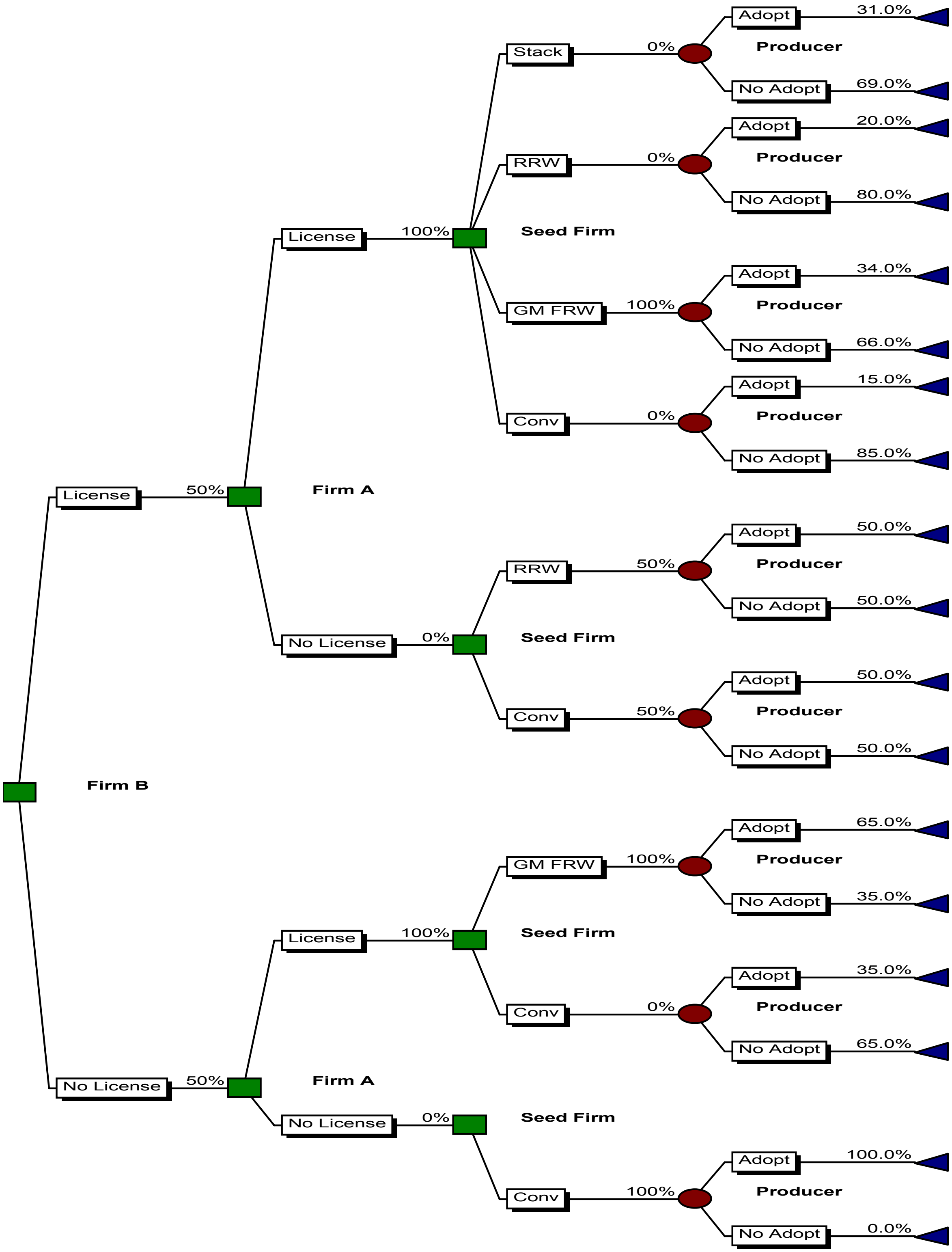

Figure 3. Change in order of play; Firm B moves before Firm A.

The results differ from the base case in that Firm B is indifferent between licensing and not licensing because it is not able to observe the move by Firm A. The reason for Firm B's indifference is the low adoption rate of RRW and the high adoption rate of GM FRW. Because of the uncertainty of whether Firm B will license, the seed firm produces GM FRW with probability 1.0 because of higher expected payoffs.

