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Regulatory Approval Decisions in the Presence of Market Externalities: The Case of Genetically Modified Wheat

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This study examines the optimal approval strategy for genetically modified (GM) wheat varieties in Canada and the United States. Without an affordable segregation system, the introduction of GM wheat will create a market for "lemons" that will result in the loss of important export markets. Using a differentiated product trade model for spring wheat, with endogenous technology pricing, a payoff matrix is generated for the possible approval outcomes. Results show that the existence of the market externality removes the first-mover advantage for wheat producers from the approval of the new GM wheat variety. There are large distributional effects; wheat producers lose economic surplus, while consumers and the biotech company gain economic surplus. With a larger domestic market, the United States is more likely to experience net gain in economic surplus from the introduction of GM wheat.

Key words: biotechnology, market externalities, non-cooperative games, strategic approval decisions, trade

Introduction

Important strategic relationships exist between research and development (R&D) expenditures, new product approval decisions, and the gains from international trade. Edwards and Freebairn (1984) demonstrate a positive relationship between the development of cost-reducing technologies and the welfare of domestic firms that compete in the international market. Furthermore, Spencer and Brander (1983) show domestic firms achieve a first-mover advantage from the approval of a cost-reducing technology. In this paper, we extend the strategic framework to a social welfare analysis, which includes consumers, domestic firms, and the profits of the innovators. Using the case of genetically modified (GM) wheat, this analysis shows that negative asymmetric information externalities can eliminate the first-mover advantage for domestic firms (i.e., farmers).

The case of GM wheat has relevance to policy makers. As of March 2004, both the U.S. and Canadian governments have been faced with the decision of whether to approve a GM spring wheat variety which is tolerant to the low-cost herbicide Roundup®.[1] According to

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[1] In the United States, the approval process for new GM crops occurs in consultation with the Environmental Protection Agency, the U.S. Department of Agriculture, and the Food and Drug Administration. The approval process in Canada starts with an oversight committee of industry and scientific experts and is finalized through consultation between the Canadian Food Inspection Agency and Health Canada. While the current approval process for GM crops in both countries is based solely on scientific criteria, farm groups in both countries are advocating a change in the process to address market acceptance issues (Hirsh, 2003).

the Canadian Wheat Board (CWB), GM wheat is viewed as an inferior product by many wheat-importing countries. Moreover, it is difficult and costly to segregate GM wheat from non-GM wheat because they are not visually distinguishable from each other. Due to this lack of ability to segregate the two types of wheat, the market place is unable to distinguish adopters of GM technology from non-adopters. Given these conditions, the introduction of GM wheat will result in "a market for lemons," as described by Akerlof (1970), where all wheat exports from the GM adopting country are assumed to be inferior in countries where GM wheat is viewed as inferior to other bread wheat varieties.[2] This information externality will change trade flows, price levels, and the welfare impacts of innovation.

The welfare impacts of the introduction of GM wheat are estimated using a partial equilibrium trade model with a vertical structure where the technology provider uses its monopoly to maximize profits, and the wheat producers are assumed to be competitive with a differential willingness to pay for the technology. The Canadian and U.S. governments are assumed to act strategically to maximize domestic welfare. We calculate the optimal approval decisions for GM wheat in the United States and Canada using a non-cooperative game.

There are two important empirical results reported in this paper. First, without an affordable segregation system, the findings reveal there is no first-mover advantage for wheat producers in either country from the approval of a GM variety because of the "lemons" problem and the loss of export markets. Second, the optimal approval strategy for a new crop, and the outcome for the bilateral game, are dependent on the welfare function of the government regulators. The results show that wheat producers in both countries are made worse off, while the biotech firm and consumers are made better off from the approval of GM wheat. This finding implies wheat producers will lobby *against* the approval of GM wheat and the biotech firm will lobby *for* the approval of GM wheat—creating a difficult decision-making arena for governments seeking to increase private-sector investment in agricultural R&D.

The remainder of the paper is organized as follows. First, an overview is provided to give further background to the problem. Next, the theoretical model for the strategic game is described, including how the optimal strategies and the first-mover advantage are a function of the payoff matrix. The components of the partial equilibrium trade model are then presented, highlighting the farmer demand for the technology, technology pricing behavior by the innovator, the international supply and demand for GM and non-GM wheat, and finally the data used to parameterize the model. In the next section, the economic outcomes and payoff matrix for the four possible approval outcomes are discussed. The payoffs are then used to derive the optimal approval strategy for Canada and the United States, as well as a sensitivity analysis for key parameters. Conclusions and policy implications are given in the final section.

Background

Advances in agricultural biotechnology have allowed new crop varieties to be created with transgenic processes. In a transgenic process, a gene (or a small group of genes)

[2] This assumption is plausible when access is governed by national regulation, label requirements, or state trading enterprises.

from one species that is responsible for a desirable trait is transferred to the DNA of plant cells of an existing variety. These new transgenic varieties are commonly referred to as genetically modified or GM crops (McHughen, 2000).

