GMO Testing Strategies and Implications for Trade: A Game Theoretic Approach

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Abstract: Since their commercial introduction in 1996, genetically modified (GM) crops have been quickly adopted world wide, but some GM crops/varieties have not received regulatory approval for use in some importing countries, leading to asynchronicity in regulatory approvals. In this context, the international agricultural trade relied on analytical GMO testing which is a statistical process, along with identity preserved systems to segregate GM and non-GM crops. This led to a situation where measurement uncertainty became an important issue as it can lead to potential holdups at the point of import. In this background, this paper examines the implications of measurement uncertainty associated with GMO testing on the behavior of importers and exporters in a game theoretic framework. The results indicate that relative size of identity preservation costs, testing and rejection costs, the premiums offered in the non-GM markets and measurement uncertainty all have direct impacts on the behavior of importers and exporters.

Key words: GMO testing, measurement uncertainty, identity preservation systems, agricultural trade

Since their commercial introduction in 1996, biotech or genetically modified (GM) crops have been quickly adopted reaching 282.4 million acres worldwide in just over ten years (James, 2007). GM crops have increased agricultural production, have reduced input use, and have yielded large economic benefits for adopters and consumers around the world (Brookes and Barfoot, 2008; Marra, Pardey, & Alston, 2002; Konduru, Kruse and Kalaitzandonakes, 2008). At the same time, markets seeking to avoid GM crops have also developed. Some of these markets have been driven by the interest of food manufacturers and retailers to avoid GM ingredients in their products in order to cater to certain consumer segments (Kalaitzandonakes & Bijman, 2003) or to sidestep relevant mandatory labels (Carter and Gruere, 2003). Others have been driven by food standards that explicitly prohibit the use of GM ingredients (e.g. standards for organic foods). Yet, others have been created by the need to avoid GM crops that have not received regulatory approval for use in some importing countries but are authorized for production in some exporting ones. These GM crops are frequently referred to as "unapproved events" and have become infamous when they have turned up in markets they were not allowed (e.g., as in the cases of Starlink™ corn and Liberty Link™ Rice – (Lin, Price and Allen, 2003; Carter & Gruere, 2006)).

Separation of GM and non-GM crops is generally difficult within a commodity system that has been built for scale, speed and efficiency achieved through aggregation. For this reason, so-called identity preserved (IP) systems are typically used to segregate GM from non-GM crops and guide them through relevant supply chains and across export markets. These systems often require significant adjustments in supply chain operations along with heavy use of analytical GMO testing.

Specifically, IP systems involve more coordination and planning than commodity systems. In the context of international trade, changes in the supply chain must begin at the time when a cargo is procured by an end user --usually an importer. Under typical conditions an importer's order can be fulfilled within 3-6 months. Non-GM cargos instead require procurement 12-18 months ahead of delivery. Exporters must reach, either directly or through intermediaries, all the way back to individual farms to contract acres for non-GM crop production well ahead of the production season. In some cases, they have to reach all the way back to the seed stock. Additional changes in the functions of the marketing chain are also necessary, as the production of the contracted acres must be protected from commingling with GM crops in the field, during harvest and transport, in storage, in the rail cart or barge, and all the way to the export vessel.

Another key tool in managing compliance in non-GM supply chains is analytical GMO testing which is performed in the field and in laboratories in order to detect the presence or confirm the absence of certain GM crops. In practice, GMO testing occurs multiple times along a supply chain, most frequently, when a cargo changes custody (ownership). GMO testing is indeed a standard procedure for cargoes directed to non-GM markets and when asynchronous approval conditions between export and import markets exist.

Despite the typical reliance on GMO testing in the various non-GM supply chains some key practical issues remain unresolved, chief among them the presence of measurement uncertainty. Since GMO testing is a statistical process, repeated sampling and testing of the very same cargo would regularly produce different results. There are several sources of variance in GMO test results, including differences in the testing and sampling methods and protocols as well as inherent error rates in all types of analytical tests (Laffont et al., 2005; Powell & Owen, 2002; Remund, Dixon, Wright, & Holden, 2001). Even if identical testing methods and protocols were used, conflicting test results would occur, unless the very same sample was tested across all laboratories. However, given the lack of standardization in GMO testing methods and protocols around the world and the inherent variance in sampling, significant differences in GMO testing results across labs are normally expected.