Alternative equilibrium criteria. Because of uncertainty in adoption rates, a mixed strategy equilibrium was expected, and "one sequential equilibrium" algorithm in *Gambit* was used to assess the mixed strategy sequential equilibrium. A pure strategy sequential equilibrium is deterministic. The "One Nash equilibrium" algorithm in *Gambit* analyzes pure strategy equilibriums. Using the "One Nash equilibrium," the pure strategy equilibrium is for Firm A to license, Firm B to license, and the seed firm to produce the GM FRW variety. Using all other equilibrium solving algorithms in *Gambit* derives the same pure strategy equilibrium.

Model II: Purchasing a Seed Firm for Trait Commercialization

Agbiotechnology firms have used other modes of entry rather than only licensing. Part of Monsanto's commercialization strategy of GM corn and soybean was to purchase Dekalb Genetics Corp., Cargill's international seed business, and Plant Breeding International Cambridge Ltd. and recently acquired Channel Bio Corporation. This is not dissimilar from DuPont's acquisition of Pioneer Hi-Bred as a means to create synergies in agbiotechnology. Of interest in this study is Syngenta's acquisition of AgriPro (the largest private sector wheat breeding firm in North America) through their purchase of Advanta BV which gives Syngenta strategic options for commercialization strategies for its GM corn, soybean, and, possibly, wheat traits (Syngenta, 2004).

Coinciding with the acquisition of seed firms, agbiotechnology firms also licensed their GM traits to independent seed firms and universities to complement the commercialization strategy. This commercialization strategy was incorporated into the trait commercialization model. Firm A can now release its GM trait through a license to an independent seed company or by purchasing a seed firm.

Data and assumptions. Firm A's payoffs are the same as those defined in Model I if it chooses to license or not license. However, if it chooses to purchase a seed firm, its payoffs change. Under this strategy, Firm A increases its payoffs by becoming a player in the seed industry, because it owns conventional varieties and benefits not only from the sale of its GM FRW trait, but also from the sale of any wheat variety. Firm B's payoffs do not change from the first model. If Firm A purchases a seed firm, Firm B's decision to license means that it licenses the RRW trait to all seed firms, but only Firm A's seed firm will be able to produce a stacked variety. Thus, if Firm 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 allowed because of high uncertainty regarding competition and share of seed sales[4].

Financial data were approximated to represent the prospective acquisition costs of a seed firm 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-\$1.50/bushel higher than public varieties and, assuming that 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 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 about \$11.5 million. Thus, the value to Firm A of a seed firm for the purposes of commercializing a GM HRS wheat trait was about \$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 Firm A are shown in Table 6.

Table 6. Payoffs to Agbiotechnology and Seed Firms (in millions of \$)

	Conventional	GM FRW	RRW	Stacked
π_A	\$7.90	\$143.9	\$61.8	\$143.9
π_B			\$75.3	\$75.3
π_S	\$63.4	\$63.4	\$63.4	\$63.4

If a conventional variety were released, Firm A gains 15% of the HRS wheat seed revenue less the annual cost of owning and generating a seed firm. The payoffs to the seed firm do not change because Firm A is now in the seed industry. If a GM FRW variety were released, Firm A's payoff includes the potential revenue from the technology fee along with the potential revenue from seed sales less the cost of purchasing a seed firm. If Firm A purchases a seed firm, the only mode of commercialization of GM traits is through Firm A. Thus, Firm A gains the potential revenue from seed sales if the variety is genetically GM modified.

The payoff to the seed firm remains constant because the size of the seed industry. If a RRW variety were released, Firm 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 Firm 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 Firm B that includes revenue from its technology fee plus the herbicide cost.

<u>Base case results</u>. The base case of Model II encompasses Model I. and includes a third strategy for Firm A of purchasing a seed firm (Figure 4). The mixed strategy sequential equilibrium is as follows (Table 7): Firm A would purchase a seed firm with probability 1.0,

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[4] This representation has a limitation. It may be of interest to allow Firm A to pursue 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 its own varieties. However, 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 is limited but is retained for illustration of the strategic interpretation.