Herbicide-tolerant (HT) varieties have been very successful GM crop innovations, making up a significant proportion of soybean, canola, and corn acreage in North America (Fernandez-Cornejo, 2004). Among the HT varieties, those tolerant to Roundup are the most prevalent. A GM spring wheat variety which is tolerant to Roundup has been developed, and the owner of the new variety is seeking regulatory approval in both Canada and the United States (Bell, 2002). If these HT varieties are introduced, they would be the first GM wheat placed on the world market.

Many consumers, particularly in Europe and Asia, fear that the consumption and production of GM varieties will have long-term adverse impacts on human health and the environment.[3] These concerns are resulting in demands for regulation, product labeling, and, in the case of some countries, outright bans on production and importation. In 2004, the Canadian Wheat Board reported that 87% of wheat-importing countries want assurance that Canadian exports do not contain GM wheat (Reuters News Service, 2004). Despite having no outright ban on importing GM products, some countries have put in place GM tolerance levels which are prohibitive. For example, the European Union standards allow for 0.9% GM contamination in a non-GM shipment (i.e., a bulk wheat shipment) (Downey and Beckie, 2002).

Based on our own earlier research (Furtan, Gray, and Holzman, 2003), we make the assumption that the United States and Canada do not have the ability to affordably distinguish (i.e., segregate) GM and non-GM wheat to anticipated tolerance levels. Consequently, we argue that growing GM wheat will result in the loss of access to these non-GM markets.[4] As reported in table 1, these non-GM markets are some of the largest markets for Canadian and U.S. wheat exports.

Theoretical Model for the Two-Stage Dynamic Game

The decision to approve GM wheat in the United States and Canada is modeled as a two-stage dynamic game with complete and perfect information. The regulators in each country are assumed to have the objective of maximizing domestic social welfare and to be fully aware of economic consequences of approval in either country. The players' moves occur in sequence, both players' payoff functions are known, and at each stage of the game the players know the previous decision made by the other player (Gibbon, 1992). Given the binary choice of the regulators (to approve or not approve), there are only four possible outcomes and four payoff sets. The choices made by the regulators depend not only on the payoffs, but also on the sequence of decision making, influenced by whether a first-mover advantage exists.

To determine whether a first-mover advantage exists, the payoffs where country A moves first are compared to the payoffs where country B moves first. If either country can improve its equilibrium payoff by approving first and deterring approval by its rival,

[3] Consumer resistance to GM wheat exists because of the perceived long-term health implications from consuming the product. We do not evaluate the assertion that GM crops may be harmful to human health.

[4] This problem has been acknowledged, and the biotech firm has stated publicly it will not commercialize the GM varieties until an affordable system of segregation is put in place.

Table 1. Spring Wheat Domestic and Export Sales Data for Canada, the United States, and ROW (tonnes, 1996–2000 five-year average)

		Consuming Market			
Source	Quality Level	GM-Accepting (g)	Non-GM (n)	Canada (c)	U.S. (u)
Canada (c)	Low (l)	628,000	553,000	134,000	0
	Medium (m)	629,000	2,830,000	890,000	326,000
	High (h)	708,000	3,023,000	1,093,000	562,000
U.S. (u)	Low (l)	80,116	25,597	0	459,059
	Medium (m)	341,310	708,042	48,994	1,180,439
	High (h)	1,230,367	3,981,348	231,698	4,918,498
ROW (r)	Low (l)	537,900	838,750	0	10,000
	Medium (m)	2,004,900	3,126,250	0	41,800
	High (h)	2,347,200	3,660,000	0	119,860

Sources: Canadian Wheat Board (2002); USDA/ERS (2002); and calculations by the authors.

then that country has an incentive to act quickly and be the first mover. If only one country has a first-mover advantage, there would be an incentive for the country's regulators to speed up the process in order to be the first mover and strategically influence the outcome. If a first-mover advantage exists for both countries, the theoretical solution will be indeterminate; practically, the solution will depend on which country is able to license the technology first. When neither country has a first-mover advantage—i.e., no incentive or no ability to affect its rival's actions—the outcome of the game is independent of which country moves first.

When the sequence of moves in the game has been determined, the game is solved through a process of backward induction. In the case where country A moves first, country B will make the payoff-maximizing response to this move (see figure 1). Country A, having knowledge of how B will respond, will then choose the action which will lead to the outcome with the highest payoff, given this response. Given A's optimal move, and B's optimal response, the outcome of the game is determined.

