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USING SIMULATION FOR ECONOMIC POLICY ANALYSIS IN THE GLOBAL AGRICULTURAL SUPPY CHAIN

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ABSTRACT

The purpose of this paper is to demonstrate how discrete dynamic simulation can be used to measure the impact regulation has on business processes and therefore operational-contractual costs in global agricultural supply chains. In particular, we examine how regulation of genetically modified organisms (GMOs) in the European Union (EU) affects the cost of contracting for soybean supplies between farmers and grain elevator firms in the U.S. Using a simulation model of business processes at a grain elevator operation, we examine how sensitive contract costs are to changes in a purity threshold for non-GMO content set by EU regulation. Results indicate elevator business processes are extremely sensitive to changes in non-GMO thresholds. Even at small changes in purity, contracting costs varied between $0.04-0.09 cents per bushel. The implication is regulation of GMOs might protect EU consumer rights, but protection may be costly and borne by agribusinesses in the U.S. agricultural supply chain.

1 INTRODUCTION

Almost two decades have passed since agrobiotechnology entered the global marketplace. After years of sizable investments made by biotechnology giants such as Monsanto, genetically modified (GM) crops were quickly adopted by farmers in key agricultural producing countries (Kalaitzandonakes 2003). Since that time, the story of rapid, global adoption of GM crops has become familiar to many.

Equally familiar has been the reluctance of some consumer groups to buy products containing GMOs. In particular, consumers in Europe and in other parts of the world have not embraced GM technology. In response to consumer concerns, many countries have installed mandatory labeling and traceability regulations for food and feeds containing GMOs. And while the European Union (EU) and Japan have opted to regulate agricultural biotechnology through mandatory labeling and allowable GM content found in food and feed products (e.g., GM thresholds), the U.S. and Canada have encouraged voluntary labeling at low thresholds.

Given the rapid, and uneven, regulation of GMOs in the global marketplace, how will EU regulation of GMOs affect agribusinesses operating in the global agricultural supply chain? From an economic policy analysis perspective, how can we understand the possibilities?

This study features the use of a discrete dynamic simulation model of an elevator operation in the U.S. to identify how GMO regulation affects business processes and therefore contracting costs between farmers and an elevator operating in the Midwest. In section two, we explain how GMO regulation creates economic incentives for changes in business processes at the elevator stage in the agricultural supply chain. Those adaptations result in additional costs when procuring soybeans with restricted non-GMO content. In section three, we describe the development of the simulation model, how changes in business processes were modeled, how we measured contracting costs, and the scenarios used in the analysis. Section four discusses results from the analysis. In general, regulation of GMOs in the form of restrictive content for non-GMO thresholds in soybeans can significantly increase the contracting costs between farmer and elevator. By elevators using a simple strip test of presence/absence of GMO content, contracting costs varied between $0.04 to $0.09 cents per bushel. In an industry where profit margins are slim (e.g. 2 cents), such regulation represents sizeable costs and could potentially create economic incentives for structural change in the global agricultural supply chain.

2 GMO REGULATION AND ITS IMPACT ON BUSINESS PROCESSES IN AGRICULTURE

Since commercial introduction in 1996, global acreage devoted to GM crops has continued to grow. In 2003, GM crop acreage represented 25 percent of total global acreage devoted to cultivation, or 167.2 million acres (Pew, 2004). The lead producer has been and continues to be the United States. In 2003, the U.S. produced 105.7 million acres, followed by Argentina (34.4), Canada (10.9), Brazil (8.4) and China (6.9). These countries represented 98 percent of total GM production in 2003.

While many countries have adopted GM crops, fewer countries have provided regulatory frameworks that encourage the importation of these crops for food and feed purposes. For example, the U.S. approach has defined GM crops as not significantly different from their commodity counterparts—the substantial equivalence principle. The U.S. approach means new regulation has not been needed for mandatory labeling of GM content in food or feed products given the similarities. However, in Europe and other countries such as Japan, regulatory frameworks have featured mandatory labeling of products containing GM content, or GMOs. For example, the EU regulations represent the most stringent in the global marketplace where food and feed products require labeling if GMO content exceeds an 0.9 percent threshold—a purity standard for GMO content (EC No 1830/2003).