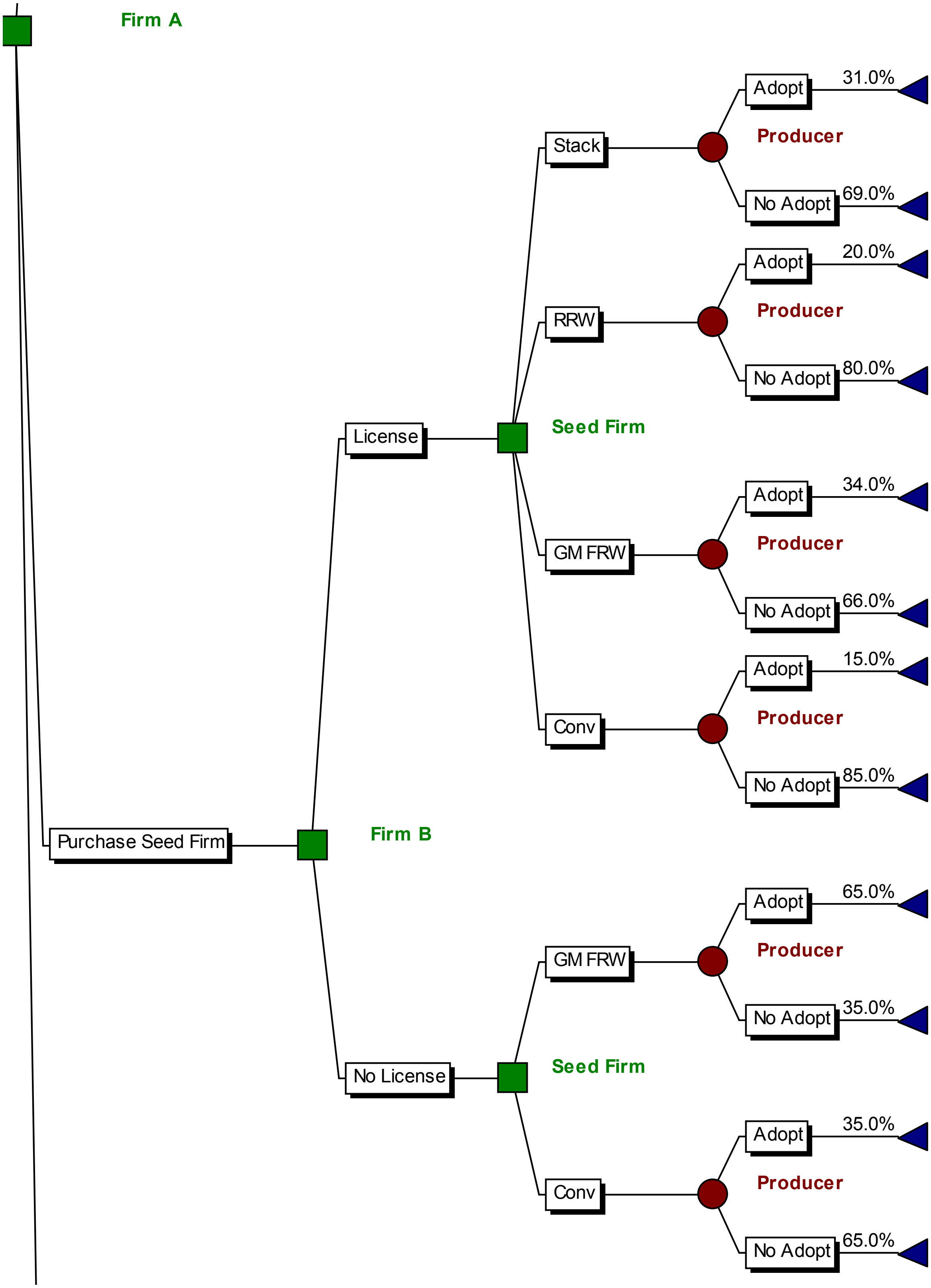

Figure 4. Model II: Branch of Game Tree allowing Firm A's strategy to purchase a seed firm

Table 7. Model II: Base Case Results

Firm A Strategy			**Firm B Strategy**		**Seed Firm Strategy**			
Purchase Seed Firm	*License*	*No License*	*License*	*No License*	*Conv*	*RRW*	*GM FRW*	*Stack*
1.0			.96	.04		.01	.7	.29

Firm B would license its RRW trait with probability .96 and not license with probability .04. If Firm B licenses its trait, Firm A would use its seed firm to produce GM FRW with probability .7 and stacked RRW/GM FRW with probability .29. The seed industry would produce a RRW variety with probability .01. If Firm B does not license, Firm A would produce the GM FRW variety with probability 1.0.

The reason that Firm A chooses to purchase a seed firm rather than license its GM FRW technology is because of the payoffs resulting from owning a seed firm. With this strategy, Firm A now gains payoffs from the sale the wheat seed, along with its GM FRW technology. The combination of high adoption rates for GM FRW and stacked varieties, along with the low annual cost of owning a seed firm, also contribute to Firm A's equilibrium strategy of GM trait introduction by purchasing the seed firm.