For purposes of calculating the optimal strategy, it is initially assumed that the regulators wish to maximize domestic social welfare, which includes the monopoly profits of the technology owner, producer surplus of the competitive farm sector, and consumer surplus. The social welfare will be affected by the actions of both the domestic and foreign regulators, as the decisions to approve GM wheat will affect export markets, wheat prices, the endogenous adoption rate and price of the new technology, and the impact on the costs of wheat production. More specifically, the objective function of the regulators in Canada can be written as:

$$\text{(1)} \qquad \max_{l_c \in (0,1)} SW_c = \pi_c(w_c^{T^*}) * l_c + PS_c^F\left[P_c^W(l_c, l_u), l_c, w_c^{T^*}\right] + CS_c\left[P_c^W(l_c, l_u)\right],$$

where l_c is chosen from a discrete set where 0 represents the decision not to approve GM wheat, and 1 represents the decision to approve GM wheat; SW_c is Canadian Social Welfare; π_c is the profit of the monopoly technology owner charging the profit-maximizing price of $w_c^{T^*}$, which only exists when l_c is equal to 1; PS_c^F is the producer surplus of farmers in Canada, which is a function of the price of wheat (P_c^W), the approval of the

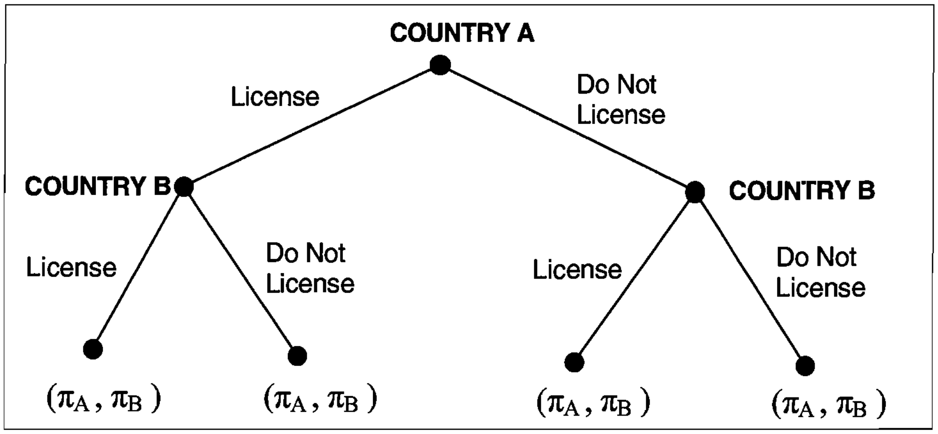

Figure 1. Payoffs for Country A and Country B

cost-saving technology (l_c), and the price charged for the technology ($w_c^{T^*}$); and CS_c is the domestic consumer surplus which is affected by the price of wheat. The price of wheat is endogenously determined within a trade model, and is affected by supply and demand impacts of domestic approval (l_c) and U.S. approval of the technology (l_u). The objective function of the U.S. regulators is symmetric with respect to the subscripts u and c, or:

$$(2) \qquad \underset{l_u \in (0,1)}{\text{Max}}\ SW_u = \pi_u(w_u^{T^*}) * l_u + PS_u^F\left[P_u^W(l_u, l_c), l_u, w_u^{T^*}\right] + CS_u\left[P_u^W(l_u, l_c)\right].$$

The optimal strategic behavior of the regulators in each country depends on the payoff matrix for the four possible outcomes of the approval process. The existence of the "lemons" problem makes the theoretical effects of approving a cost-reducing technology ambiguous. Because the approval of GM wheat will reduce the demand for exports and simultaneously reduce the cost of production, the total domestic social welfare can either increase or decrease, contingent upon which effect is larger. The impact of foreign approval is also ambiguous, given the increase in foreign supply combined with a substitution away from domestic products. Based on the ambiguous nature of these theoretical effects, gaining practical insight into the optimal strategies for the approval of GM wheat in Canada and the United States requires quantitative estimates of the functions described generally in equations (1) and (2).

The Partial Equilibrium Trade Model

To quantify the impacts of GM wheat approval in Canada and the United States, we use a partial equilibrium model incorporating both vertical and horizontal market relationships. This partial equilibrium model is described in the following order: the farmer's demand for the technology, the innovator's incentives to price the technology, the product-differentiated international supply and demand model for GM and non-GM wheat, and finally, the market-clearing conditions.

The Farmer's Demand for the Technology

The farmer's demand for the new technology is based on the profitability of adopting GM wheat versus continuing to grow non-GM wheat. The innovating firm is assumed to charge a single price (w^T) for the Technical Use Agreement (TUA),[5] which is a binding contract between the wheat producer and the biotech firm that allows the producer to use the GM crop variety in return for a fixed price per acre planted. There are heterogeneous wheat producer groups, which differ by individual farm characteristics such as tillage systems, crop rotations, soil texture, and varying environmental conditions. This heterogeneity will affect the magnitude of both the herbicide cost savings and the yield advantage from adopting GM wheat, resulting in a stepped aggregate supply curve for wheat. Producers in group i in country j will adopt GM wheat only if the benefits from growing GM wheat minus the cost of the technology exceed the return from non-GM wheat, or:

$$P_j^W Y_{ji}' - C_{ji}' - w_j^T \geq P_j^W Y_{ji} - C_{ji}, \tag{3}$$

where P_j^W is the price of GM wheat in country j, Y_{ji}' is the GM wheat yield for group i, C_{ji}' is the GM wheat herbicide cost, w_j^T is the per acre price of the technology, Y_{ji} is the non-GM wheat yield, and C_{ji} is the non-GM wheat herbicide cost. Without segregation, both adopting and non-adopting producers receive the price of GM wheat, which is the "lemons" result.