Since differences in sampling procedures and testing methods imply that some divergence of GMO test results at origin and destination are to be expected, could this be a cause of delays or rejections of cargoes at destination? The potential holdup costs from such circumstances can be quite large. Depending on the size of cargo and port of import, demurrage charges from re-directing a vessel to an alternative destination, quality deterioration and other costs could add up to large sums per held-up cargo. These types of uncertainty and costs would be expected to influence the behavior of importers and exporters, their testing strategies and trade (Kalaitzandonakes, 2006).

In this study we examine the implications of measurement uncertainty associated with GMO testing on the behavior of importers and exporters in non-GM markets and in commodity markets where certain GM crops have not received regulatory approval and cannot be exported to some destinations. As we explain below, because of the inherent measurement uncertainty in GMO testing, importers and exporters face incomplete and asymmetric information in their transactions. Under such conditions, the equilibrium testing strategies for the exporters and importers can be obtained through the use of a dynamic game of incomplete information (Gibbons, 1992). In this study we use this framework to derive optimal GMO testing strategies in the presence of measurement uncertainty and to examine the relevance of various organizational and institutional factors for improving the efficiency and performance of market exchanges.

Incompleteness and Asymmetries of Information and Economic Behavior

Incomplete and asymmetric information between exporters and importers on the presence of GM crops in shipments is expected to affect their behavior. In his famous "Market for Lemons" paper, Akerlof (1970) explained that when the quality of a good is undistinguishable beforehand by the buyer and incentives exist for the seller to pass off a low-quality good as a higher-quality one, such informational asymmetries can lead to the disappearance of a market for high-quality products. In this case, gains from trade have to be forfeited.

Even though our GM crop trade problem is similar to the problem of lemons, the buyers (importers) in our model can assess, though imperfectly, the quality of the shipment before accepting it through analytical testing. However, the decisions of exporters to certify the absence of GM crops in their shipment and the decision of importers to accept or reject a shipment have to be taken under both imperfect and asymmetric information. In our context, information is imperfect because uncertainties in testing do not permit the exporter or the importer to assess with certainty whether or not GM crops are present or absent in a shipment. GMO tests are designed to indicate with some probability that GM crops are absent in a shipment despite their potential presence (Type I error) or indicate that GM crops are present in the shipment despite their potential absence (Type II error). Hence, there is scope that the importer and exporter arrive at different assessments on the GM content of a shipment despite best and honest efforts by both to arrive at a common one.

At the same time, information is also asymmetric because importers do not typically possess the same information exporters might have about the shipment. For instance, exporters might know the geographic origin of a shipment and the local level of GM crop adoption which could be suggestive of its potential GM content. They might also have information on the rigor of the IP procedures used in the procurement of a given shipment and could infer the extent of successful segregation. As a result, importers may have to decide whether to accept shipments based on the information provided by the exporter in the form of documents accompanying a cargo or by analytically testing the shipment at the point of import on their own. History suggests that the governments of importing countries and importers themselves have typically preferred to perform their own tests (Maskus, Wilson and Otsuki, 2000).

For the purpose of this analysis, we adopt a generalized concept of measurement uncertainty for GMO testing. Specifically, we define measurement uncertainty to be the probability of a shipment which through GMO analytical testing at the point of sale (e.g. export port) confirms the absence of certain GM events but fails to reconfirm their absence when testing is repeated at the point of purchase (e.g. point of import) leading to the commercial rejection of the shipment.

Under these circumstances, a number of questions exist. What are the optimal testing strategies for importers in the presence of measurement uncertainty? What information should exporters convey to importers? And what are the factors that can improve the efficiency of their exchange? Game theory has proved a useful tool in the analysis of such questions because it provides a framework to analyze strategies based on the information agents possess and the rewards they receive. For instance, McCluskey (2002) used game theory to analyze the different strategies that are available to consumers and producers of organic foods in the presence imperfect and asymmetric information. Producers could sequentially decide whether to use costly organic production methods or less expensive conventional ones and then whether or not to market and claim their product as organic, even if it was not produced through organic production practices. Since organic foods are credence goods –goods whose quality cannot be ascertain even after they have been consumed- consumers have to decide whether or not to trust producer claims. In this setting, McCluskey concluded that a third party should monitor the claims and that the involvement of government could improve efficiency in the organic market.