The EU regulation has been developed to allegedly protect consumer rights 'to know' the level of GM content in food, but additional investments have been necessary to create traceability systems for market segmentation of food products into GM and non-GM categories (Kalaitzandonakes 2004). And the more stringent (lower) the purity threshold for non-GM content in food and feed, the greater the cost (Kalaitzandonakes et al. 2001).

The reason costs escalate is because lower purity thresholds require a change in business processes within the agricultural supply chain; the lower the threshold, the more significant and costly adaptations are in business processes to handle, store and ship grain with lower non-GM thresholds. For example, at the elevator stage in the agricultural supply chain, managers must identity preserve non-GM grain by: (a) taking deliveries at off peak times to minimize the risk of co-mingling GM with non-GM; (b) test for GM content arriving at the pits; (c) requiring farmers to clean combines and other equipment more rigorously; (d) requiring farmers to isolate production of non-GM varieties from GM varieties or increased border row restrictions; and (e) dedicating bin storage capacity for non-GM supplies on farm and at the elevator to minimize the risk of accidental mixture with GM supplies. As the non-GM threshold decrease, costs increase substantially, even with small changes in purity thresholds. The question is: how sensitive are costs to such changes in non-GM thresholds? That is, what is the cost of stringent GM regulation on agribusinesses operating in the global agricultural supply chain?

To understand the possibilities, we developed a dynamic discrete simulation model of elevator-farmer operations in the agricultural supply chain. Given regulation of GMOs creates the need to adapt business processes, simulation was chosen to capture such process specific adaptations in the model. Once changes in operations were measured, costs for adaptation were calculated depending on the non-GMO threshold, volume and type of contract used between farmer and elevator.

For this analysis, we examined two contract types, buyer-call and harvest delivery. The harvest delivery contract provides the farmer with residual control over delivery (e.g. timing, volume per delivery). The buyer-call (BC) contract provided the elevator with delivery control. We examined the cost impacts stringent purity thresholds (those ranging from 0.3 to 2.0) had on elevator operations using BC and HD contracts. In what follows, we describe how the simulation model was developed and how we captured costs associated with changes in business processes at the elevator stage in the agricultural supply chain.

3 DEVELOPMENT OF THE SIMULATION MODEL

The model has been developed with the Arena simulation software, which is a general purpose discrete-event simulation tool. The model has three basic components that define its structure. These components include: on-farm, business process, and the economic analysis modules.

3.1 On-Farm Module

All parameters of the model are stored in an Excel workbook so they can be modified to reflect the design and operations of the elevator under different process and contract structure assumptions (e.g., timing of deliveries from farms, routine handling of non-GMO supplies). The parameters used in the analysis are yearly data from the case study elevator, which is a large river terminal elevator. Data were collected through multiple personal interviews of plant managers and sorting through confidential company records. The required data necessary to model an elevator plant can be categorized as on-farm and elevator plant data.

To mimic how trucks randomly arrive at the elevator during the season, a large number of on-farm and plant variables were necessary to structure deliveries to reflect actual operations at the elevator. Also, contract structure variables were necessary to control for the different terms found within the buyer call and harvest delivery contracts. These variables are used during the simulation to structure the timing and volumes of non-GMO soybeans that are shipped to the elevator.

3.2 Business Process Module

The business process module is the core of the model. Within the model, trucks carrying commodity corn and soybeans arrive based on exponentially distributed shipments that have been estimated from the case study elevator. Based on these distributions, shipments begin arriving at the elevator during September 1-May 31st. Empirical (discrete) distributions are also constructed from case study data to determine the number of trucks (and their load capacities) to be shipped during the season.