The Pricing Behavior of the Technology Owner

The technology owner is protected by patent, and therefore is modeled as a monopoly supplier of Roundup-Ready® GM wheat. Given the new technology is being sold to heterogeneous wheat producers (i.e., the wheat producers have different cost advantages from adopting GM wheat), the monopolist faces a downward-sloping stepped demand function for the technology in each country. Facing the stepped demand curve, the monopolist is assumed to charge a single profit-maximizing price in each country. This price charged to producers for the new technology is specified in the Technical Use Agreement. The TUA includes the cost of the seed and any profit the company can extract from producers. The marginal cost of producing the non-rival TUA is assumed to be zero; thus the objective function of the monopolist in country j becomes one of revenue maximization, as shown in equation (4):

$$\underset{w_j^T}{\text{Max}}\ \pi_j = w_j^T * N_j(w_j^T), \tag{4}$$

where π_j is producer surplus of the innovator, w_j^T is the price charged per acre for the technology, and $N_j(w_j^T)$ represents the number of acres where the technology is adopted.

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[5] In other herbicide-tolerant crops, the biotech firm has used a single price for its technology, rather than attempt to price discriminate across producers.

The Wheat Trade Model

The price impacts of the introduction of GM wheat are modeled in a partial equilibrium trade framework. The model is built around the demand and supply of heterogeneous products—GM and non-GM spring wheat, which is further differentiated by country of origin and level of protein. This level of differentiation is required to capture the impacts of relative supply and demand that will occur within particular market segments, and allows the potential for two-way trade common in the wheat market (e.g., the United States is a significant importer and exporter of spring wheat).

The global wheat demand is divided into four consuming "regions": (*a*) the U.S. domestic market, (*b*) the Canadian domestic market, (*c*) one foreign region which is indifferent between GM and non-GM wheat, and (*d*) one foreign region which is intolerant to GM products and will import only non-GM products.

In each consuming region, spring wheat demand is further differentiated by protein levels and by origin of supply. Wheat is differentiated by protein into three levels: (*a*) wheat with 14% protein and higher, (*b*) wheat with protein content between 12.5% and less than 14%, and (*c*) wheat with under 12.5% protein. Each protein level has different milling and baking qualities and tends to be used for different purposes. These protein levels are treated as separate markets, but we assume lower protein wheat is weakly inferior (Lapan and Moschini, 2001) to high protein wheat, such that at equal prices, higher protein wheat becomes perfectly substitutable for low protein wheat.[6] Within a protein level, wheat produced in different countries [i.e., Canada, the United States, and the rest of the world (ROW)] also differs by milling and baking properties, and these products are treated by the industry as distinct, but highly substitutable (Wilson and Dahl, 1999; Larue, 1991). This differentiation results in markets for nine different wheat types in each consuming region. Within each protein range, demand for wheat from a specific origin is a function of the prices from all origins. The demand equation for each type of wheat in the three GM consuming regions is given by (5):

$$(5) \qquad D_{jz}^{v} = \gamma_{jz}^{v} + \sum_{j} \delta_{jz}^{v} P_{jz}^{v} \quad \text{for } v = c, u, g; \; j = c, u, r \quad \forall z.$$

Equations (6a)–(6d) show the demand for wheat in the non-GM consuming region, which is dependent on the approval decisions of Canada (l_c) and the United States (l_u):

$$(6a) \qquad D_{jz}^{n} = \gamma_{jz}^{n} + \sum_{j} \delta_{jz}^{n} P_{jz}^{n} \quad \text{when } l_c = 0; \; l_u = 0; \; j = r, c, u \quad \forall z,$$

$$(6b) \qquad D_{jz}^{n} = \gamma_{jz}^{n} + \sum_{j} \delta_{jz}^{n} P_{jz}^{n} \quad \text{when } l_c = 1; \; l_u = 0; \; j = r, u; \text{ and } D_{cz}^{n} = 0 \quad \forall z,$$

$$(6c) \qquad D_{jz}^{n} = \gamma_{jz}^{n} + \sum_{j} \delta_{jz}^{n} P_{jz}^{n} \quad \text{when } l_c = 0; \; l_u = 1; \; j = r, c; \text{ and } D_{uz}^{n} = 0 \quad \forall z,$$

$$(6d) \qquad D_{jz}^{n} = \gamma_{jz}^{n} + \sum_{j} \delta_{jz}^{n} P_{jz}^{n} \quad \text{when } l_c = 1; \; l_u = 1; \; j = r; \; D_{uz}^{n} = 0; \text{ and } D_{cz}^{n} = 0 \quad \forall z.$$

From equations (5) and (6), v represents the consuming regions (c = Canadian domestic market, u = U.S. domestic market, g = ROW GM-accepting, and n = ROW non-GM

[6] The substitution from higher protein to a lower protein is modeled through the aggregation of supply if a price inversion would otherwise exist.

markets); z indicates quality level (l = low, m = medium, and h = high); and j represents the spring wheat-producing regions (c = Canada, u = United States, and r = ROW).