In Model I, Firm A chose to license its technology to other seed firms because its two strategies were to license or not license. Including the third strategy of purchasing a seed firm gives Firm A more flexibility in its decision making. In Model II, the cost of owning the seed firm is conducive for Firm 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 low cost of owning the seed firm.

Because of the lack of historical data relating to trait-stacking and licensing of GM wheat varieties, data from the price impact model and surveys on weed and fusarium head blight infestations along with industry averages were used to develop a likely situation as represented in the base case. However, this is highly stylistic and represents one of many possibilities. Therefore, sensitivities were conducted on the cost of purchasing a seed firm and adoption rates to illustrate different possible scenarios and the equilibrium strategies resulting from each.

Cost of owning and operating a seed firm. The base case assumed that the annual opportunity cost of owning a seed firm dedicated to the production of wheat varieties was $1.6 million per year. Sensitivities were conducted on this value to evaluate changes in equilibrium strategies as the cost of owning a seed firm changes. As the cost of the seed firm increases from $5 million to $30 million per year, Firm A's equilibrium strategy moves from purchasing a seed firm to licensing its GM FRW technology to other seed firms (Figure 5). At a cost of $15 million per year, Firm A's mixed strategy is to purchase a seed firm with probability .99 and license its technology with probability .01. At a cost of $20 million per year, Firm A's mixed strategy is to purchase a seed firm with probability .81 and license with probability .19: and at $25 million, Firm A's mixed strategy is to purchase a seed firm with probability .07 and to license with probability 93%. Firm A's most probable strategy moves from purchasing a seed firm to licensing its technology between $20 million and $22.5 million. At $22.5 million, Firm A's mixed strategy is to purchase a seed firm with probability .39 and to license with probability .61 Because Firm B's payoff does not change, Firm B's mixed strategy, regardless of Firm A's strategy, is to license with probability .96 and not license with probability .04.

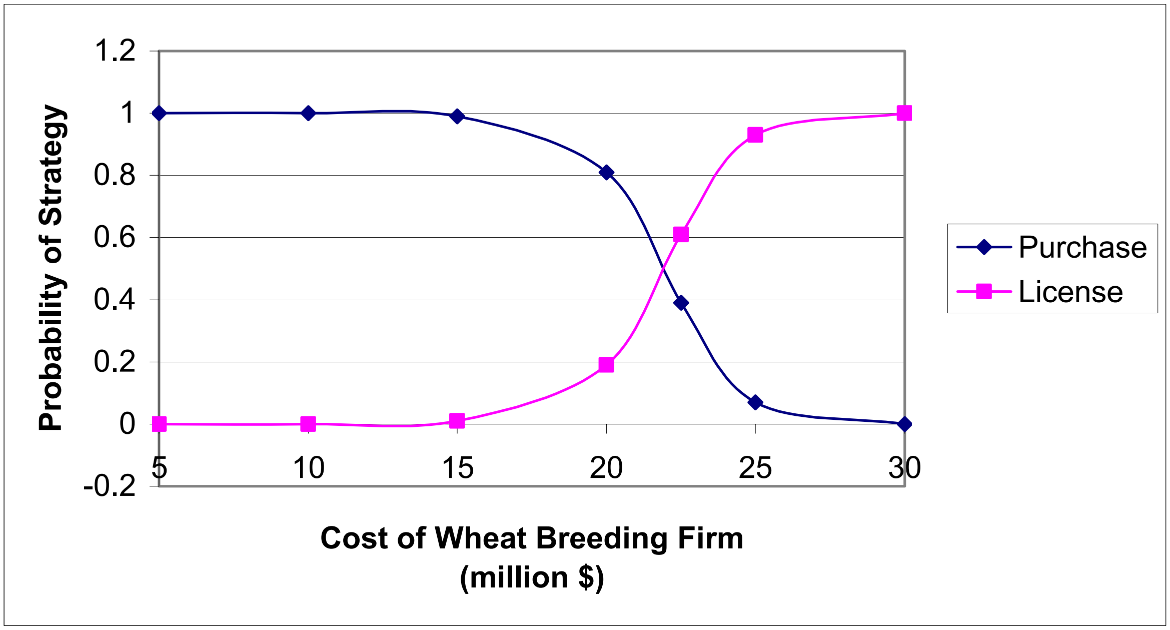

Figure 5. Change in Firm A's entry strategy as the cost of purchasing a seed firm increases.