The equilibrium strategies for our exporters and importers in the presence of incomplete and asymmetric information can be obtained from a dynamic game of incomplete information. This approach has not been used in this setting before but Abbot et al. (1996) proposed using dynamic games of incomplete information in analyzing trade policy issues when uncertainty is present and the payoff functions for the players in the market change from time to time. The game that we need here is a dynamic or a sequential one because exporters and importers do not act simultaneously. The exporter first provides information about the GM content of the shipment and then the importer decides whether or not to duplicate the test and accept the shipment. Importantly, the later players must have some information on the first player's choice otherwise the difference in time would have no strategic effect. The game should also be of incomplete information as each player's payoff function (the function which determines the payoff from the combination of actions chosen by players) is not common knowledge to the other player. For this reasons, we will use a dynamic game of incomplete information (Gibbons , 1992; Gardner, 1996) involving two players (one with private information, the other without) and two moves (first a message sent by the informed player, then a response taken by the uninformed player).

For our analysis then we begin with a simple world state where GM crops produced and traded are approved in all the regions of the world (i.e. a world where there are no unapproved events). In this context, we will study the impact of measurement uncertainty as well as the impacts of rejection costs, market premiums and other factors on the equilibrium testing strategies of importers and exporters. Then in Section IV, we will analyze testing strategies and market equilibriums in a more realistic world where there are both approved and unapproved GM crops. Finally, in Section V we will synthesize the results and provide some concluding comments.

Testing Strategies & Equilibriums in Commodity and non-GM Markets

As discussed above, we assume here that both conventional and GM crops are grown and that there is demand for both commodity (where GM and conventional crops are commingled) and non-GM crops. We also assume that there are no unapproved GM crops anywhere in the world and hence there are no inherent trade restrictions on GM crops.

Game Description

The game of interest then has two players, an exporter and an importer. There are two exporter types: The first (IP-type) exports identity preserved (IP) non-GM crops and the second (NIP-type) exports commodities whose identity is not preserved (NIP). The term “identity preserved” in this game means that the exporter has managed the supply chain operations and has used analytical GMO testing in order to avoid commingling of non-GM and GM crops. Accordingly, the exporter can certify that an IP shipment “does not contain GMOs” with some degree of certainty. For exporting IP crops the exporter incurs identity preservation costs and testing costs (Bullock, Desquilbet and Nitsi, 2000, Kalaitzandonakes, Maltsbarger and Barnes, 2001; Wilson, Janzen and Dahl, 2003).

Both direct and indirect IP costs are incurred in non-GM IP systems (Kalaitzandonakes, Maltsbarger and Barnes, 2001). Direct IP costs result from:

- Coordination and control: Non-GMO IP systems require more market coordination resulting in higher transaction costs. Such costs typically include salaries and wages for sourcing and management personnel, specialized information systems, third party certification fees, and so on.
- Re-engineering of operations: As firms adapt their production and marketing operations for IP, they often incur extra capital, labor and material costs. For instance, farmers incur higher costs from extra labor for equipment cleaning during planting, harvest and storage as well as increased field isolation to prevent pollen flow from adjacent fields. Elevators incur higher costs from extra labor for facility clean outs, and higher testing costs (Lin et al. 2003).

Indirect IP costs are mostly implicit costs that result from loss of flexibility; inefficiencies due to underutilization of production, storage, transportation and processing assets; and lost profits (e.g. foregone storage margins and carrying spreads and potential loss of technology benefits from use of GM crops). In this analysis we consider testing costs separately from all other IP costs incurred in IP systems.

To compensate for the added IP and testing costs and generate interest, importers must offer premiums to exporters for the procurement of non-GM IP crops. The premiums offered are reflective of the underlying consumer demand and willingness to pay in the non-GM markets (Parcell, 2001). In our analysis, the premium paid to IP crops are represented net of IP costs (i.e. actual premiums minus IP costs).

Importers in the game are also of two types. The first type tests the shipments and accepts them if they conform to the exporters' certifications, otherwise they reject them. The second type of importer doesn't test the shipment before accepting it. If a shipment is rejected then it is sold at a discount or rerouted to a different market. The game does not go into the details of what happens to a rejected shipment, but only takes into consideration the cost of rejection.