The total supply of spring wheat in region j before approval of GM wheat is dependent on a weighted average producer price of spring wheat in that region. The proportion of the total wheat crop falling into quality class z is exogenous within the model, and is defined as a constant (γ_{jz}).[7] The total supply of spring wheat of quality level z for each region j is written as:

(7) $$S_{jz} = \gamma_{jz}(\alpha_j + \beta_j P_j), \quad \text{for } z = l, m, h; \text{ and } j = c, u, r,$$

where P_j is the price of spring wheat (weighted average price across all quality classes).

After the approval of the cost-reducing GM wheat in country j, the supply curve for wheat shifts to the right. The distance of the intercept shift is given by:

(8) $$\alpha_j' = \left(\frac{\sum_{i=1}^{h} [P_j(Y_i' - Y_i) - C_i' - C_i - w_j^T] G_i}{\sum_{i=1}^{h} (Y_i' * G_i) + \sum_{i=h}^{k} (Y_i * N_i)} \right) * \left(\frac{-1}{\beta_j} \right),$$

where α_j' is the horizontal intercept shift, G_i is the area of GM wheat, and N_i denotes the non-GM wheat area. The numerator of the first term is the total cost saving per tonne as calculated from equation (3), the denominator is total production, and the whole term represents the average per tonne reduction in cost; the second term is equal to the negative inverse of the slope of the supply curve used to translate the cost reduction into a rightward shift of the supply curve.

The supply curve in region j after approval of GM wheat is designated by:

(9) $$S_{jz}' = \gamma_{jz}\left(\alpha_j + \alpha_j' + \beta_j P_j\right) \ \forall z.$$

The partial equilibrium model described in equations (3)–(9) is closed with market-clearing conditions where the quantity of each protein level produced is equal to the quantity demanded, as shown by:

(10) $$S_{jz} \equiv \sum_{v} D_{jz}^{v} \ \ \forall j, \ \forall z.$$

Data

The partial equilibrium model outlined above is parameterized using industry data and elasticity estimates obtained from the literature. A more econometric approach is ruled out given the ex ante nature of the analysis.

Data to generate the stepwise demand function for the GM wheat technology were provided by industry, as reported in Holzman (2001). These data included yield advantage of GM wheat and the herbicide cost savings, and proportion of land in each wheat

[7] The parameter γ_{jz} is a function of the weather, rather than an endogenous management variable.

producer group.[8] The GM wheat yield advantage ranged from zero to 5% higher than non-GM wheat, and was attributed to improved weed control over non-GM wheat. The herbicide cost savings ranged from more than $10 per acre to zero. These cost and yield data were combined with the endogenous wheat price to create a demand curve for the technology.

International wheat trade data were obtained from the Canadian Wheat Board (CWB, 2002), the International Grains Council (2002), and the USDA's Economic Research Service (USDA/ERS, 2002).[9] Domestic and export sales data for Canada, the United States, and ROW are based on a five-year average from 1996 to 2000 (USDA/ERS, 2002; CWB, 2002), and are reported in table 1. The export price for high and medium quality wheat is a five-year weighted average Minneapolis cash price for hard red spring wheat (13% to 15% protein level). The price for low quality wheat is based on a five-year average Kansas City cash price for hard red winter wheat (ordinary protein).

The demand equations were parameterized using an Armington approach, where there is a common elasticity of substitution among the commodity goods within a group. In this case, a group consists of wheat of the same protein level from the three countries of origin. In the Armington model, the own- and cross-price demand elasticities for wheat in market are calculated using historical market shares (which are calculated from table 1), the elasticity of substitution, and the overall elasticity of demand for wheat. The elasticity of substitution value used in the model is 20, and the overall elasticity of demand is -0.15 (Alston, Gray, and Sumner, 1994). The own- and cross-price elasticities of demand were calculated as follows:

$$\eta_{jz}^{v} = -(1 - s_{jz}^{v})\sigma_{jz} + s_{jz}^{v}\eta_{jz}, \tag{11}$$

$$\varepsilon_{jz}^{v} = s_{jz}^{v}(\sigma_{jz} + \eta_{jz}), \tag{12}$$

where η_{jz}^{v} and ε_{jz}^{v} are the own- and cross-price elasticities of demand in market v for wheat of quality level z produced in country j; s_{jz}^{v} is the share of total consumption of spring wheat in market v supplied by country j; σ_{jz} is the elasticity of substitution between supplying regions; and η_{jz} is the overall elasticity of demand.

These demand elasticities are combined with price levels and the quantity data reported in table 1, to parameterize the linear demand functions reported in equations (5) and (6). The supply functions are parameterized using prices, the quantities reported in table 1, and a price elasticity of 0.5. These supply and demand equations are used together to estimate the outcome of GM wheat approval.