Based on these shipments which mimic grain shipped from a network of farms, trucks arrive at the elevator and are unloaded at the pits. Grain from these trucks then flows to the appropriate bins for storage. During the simulation, visual basic technology (code) is used to schedule shipments of grain to reflect actual operations at the elevator. The model is configured to handle three shipping modes: trucks, rail cars, and barges. The code tracks the number of bushels stored at the elevator across all bins and signals release of stocks at the appropriate shipping times. All of the types of variables used on-farm and at the elevator plant are listed in the Table 1 below.

3.3 Economic Analysis Module

After each simulation, output statistics on key variables are exported into Excel Workbooks. To derive the transaction costs under buyer call and harvest delivery contract structures, draws from empirical distributions on the relevant transaction costs are made then assigned to the appropriate variables exported from the business process model. The @Risk program is used for this part of the analysis to derive the appropriate average estimates for costs. Examples of such key indicators include the utilization of the bins, number of trucks (and volume) rejected at pits because GM threshold is greater than the contractually agreed upon amount, and the like.

4 THE CASE STUDY

The case study elevator used in this study is a large river terminal facility located on the Illinois river and is owned by one of the largest grain merchandising companies in the global agrifood chain. The elevator primarily handles commodity corn and soybeans, and some non-GMO soybeans using buyer call and harvest delivery contracts. The elevator utilizes two pits and eight bins. Bin volumes ranged from 38,000 up to 1,850,000. Total storage capacity was equal to 4.39 million bushels. Based on case study data, the elevator handled (on average) more than 12 million bushels per year. The elevator did not operate grinding activities.

Also, the elevator only shipped grain using barges, although shipment of outbound grain is possible using trucks. From December 15th until March 15th, shipping operations cease because of low water levels and winter conditions. As such, the simulation model does not allow shipping to occur during these months. All grain received prior to December 15th is carried a minimum of 90 days.

Table 1: Agricultural Supply Chain Model Parameters

On-Farm	Contract variables for a network of farms	Total Volume of Commodity Corn Produced Total Volume of Commodity Soybeans Produced Timing and Volume of Commodity Deliveries GM Contamination of Non-GMO Supplies Volume of Non-GMO Supplies Timing of Non-GMO Supplies
	Scenario variables	Empirical distribution for assigning GM content to bushels
Elevator Plant	Pit variables	Delays, capacities, crop type
	Bin variables	Conveyor delays, capacities, crop type
	Schedule variables	Schedules for the plant such as number of working hours and open days per week
	Shipping variables	Shipping priorities by crop type, number of barges, rail cars, trucks, timing of shipments
	Scenario variables	Change in business processes such as dedicated pits, bins, and modes of shipping non-GMO supplies; Empirical distributions for testing at pits and shipping

4.1 Measurement of Costs

One of the most significant types of transaction costs measured by the simulation model is search and bargaining costs associated with the elevator having to replace non-GMO soybean shipments. The reason is because non-GMO soybean supplies exceed the desired GM threshold; a form of contract performance failure on the part of the farmer. Within the simulation model, testing of GM thresholds occurs when trucks arrive at pits and before barges of non-GMO supplies are shipped to end-users. For arriving trucks, the model tracks the number of non-GMO bushels that fail a simple ELISA (or, enzyme-linked immunosorbent assays) test commonly referred to as a "strip test" (Mason 1992). The strip test is conducted at the pits to determine if there is a GM seed present in the sample. For departing barges, the model tracks the number of barges (and bushels carried) that fail a PCR (or, polymerase chain reaction) test (Innis et al 1990). The PCR test provides an estimate of the amount of GM content found in the sample where the ELISA test only concludes the presence of a GM seed.