The payoffs of the players are calculated for different strategies and finally an equilibrium strategy is obtained. In this game we focus on a separating equilibrium[1] in which the IP-type exporter certifies that the shipment "does not contain GMOs" and the NIP-type exporter does not provide any such certification. We specifically focus on the possibility of a separating equilibrium in order to examine if there is incentive for the IP-

[1] A separating equilibrium is one in which each type of exporter provides a different type of certification (or market signal). The opposite of this one is pooling equilibrium in which both types of exporters provide the same type of certification.

type exporter to cheat and whether market segmentation of non-GM and commodity markets can be achieved.[2]

Dynamics of the Game

In a situation where the importer has incomplete information about the exporter's type, the IP-type exporter has no incentive to imitate the NIP-type. The NIP-type exporter, however, has an incentive to imitate the IP-type exporter since there is a premium associated with the export of IP non-GM crops. For this scenario, we will derive the Perfect Bayesian Equilibrium (PBE) according to the procedure below:

In the dynamic game of incomplete information (see figure1 below), we assume:

- Nature moves first and draws a type t_i for the Exporter from a set of feasible types T = {IP-type, NIP-type} according to a probability distribution $p(t_i)$ where $p(t_i) > 0$ for every i and $p(t_1) + \ldots + p(t_I) = 1$. Therefore p(IP) + p(NIP) = 1.

The exporter observes type t_i and then chooses an action from a set of feasible actions E = {Certification (C), No Certification (NC)}. The action C means that the exporter provides documentation which certifies that the shipment does not contain

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[2] The NIP-type exporter's incentive to cheat is interpreted broadly here. Commodity exporters from countries with broad adoption of GM crops would be unlikely to attempt to sell a commodity shipment in the non-GM IP market. Nevertheless, there might be situations where "soft" (not rigorous) IP procedures maybe followed to minimize IP costs while attempting to obscure any GM crop presence through commingling with other IP non-GM lots. Similarly exporters from countries with little or no adoption of GM crops might attempt to export shipments that have not been specifically segregated or tested on the assumption that GM crops could not be present. Such behavior has occurred in the market and has led to rejections of export shipments (e.g. rice from China and corn and soybeans from Brazil) especially in import markets with strict standards (e.g. the EU).

GMOs. The action NC means the exporter does not provide certification about the presence/absence of GMOs in the shipment.

- The Importer observes E, but not type t_i and then chooses an action from a set of feasible actions F = {test (T), no test (NT)}. (T) implies the importer tests the shipment again and decides whether to accept the shipment or not. If the importer does not accept the shipment, the shipment incurs rejection costs. (NT) suggests that the importer accepts the shipment without testing.

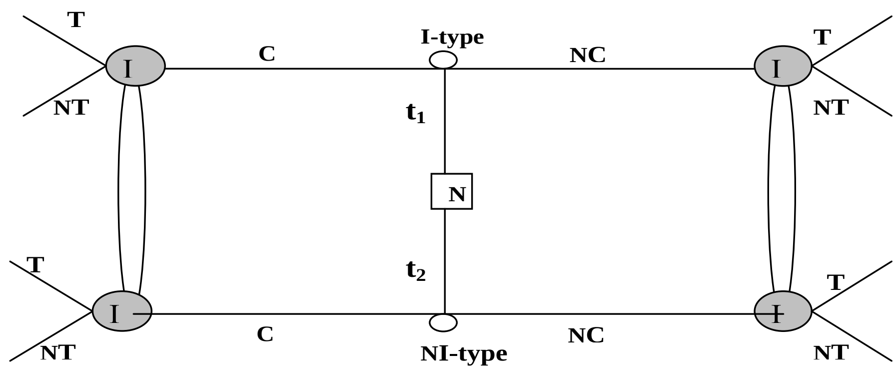

figure 1: Dynamic game of incomplete information

The probabilities of the shipment passing/failing a GMO test at the points of export and import, the payoff functions for both players, the beliefs for importer according to Bayes' rule and the equilibrium strategies for the exporter and the best response of importer are all derived and presented in A*ppendix I*. Here we discuss the equilibrium conditions and their implications in some detail.

When the dynamic game of incomplete information described above is solved, it shows that a separating equilibrium is possible under the following three conditions:

(i) $\frac{p}{R} > \frac{P(\alpha_I > \alpha_T / \alpha_E \leq \alpha_T)}{P(\alpha_I \leq \alpha_T / \alpha_E \leq \alpha_T)}$

(ii) R >0 and

(iii) $t < [1 - P(q / \alpha_E \leq \alpha_T)](Z_I - Z_{NI})$ (See appendix for the notations)

In this separating equilibrium, the IP-type exporter certifies that a shipment does not contain GMOs and the NIP-type exporter does not certify the shipment. The best response for the importer is to test only those shipments that claim non-GM status. This suggests that there is no incentive for the NIP-type exporter to cheat through false claims. Finally, the results show that the additional IP costs are borne by IP-type exporters and importers and hence the by the final consumers of non-GM products.