Model Results and Sensitivity

The partial equilibrium model was solved using the Solver Routine in MSExcel®. In scenarios where approval took place, the model was solved recursively, solving for the endogenous wheat prices and then the profit-maximizing technology price, then repeating the process until all prices converged to stable values. The partial equilibrium model was solved for each of four possible approval outcomes to create the payoff matrix

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[8] Wheat producers were disaggregated into 18 groups in Canada and 24 groups in the United States.

[9] We also obtained from the CWB a list of wheat-importing countries that will not accept GM wheat.

for the strategic game. The economic outcomes of these four scenarios are described briefly below, before we examine the optimal approval strategies.

- *Scenario 1.* The equilibrium conditions for the case in which GM wheat is not approved in either country are presented in the first column of table 2. These initial equilibrium conditions are used as a base comparison for each of the approval decisions.

- *Scenario 2.* An autonomous move by Canada to approve GM wheat results in the economic outcomes reported in the second column of table 2. This move reduces both the Canadian and U.S. wheat producer price. The Canadian producer price declines from $149.61/tonne to $134.43/tonne due to the loss of the non-GM market, reflecting the fact that markets view all Canadian wheat as being GM (i.e., the "lemons" problem). This results in a loss of $160.3 million to Canadian wheat producers, while domestic consumers gain $26.4 million from lower prices.[10] Although U.S. producers receive the benefit of greater demand in the non-GM markets, this is more than offset by additional Canadian wheat being sold in the other U.S. markets, resulting in a net reduction in the U.S. price and a loss of $13.7 million in economic surplus to wheat producers. Interestingly, this loss is more than offset by the gain to U.S. consumers with access to cheaper Canadian wheat. In this scenario, the biotech firm's profits are maximized with a TUA price of $6.43 per acre, with an adoption rate of 74% resulting in $100.5 million in surplus. Total economic surplus in Canada declines by $33.5 million, while the economic surplus in the United States increases by $45.9 million.

- *Scenario 3.* An autonomous move by the United States to approve GM wheat results in the economic outcomes reported in the third column of table 2. In this case, the U.S. wheat producer price declines from $152.42/tonne to $142.49/tonne. The price decline occurs because U.S. wheat is shut out of the non-GM-accepting markets, which are now filled by Canada and the ROW. The result is a loss in wheat producer surplus of $116.4 million and a gain in U.S. consumer surplus of $59.4 million. The biotech firm is able to charge a fee of $5.89/acre with 83% adoption, resulting in revenues of $74 million. The net effect on the United States is a gain in economic surplus of $17.3 million. The net effect of U.S. approval on Canadian producers is slightly positive, indicating that the substitution effect on demand more than offsets the supply-increasing effect. Canadian consumers benefit by $15.7 million through lower prices of U.S. wheat. The overall impact is a gain with a total economic surplus of $25.3 million in the Canadian economy.

  The approval of GM in either the United States or Canada improves the economic surplus of the respective exporting neighbor. This result stands in contrast to the usual "treadmill" or "beggar thy neighbor" impact of technology adoption. This interesting finding is likely driven by the substitution effect in the non-GM market.

[10] We have no information on how markets within a "region" may divide up in terms of accepting and not accepting GM wheat. Therefore, it is assumed here that the "region" market is homogeneous with respect to its acceptance of GM wheat.

Table 2. Equilibrium Conditions for the United States and Canada

	SCENARIO			
Description	[1] Neither Country Approves GM Wheat	[2] Canada Approves GM Wheat	[3] United States Approves GM Wheat	[4] Both Countries Approve GM Wheat
United States:				
Price ($US/tonne)[a]	$152.42	$151.38	$142.49	$124.30
Quantity Produced (mil. tonnes)	13.20	13.16	12.86	12.06
TUA Price ($/acre)	$0	$0	$5.89	$5.85
Adoption Rate (%)	0%	0%	83%	82%
GM Cost Savings ($/tonne)	$0	$0	$2.04	$1.64
U.S. Welfare Changes ($ mil.):				
Wheat Producers	$0	-$13.7	-$116.4	-$345.4
Biotech Firm	$0	$0	$74.3	$72.9
Consumers	$0	$59.6	$59.4	$543.7
Total Surplus	$0	$45.9	$17.3	$271.2
Canada:				
Price ($US/tonne)	$149.61	$134.43	$150.45	$119.98
Quantity Produced (mil. tonnes)	11.38	10.86	11.41	10.31
TUA Price ($/acre)	$0	$6.43	$0	$6.14
Adoption Rate (%)	0%	74%	0%	74%
GM Cost Savings ($/tonne)	$0	$1.54	$0	$1.46
Canadian Welfare Changes ($ mil.):				
Wheat Producers	$0	-$160.3	$9.6	-$313.7
Biotech Firm	$0	$100.5	$0	$96.0
Consumers	$0	$26.4	$15.7	$171.0
Total Surplus	$0	-$33.5	$25.3	-$46.7

Source: Calculations by the authors.