These rejected non-GMO soybean bushels represent the total volume in each simulation that must be replaced by elevator management. The simulation model exports the total number of rejected non-GMO bushels into Excel where a per bushel (transaction) cost is used to calculate search and bargaining costs under buyer call and harvest delivery contract structures. However, the allocation of search and bargaining costs depends on the assignment of liability found within the non-GMO soybean contract. In this study, elevator management was liable for ensuring the appropriate volumes (with the agreed upon threshold) were sent to end-users.

Provided the elevator has the liability of replacing these supplies, search and bargaining costs could be excessive for three reasons. Given non-GMO soybean production is controlled by contractual arrangements with other elevators and end-users in the agri-food chain, replacement of non-GMO supplies at the elevator may be costly if not impossible. The reason is simple: the rights to other non-GMO supplies may have already been allocated making purchase of replacement supplies perhaps impossible. Even if yields of non-GMO soybeans are high during the crop year, there is no guarantee replacement of supplies will be without additional costs. How will elevators source alternative non-GMO supplies where production is tightly controlled by other contractual arrangements? In a crop year where yields are low, search and bargaining costs could be even higher. The flip side is if the elevator is unable to secure replacement supplies then end-users must be compensated; the elevator by not securing non-GMO supplies with the appropriate thresholds essentially fails to meet contractual obligations. Failure to perform according to the contract means the elevator will pay to secure other supplies or be forced to compensate end-users. In either case, replacement of non-GMO supplies is not without cost.

The simulation model also tracks the frequency of testing during elevator operations. The model tracks the number of trucks and barges containing non-GMO soybeans that are tested. At the pits, the model tracks the number of times each truck is tested and the total number of trucks tested using a strip test. Next, the simulation model exports these data into Excel where measurement costs (for testing) are calculated. In this study, elevator management tested each truck twice before dumping non-GMO supplies at the pits. Each strip test cost $3. Elevator management also pays to have a third-party test a barge of non-GMO supplies that has been rejected prior to shipping. Based on case study data, the test costs $500 per barge. The simulation model tracks the number of barges that fail a PCR test and then exports these data into the Excel file. Next, the economic analysis module assigns the appropriate per bushel cost for testing under both contract structures.

The third type of transaction costs measured by the simulation model is adaptation costs. Adaptation costs refer to either direct or indirect costs of adapting business processes at the elevator to manage non-GMO soybeans (with varying thresholds) under buyer call and harvest delivery contracts. Direct costs represent those payable costs to handle non-GMO soybeans with varying thresholds. The model tracks the number of times bins are cleaned prior to delivery of non-GMO supplies during harvest delivery and buyer call periods. The model exports these data into Excel. Next, the economic analysis module assigns the appropriate costs for cleaning. Based on case study data, cleaning costs are a function of the size of bins used for storage of non-GMO soybeans.

Another type of direct costs associated with handling non-GMO soybeans with varying thresholds is increased coordination costs. Elevator management also expends resources to search and identify farmers in the surrounding area to produce non-GMO soybeans. In addition, on-farm production practices are to be strictly followed to assure GM thresholds do not exceed the agreed upon level in the contract. As such, elevator management expends some resources during the year to train farmers to assure on-farm production practices are followed. Based on case study data, coordination costs vary depending on the volume of non-GMO soybeans to be produced under contract.

Perhaps the largest of the adaptation costs are those costs associated with efficiency losses at the plant. Efficiency refers to the level of utilization of bins during the crop year. The model tracks efficiency levels across all bins during baseline operations. The model also tracks changes in efficiency levels between baseline and experimental scenarios (discussed in the next section) of alternative contract structures. Daily differences in utilization of bins are tracked by the simulation model. Utilization data is exported into Excel. Next, the @Risk program is used to draw from an empirical distribution to assign a daily margin which represents the foregone opportunity costs the elevator incurs because of lost volume in storage. Based on case study data and industry sources, storage margins (on average) range from 0.0 to 0.03 during the year. Given the functional form of this distribution was unknown, this study used a uniform distribution to assign daily margins that were foregone due to changes in utilizations. The assumption in the analysis is these per bushel margins are equally likely during the year. The economic analysis module sums these daily costs and divides the total by the contract volume in the experimental scenario to estimate a marginal cost associated with adapting the business processes at the elevator when handling non-GMO soybeans with varying thresholds.