As the cost of the seed firm increases, the production decisions of the seed firms also change (Figure 6). If Firm B does not license its RRW technology to Firm A, all seed firms (Firm A + other seed firms) continue to produce GM FRW with probability 1.0 as the cost of purchasing a seed firm increases. If Firm B licenses its RRW technology to Firm A, the production mix of HRS varieties changes as the cost of the seed firm increases. At a cost of $5 million per year, Firm A's seed firm will produce a GM FRW variety with probability .72, a stacked variety with probability .27, and a RRW variety with probability .01. At a cost of $20 million per year, Firm A's seed firm will produce a GM FRW variety with probability .82 and a stacked variety with probability .18. At a cost of $30 million per year, Firm A's seed firm will produce a GM FRW variety with probability .84 and a stacked variety with probability .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.

Adoption rates. The equilibrium strategy for Firm A does not change as adoption rates change. As the adoption rates of GM wheat varieties decrease, the seed firm moves to producing more conventional varieties. Sensitivities were conducted on the percentage of total potential acres planted to GM varieties, ranging from 10% to 100%. The results of this sensitivity were much like those in the first game. At 10% of total potential acres, the mixed strategy sequential equilibrium was for Firm A to purchase the seed firm, then Firm B would license with probability .5 and not license with probability .5. Regardless of the purchasing and licensing decisions of the agbiotechnology firms, the seed firm's pure strategy was to produce a conventional variety.

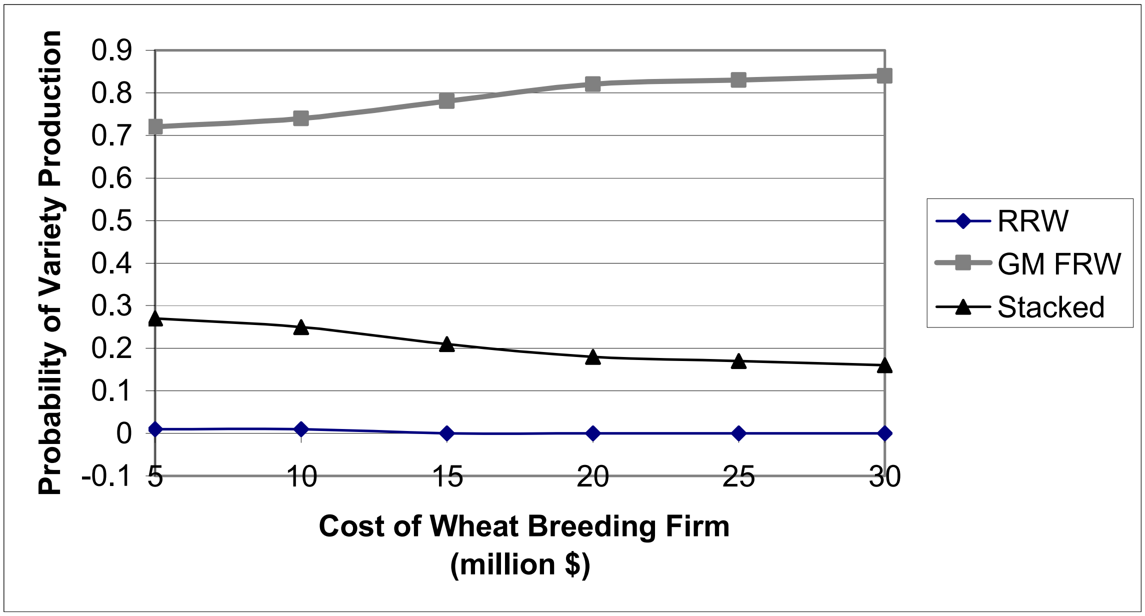

Figure 6. Change in variety production as the cost of a seed firm increases.

As the percentage of total potential GM acres increased to 80% and over, Firm B then found it preferable to license its technology because of the greater probability of RRW or stacked adoption. Also, at these levels, the seed firms begin to produce GM FRW, stacked, and some RRW varieties. Firm A, however, would not change its strategy of purchasing a seed firm. If Firm A purchases as seed firm, it receives payoffs from selling each possible HRS wheat variety, including conventional. If Firm A licenses, it only receives a payoff if its GM FRW trait is adopted in a single or stacked trait variety. This, combined with the low base case annual cost of purchasing the seed firm, results in Firm A always finding it beneficial to purchase a seed firm rather than license its technology. This result would change as the annual cost of a seed firm changes, as was shown in the prior sensitivity.