[a]The equilibrium prices are based on a weighted average price across all quality levels of wheat. Given the United States has a greater proportion of higher quality wheat, it has a higher weighted average price (all values are in $US).

- *Scenario 4.* The simultaneous move by Canada and the United States to approve GM wheat results in the economic outcomes reported in the final column of table 2. The combined action produces by far the largest negative impacts on price—the U.S. price decreases to $124.30/tonne, while the Canadian price decreases to $119.98/tonne. This decline in wheat price slightly reduces the producer's willingness to pay for the technology as compared to the autonomous approvals, reflecting a reduction in the value of the marginal yield increases. The wheat producers suffer significant economic losses in both countries, losing $313.7 million in Canada and $345.4 million in the United States. The U.S. producer loss is more than offset by a gain of $543.7 million to consumers which, when combined with the gains to the biotech firm, results in an increase in total surplus of $271.2 million per year. In Canada, with a more limited gain to consumers of $171 million, there is a decrease in total economic surplus of $46.7 million. These differing results suggest that the size of the domestic market is an important determinant for the overall impact on the economy.

Optimal Approval Strategies

The outcomes of the four approval scenarios can be used to construct a payoff matrix for the dynamic game of strategic GM wheat approval. This is done in table 3, where the numbers appearing in bold italics report the total economic surplus for Canada and the United States for each of the outcomes, which we assume are measures of social welfare for each country. To find the optimal strategic behavior, we begin by examining whether there is a first-mover advantage in either country in the payoff matrix. Examining the payoffs for the United States, table 3 shows this country receives a higher payoff when it approves GM wheat, regardless of whether Canada approves or not (i.e., \$17.3 million versus \$0, and \$271.2 million versus \$45.9 million). Because Canada cannot influence the U.S. decision, it does not have a first-mover advantage.

As observed from table 3, the payoffs for Canada reveal that Canada has the higher payoffs when it does not approve GM wheat, regardless of whether the United States licenses or not (i.e., \$0 versus -\$33.5 million, and \$25.3 million versus -\$46.7 million). This result indicates the United States cannot influence the Canadian decision, and therefore does not have a first-mover advantage. The lack of a first-mover advantage for either country implies that the outcome will be invariant to the sequence of moves. In this case, the outcome of the game is obvious; the optimal U.S. strategy will be to approve GM wheat, and the optimal strategy for Canada will be not to approve, resulting in an outcome of Payoff Set 2 (table 3).

The optimal strategies of the two countries would differ if the regulators placed sufficient weight on maximizing the welfare of one particular group in each country. If the regulators were solely interested in the welfare of consumers or the biotech company, there would be no first-mover advantage; thus, the optimal strategy for both regulators would be to approve the technology, resulting in Payoff Set 4 (table 3). In the case where the regulators were solely interested in wheat producer welfare, neither country would have an incentive to approve the variety, and would choose to maintain the status quo.

Sensitivity Analysis

To determine the robustness of the model results, a sensitivity analysis is performed on the key parameters. First, a sensitivity analysis is conducted on the elasticity of substitution (see table 4), and second, on the overall elasticity of demand parameter values (table 5). The sensitivity analysis results are contrasted with the results of the initial solution in the case of consumer resistance to GM wheat.

An elasticity of substitution value of 20 for wheat from countries of different origins was used for the initial solution. For the sensitivity analysis, we re-solve the model using elasticity of substitution values of -10 and -30 (table 4). Using an elasticity of substitution value of -10 increases the producer welfare loss to the country approving GM wheat. This result follows from the structure of the Armington model. Reducing the elasticity of substitution makes it more difficult for the country that approves GM wheat to divert wheat into the GM-accepting markets, which further reduces the producer price. Using an elasticity of substitution of -10 does not change the optimal approval strategy (compared to the initial solution) if governments consider only wheat producer welfare changes.

Table 3. Non-Cooperative Game Payoffs ($US millions)

		Canada Does Not Approve		Canada Approves	
		Change in Canadian Welfare	Change in U.S. Welfare	Change in Canadian Welfare	Change in U.S. Welfare
U.S. Does Not Approve		— Payoff Set 1 —		— Payoff Set 2 —	
	Biotech Firm	0	0	100.5	0
	Wheat Producer	0	0	-160.4	-13.7
	Consumer	0	0	26.4	59.6
	Total Surplus	***0***	***0***	***-33.5***	***45.9***
U.S. Approves		— Payoff Set 3 —		— Payoff Set 4 —	
	Biotech Firm	0	74.3	96.0	72.9
	Wheat Producer	9.6	-116.4	-313.7	-345.4
	Consumer	15.7	59.4	171.0	543.7
	Total Surplus	***25.3***	***17.3***	***-46.7***	***271.2***

Source: Calculations by the authors.