4.2 Experimental Scenarios

Experiment one examines costs of transacting under buyer-call and harvest delivery contract structures assuming elevator management continue to use current testing practices at the case study elevator. That is, elevator management uses qualitative, inexpensive strip-testing practices to detect GM content in deliveries. In this study, elevator management chose to use an enzyme-linked immunosorbent assay, or ELISA, test to detect GM content. An ELISA test tests for a specific protein that the GM DNA produces in the plant (Davis and Hindman 2000).

The first step in the analysis was to develop a baseline of operations for the case study elevator. Parameters of the model were set to match actual operations and through face-to-face validation of system statistics, a baseline of operations was established. Raw statistics on truck arrival patterns, bin utilizations, and barge shipments during the year were used to establish a baseline of operations where only commodity corn and soybeans were handled. The baseline was then used as a benchmark to measure changes in transaction costs under each experimental scenario.

In each scenario, a different volume of non-GMO soybeans were shipped from a network of surrounding farms to the elevator. In the harvest delivery scenarios, shipments of non-GMO soybeans begin shipping on September 1 and continue through early November. The arrival patterns for number of trucks per day arriving at the elevator and beginning of deliveries were randomly assigned following empirical distributions constructed from case study data on actual deliveries. For example, shipments begin at some time between September 1 and October 7 (a 38 day window). In addition, the number of trucks was also randomly assigned following an empirical distribution. The idea is the harvest delivery contract affords the farmer with rights to deliver at the time the farmer chooses, not the elevator. As such, elevator management is uncertain about when shipments will begin and how many shipments will occur during the harvest delivery window. As such, the model was configured to represent the difference in control rights between farmer and elevator in the harvest delivery scenarios.

The simulation model was also configured to represent the buyer call contract structure where elevator management owned the rights of delivery. Under the buyer call contract structure, an equal amount of trucks were shipped from farms to the elevator from November 2-15 (approximately a 2 week window).

Finally, elevator management identified two types of adaptations to business processes that vary depending on the amount of non-GMO soybeans handled and their corresponding thresholds. For harvest delivery and buyer call contracts, elevator management chose to dedicate one pit and some bins to handle non-GMO soybeans. In the model, it was assumed that 0.1 percent GM contamination of non-GMO supplies occurred while in storage. Finally, the elevator assumed the liability of replacing rejected non-GMO supplies. If rejected, the farmer simply lost the non-GMO premium.

For each scenario, thirty replications were run. For each replication, draws were made from the constructed empirical distributions of the stochastic variables in the simulation. The four thresholds and three production levels used for non-GMO supplies are 0.3, 0.5, 1.0, 2.0 and 100,000, 200,000, and 450,000 respectively. Sensitivity analysis was also conducted for testing errors at the case study elevator. More practically, the simulation model exported the appropriate variables to Excel where @Risk and the economic analysis module estimated the transaction costs under buyer call and harvest delivery contract structures.

5 RESULTS

Experiment one examines costs of transacting under buyer call and harvest delivery contract structures under current testing practices at the case study elevator. That is, elevator management is assumed to continue to use ELISA (or strip) testing procedures testing for the presence of one, rogue GM seed found in deliveries. Thus, experiment one is an attempt to quantify the transaction costs under alternative contract structures given elevator management employs ELISA testing procedures.