Summary

The prospective commercialization of GM traits leads to several strategic questions for agbiotechnology and seed firms. Important issues addressed in this study include the method of trait commercialization by agbiotechnology firms and variety production decisions by seed firms. Specifically, agbiotechnology firms must decide whether to license their traits to seed firms, to purchase a seed firm, or to not license or release their traits. Historically, agbiotechnology firms have purchased seed firms at high cost as a commercialization strategy, as well as licensing traits to competing independent seed firms. Depending on the traits available for production, seed firms must decide which varieties to produce and sell to farmers. The decision of the seed firm is highly dependent on farmer adoption rates of the different varieties. Likewise, the decision of the agbiotechnology firms depends on the production decision of the seed firms. Thus, these issues are highly strategic in nature.

The purpose of this study was to determine equilibrium strategies of agbiotechnology and seed firms regarding the prospective commercialization of two GM traits. Two game theory models were developed to examine equilibrium strategies in two different scenarios. In the first model, both agbiotechnology firms had commercialization strategies of licensing and not licensing. Depending on which traits were licensed and adoption rates of varieties, seed firms made variety production decisions. In the second model, the first moving agbiotechnology firm was allowed to have a strategic option to purchase a seed firm as a commercialization strategy. The second agbiotechnology firm remained with two strategies, licensing and not licensing. Again, the seed firm made variety production decisions after the decisions of the agbiotechnology firms. These models were applied to the case of Roundup Ready® (RR) and fusarium resistant (FR) HRS wheat, although the general structure of the models could be used to analyze other crops and traits. Studies on trait commercialization and stacking are lacking in the public literature. This study uses game theory models to develop likely situations that may occur regarding the prospective commercialization of GM traits.

Results from the first model indicate that Firm A (with the GM FRW trait) would license with probability 1.0 and Firm B (with the RRW trait) would license with probability .96. The seed firm's equilibrium strategy is to sell a stacked (RR/FR) variety with probability .17 and a GM FRW variety with probability .83. Adoption rates of the different varieties are important in that as the adoption of a particular variety increases, the seed firm will likely produce that variety. This continues to the agbiotechnology firms because if the adoption of their trait increases, they will increase the likelihood of licensing. Another interesting observation is that as the order of play in the game changes, the equilibrium strategies change. The base case assumed that Firm A moved first, followed by Firm B. The order of play was switched resulting in Firm B becoming indifferent between licensing and not licensing because of the low adoption rate for RRW and not knowing if Firm A would license GM FRW.

Results from the second model indicate that Firm A's equilibrium strategy is to purchase a seed firm. Owning a seed firm provides additional revenue to Firm A through seed sales. In the base case, the cost of owning a seed firm was such that Firm A found this strategy to be optimal versus licensing its GM FRW trait. However, as the cost of owning the seed firm increased, Firm A moved from a deterministic strategy of purchasing a seed firm to having a mixed strategy of owning a seed firm and licensing. Specifically, between cost of \$20 and \$22.5 million, Firm A became indifferent between purchasing a seed firm and licensing. In each possible scenario of the second model, Firm B chose to license its RRW trait with probability .96.

This study provides several implications, both in the private and public sector. First, knowledge of possible strategic interactions and potential equilibrium strategies gives guidance to agbiotechnology and seed firms when faced with such decisions. Second, this study is applied to the case of HRS wheat and has empirical implications in that it illustrates equilibrium strategies of agbiotechnology and seed firms involved in the commercialization of RRW and GM FRW. Finally, this study provides insight into determining if and when an agbiotechnology firm would have a commercialization strategy of purchasing a seed firm. This does not only aid the agbiotechnology firm, but also public institutions that own seed varieties. If an agbiotechnology firm does not license its trait, the other seed firms and public institutions would not be able to compete in the sale of that variety.

The main limitation of this study is that it is forward-looking. It examines the prospective commercialization of two GM traits in HRS wheat. Whether these traits reach commercialization is yet to be determined. Another limitation is the number of strategy combinations in the commercialization game. Game theory is stylistic in that one game does not provide general inferences, and the results are highly dependent on the assumptions of payoffs, order of play, and the number of players. However, this study provides a framework for future studies on commercialization and trait-stacking issues.

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