Table 4. Sensitivity Analysis on the Elasticity of Substitution ($US millions)

		Canada Does Not Approve		Canada Approves	
Elasticity of Substitution = -10		Change in Canadian Welfare	Change in U.S. Welfare	Change in Canadian Welfare	Change in U.S. Welfare
U.S. Does Not Approve		— Payoff Set 1 —		— Payoff Set 2 —	
	Wheat Producer	0	0	-276.5	-11.3
	Total Surplus	***0***	***0***	***-134.7***	***81.2***
U.S. Approves		— Payoff Set 3 —		— Payoff Set 4 —	
	Wheat Producer	12.5	-214.5	-490.6	-534.9
	Total Surplus	***41.1***	***-36.8***	***-159.2***	***296.1***
Elasticity of Substitution = -30		Change in Canadian Welfare	Change in U.S. Welfare	Change in Canadian Welfare	Change in U.S. Welfare
U.S. Does Not Approve		— Payoff Set 1 —		— Payoff Set 2 —	
	Wheat Producer	0	0	-113.8	-11.7
	Total Surplus	***0***	***0***	***5.8***	***31.9***
U.S. Approves		— Payoff Set 3 —		— Payoff Set 4 —	
	Wheat Producer	7.4	-77.2	-231.8	-253.2
	Total Surplus	***18.5***	***38.8***	***-2.6***	***235.5***

Source: Calculations by the authors.

Table 5. Sensitivity Analysis on the Overall Elasticity of Demand ($US millions)

		Canada Does Not Approve		Canada Approves	
Total Demand Elasticity = -0.10		Change in Canadian Welfare	Change in U.S. Welfare	Change in Canadian Welfare	Change in U.S. Welfare
U.S. Does Not Approve		**— Payoff Set 1 —**		**— Payoff Set 2 —**	
	Wheat Producer	0	0	-160.5	-13.6
	Total Surplus	***0***	***0***	***-33.6***	***45.9***
U.S. Approves		**— Payoff Set 3 —**		**— Payoff Set 4 —**	
	Wheat Producer	9.9	-116.5	-315.5	-340.5
	Total Surplus	***25.5***	***-17.1***	***-53.4***	***257.1***
Total Demand Elasticity = -0.20		Change in Canadian Welfare	Change in U.S. Welfare	Change in Canadian Welfare	Change in U.S. Welfare
U.S. Does Not Approve		**— Payoff Set 1 —**		**— Payoff Set 2 —**	
	Wheat Producer	0	0	-160.1	-13.7
	Total Surplus	***0***	***0***	***-33.3***	***45.7***
U.S. Approves		**— Payoff Set 3 —**		**— Payoff Set 4 —**	
	Wheat Producer	9.3	-116.2	-311.6	-340.1
	Total Surplus	***25.1***	***17.5***	***-46.8***	***267.0***

Source: Calculations by the authors.

If governments consider the change in total economic surplus, the optimal approval strategy is for both countries to not approve GM wheat. This is a change from the initial solution where the optimal decision for the United States was to approve and Canada not to approve GM wheat. The change in the optimal approval strategy occurs because the U.S. producer welfare loss is now greater than the sum of the biotech firm and U.S. consumer welfare gains. Hence, whether it is optimal for the United States to autonomously approve GM wheat appears to be sensitive to model parameters.

When using an elasticity of substitution value of 30, the optimal strategy does not change (compared to the initial solution). If government regulators consider only the change in wheat producer welfare, the two countries will not approve GM wheat. An increase in the elasticity of substitution reduces the welfare loss for producers in the approving country. However, it still does not make producers better off compared with before GM wheat is approved. If the change in total welfare is the criteria used, the United States will approve GM wheat and Canada will not approve GM wheat.

The sensitivity analysis on the overall elasticity of demand for wheat (table 5) indicates that the parameter has little effect on the welfare measures for both countries. Using overall elasticity of demand values of -0.10 and -0.20 did not change the optimal approval strategy for either the wheat producer or total welfare criteria.

Conclusions

Strategic trade models demonstrate that a country will achieve a first-mover advantage from approving a cost-reducing technology. This result holds when there are no externalities, such as a lack of market information, associated with approving the new technology. In the case of GM wheat, however, there is no first-mover advantage for wheat producers because of consumer resistance to the product. Without an affordable segregation system, the market for the higher valued non-GM wheat is destroyed because of the lack of information, resulting in a reduction in producer surplus in the approving country.

Findings of this analysis reveal that a new technology can meet all the scientific criteria for approval but still be harmful to producer welfare. By ignoring consumer response, the approval process for GM crops in both the United States and Canada may result in a sub-optimal approval decision. Given current consumer attitudes toward GM technologies, this paper provides a useful framework for addressing the economic implications of approving GM crops.

The inclusion of market information in the approval process will create a challenge for government regulators because of the tradeoff between the biotech firm and wheat producer welfare. Governments are currently attempting to increase the quantity of private-sector investment in agricultural R&D. How the government resolves the tradeoff between the interests of the biotech firm and those of the wheat producers will affect the future development of agricultural biotechnology.

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