5.1 Scenario One: 100,00 Bushels

In this scenario, there were no rejections of barge shipments. However, at the pits 58 out of the 100 trucks were rejected based on the empirical distribution for contamination and the testing protocols described above. These rejections translated into per bushel transaction costs to replace these supplies equaling (on average) approximately \$0.031 for harvest delivery and \$0.06 for buyer call contract structures. While measurement, cleaning, and coordination costs were modest and the same for the two contracts, opportunity costs of storage cause the buyer call contract to be preferable by elevator management. Dedication of bins and one pit create some delays in the handling of other commodities during the season. These delays translate into lower utilization of bins in this scenario compared to the baseline. Daily utilization differences were summed over the year and a constant $0.02 per bushel opportunity costs was assigned to the lost volume. Because the rejection rates are the same under all scenarios, the per bushel opportunity cost for harvest delivery is constant at $0.035. Thus in the buyer call scenario the utilization of bins is not significantly affected (Table 2).

5.2 Scenario Two: 200,00 Bbushels

In the scenario two, there were no rejections of barge shipments. Again, many trucks were rejected because excessive GM content. Over all 30 replications, the average number of trucks rejected equaled 116 of 200 trucks. This translated into search and bargaining costs of approximately the same as the 100,000 non-GMO scenario, though there is a slight difference based on the triangular distribution used to make draws to assign per bushels costs. Also, opportunity costs in this scenario are the same as in the 100,000 scenario because the higher loss in utilization is offset by handling twice the volume. Despite buyer call contracting costs are lower than harvest delivery, the margin is slim. Thus elevator management may prefer either contract to handle non-GMO soybeans at a per bushel cost of approximately $0.07 (Table 3).

5.3 Scenario Three: 450,00 Bushels

In the 450,000 scenario, again there were no barge shipments rejected. On average across 30 replications, however, 261 of the 450 trucks were rejected. Search and bargaining costs were again between $0.03 and $0.06 for harvest delivery and buyer call contracts, respectively.

Table 2: Costs for 100,000 Bushel Contract

	HD	BC
Threshold: 0.3%		
Search and Bargain	0.0301	0.0588
Measurement	0.0100	0.0100
Adaptation:	0.0462	0.0110
Cleaning	0.0010	0.0010
Coordination	0.0100	0.0100
Opportunity	0.0352	0.0000
TOTAL ($/bushel)	0.0860	0.0800
Threshold: 0.5%		
Search and Bargain	0.0310	0.0582
Measurement	0.0100	0.0100
Adaptation:	0.0462	0.0110
Cleaning	0.0010	0.0010
Coordination	0.0100	0.0100
Opportunity	0.0352	0.0000
TOTAL ($/bushel)	0.0870	0.0790
Threshold: 1.0%		
Search and Bargain	0.0312	0.0590
Measurement	0.0100	0.0060
Adaptation:	0.0460	0.0110
Cleaning	0.0010	0.0010
Coordination	0.0100	0.0100
Opportunity	0.0352	0.0000
TOTAL ($/bushel)	0.0870	0.0760
Threshold: 2.0%		
Search and Bargain	0.0306	0.0583
Measurement	0.0100	0.0100
Adaptation:	0.0460	0.0110
Cleaning	0.0010	0.0010
Coordination	0.0100	0.0100
Opportunity	0.0352	0.0000
TOTAL ($/bushel)	0.0870	0.0790

Table 3: Costs for 200,000 Bushel Contract

	HD	BC
Threshold: 0.3%		
Search and Bargain	0.0290	0.0580
Measurement	0.0026	0.0060
Adaptation:	0.0386	0.0049
Cleaning	0.0005	0.0005
Coordination	0.0044	0.0044
Opportunity	0.0337	0.0000
TOTAL ($/bushel)	0.0700	0.0690
Threshold: 0.5%		
Search and Bargain	0.0295	0.0573
Measurement	0.0026	0.0060
Adaptation:	0.0386	0.0049
Cleaning	0.0005	0.0005
Coordination	0.0044	0.0044
Opportunity	0.0337	0.0000
TOTAL ($/bushel)	0.0710	0.0680
Threshold: 1.0%		
Search and Bargain	0.0289	0.0580
Measurement	0.0026	0.0060
Adaptation:	0.0390	0.0050
Cleaning	0.0005	0.0005
Coordination	0.0044	0.0044
Opportunity	0.0337	0.0000
TOTAL ($/bushel)	0.0700	0.0690
Threshold: 2.0%		
Search and Bargain	0.0296	0.0573
Measurement	0.0026	0.0060
Adaptation:	0.0390	0.0050
Cleaning	0.0005	0.0005
Coordination	0.0044	0.0044
Opportunity	0.0337	0.0000
TOTAL ($/bushel)	0.0710	0.0680

The most notable difference in this scenario is the zero opportunity costs associated with harvest delivery. Unlike the previous scenarios, bin utilization does not suffer when a large bin is fully dedicated to the use of storing all non-GMO soybeans.

As such, elevator management may prefer to use a harvest delivery contract at volumes similar to the 450,000 bushel scenario. On average, harvest delivery per bushel costs were $0.03 less than use of a buyer call contract (Table 4).

Table 4: Cost of 450,000 Bushel Contract

	HD	BC
Threshold: 0.3%		
Search and Bargain	0.0290	0.0588
Measurement	0.0060	0.0060
Adaptation:	0.0079	0.0079
Cleaning	0.0024	0.0024
Coordination	0.0055	0.0055
Opportunity	0.0000	0.0000
TOTAL ($/bushel)	0.0430	0.0730
Threshold: 0.5%		
Search and Bargain	0.0300	0.0587
Measurement	0.0060	0.0060
Adaptation:	0.0079	0.0079
Cleaning	0.0024	0.0024
Coordination	0.0055	0.0055
Opportunity	0.0000	0.0000
TOTAL ($/bushel)	0.0440	0.0730
Threshold: 1.0%		
Search and Bargain	0.0310	0.0585
Measurement	0.0060	0.0060
Adaptation:	0.0080	0.0080
Cleaning	0.0024	0.0024
Coordination	0.0055	0.0055
Opportunity	0.0000	0.0000
TOTAL ($/bushel)	0.0450	0.0720
Threshold: 2.0%		
Search and Bargain	0.0298	0.0590
Measurement	0.0060	0.0060
Adaptation:	0.0080	0.0080
Cleaning	0.0024	0.0024
Coordination	0.0055	0.0055
Opportunity	0.0000	0.0000
TOTAL ($/bushel)	0.0440	0.0730

6 CONCLUDING REMARKS

The results of the study suggest that if low purity thresholds for adventitious presence of GM content in non-GMO soybeans, like those currently discussed in EU, are implemented, transaction costs increase at the elevator stage in the global agri-food chain. Given the global agri-food chain, and the elevator industry in particular, operates with rather slim gross and net margins, it is unlikely that such incremental costs could be internalized. If that is true, the results of this study indicate structural change could be significant as some estimates of transaction costs ranged from as low as $0.019 up to $0.08 cents per bushel.

The use of simulation as an economic policy evaluation tool in agricultural supply chains has been grossly overlooked. We believe simulation can be used as a tool for evaluating regulatory policies because it captures the changes in business processes within firms and the associated adaptation (transaction) costs when regulatory environments change. Specifically, the empirical model presented in this study featured the use of dynamic discrete simulation of elevator operations to measure contract (transaction) costs given changes in regulation of GMOs. As we have shown, simulation can be used to assess the cost impact of regulation in the global agricultural supply chain. From an economic policy evaluation perspective, results from this study indicate structural change could occur as a result of stringent regulation of GMOs, especially given that agribusinesses operate profitably at low margins near $0.02 per bushel. However, similar empirical studies are needed to analyze the connections between regulation of GMOs, changes in agribusiness processes, and contract costs from other perspectives in the global agricultural supply chain (e.g. growers, processors). To our knowledge, this paper represents the first attempt to begin this type of empirical work where discrete simulation modeling is used to inform on how regulation of GMOs affects firms operating in the global agricultural supply chain.

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