The above separating equilibrium exists only when the three conditions above are satisfied. Condition (i)[3] indicates that the ratio of the probability of rejection over the probability of acceptance of an IP shipment which has been tested and certified by the exporter should be less than the ratio of the premium paid for a unit of IP crop and the rejection cost per unit of shipment. This condition implies that for any given level of rejection costs, measurement uncertainty in GMO testing should be below a certain limit for the equilibrium to hold. Given the large size of rejection costs relative to the typical IP premiums in non-GM markets, condition (i) implies that the measurement uncertainty in GMO testing should be quite small for the equilibrium to hold and the IP market to

[3] Condition (i) is required to show that the action 'certification' strictly dominates the action 'no certification' for an IP-type exporter. This is possible when the payoffs in equations 1 and 2 are respectively larger than the payoffs in equations 3 and 4 in Appendix I.

exist. It is worth noting that critical values for such measures could be potentially derived in an empirical context from condition (i).

Condition (ii) implies that for a separating equilibrium, there must be positive rejection costs. The existence of positive rejection costs, along with the chance that a shipment would be rejected if analytically tested, discourages the NIP-type exporters to deviate from the equilibrium path and to continue to export commodities.[4]

Condition (iii) suggests that the testing expenses should be less than some fraction of the premium in order for the separating equilibrium to exist. If the testing expenses are large and go beyond a certain limit, there is no incentive for exporting IP non-GM crops and market segmentation weakens.

If conditions (i) through (iii) fail, the separating equilibrium does not exist and a pooling equilibrium may come into existence. A pooling equilibrium in which both types of exporters converge to supply commodities thereby limiting market segmentation.

The qualitative inferences from the above equilibrium conditions are quite interesting. For instance, holding all else constant, when relative rejection costs become very large the viability of IP markets diminishes. This suggests that occasional failures in the early stages of the supply chain (e.g. at the elevator) where the rejection cost of a

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[4] In the separating equilibrium of our game, the NIP-type exporter does not certify and receives a payoff which is given in payoff equation 8 in Appendix I. If the NIP-type exporter would deviate from that equilibrium path and attempted to cheat and certify, the importer's beliefs and actions would also change leading to the NIP-type exporter's new payoff equal to that in equation 5 in Appendix I. Because when rejection costs are positive the payoff in equation 8 will be more than the payoff in equation 5, the NIP-type exporter does not have an incentive to deviate from the equilibrium path – which is what condition (ii) determines.

shipment is typically equal to the loss of premium (as the shipment can be easily diverted to the commodity stream) may not be as consequential. However, system failures at the end of the supply chain where shipment sizes are very large (e.g. at the ocean vessel) and relative rejection costs increase exponentially due to large fixed cost charges, even infrequent failure could lead to the collapse of an IP market.

Similarly, since premiums are largely capped by the willingness to pay of a given consumer segment and since failure costs are largely non-negotiable *ex post*, for an IP market to be strengthened measurement uncertainty must be minimized. This result is consistent with observed stakeholder behavior in non-GM markets where exporters and importers for many years have been actively setting private (often bilateral) standards for GM testing and sampling protocols, third party certification schemes for single point testing and in some instance purity thresholds that allow for accidental presence of GM in non-GM IP products.[5] All these private standards would tend to reduce measurement uncertainty from GMO testing in non-GM IP markets and hence strengthen the conditions for a separating equilibrium and market segmentation.

Finally, the equilibrium conditions from the dynamic game we presented above highlight some inherent tensions in the ways governments have been attempting to set standards seeking to minimize GMO measurement uncertainty and enhance the efficiency of market exchange. For instance, while standardizing sampling procedures

[5] Unintended or accidental presence of GM crops in non-GM shipments is often called "Adventitious Presence" or AP. AP standards exist not only in bilateral agreements of trading parties in non-GM markets but in many GM mandatory labeling regulations. For instance, the EU's mandatory labeling regulation allows for up to 0.9% of the content of a non-GM shipment to be GM. Similarly, mandatory labeling in Japan set AP thresholds at 5%. In effect, AP standards define what a "GMO" effectively is.

along the lines outlined by ISPRA in the EU would tend to reduce measurement uncertainty in GMO testing and could encourage IP markets, they would also tend to increase testing costs exponentially (Kalaitzandonakes, 2006). Condition (iii) clarifies that with capped premiums, such costs increases could more than counter reductions in measurement uncertainty and undercut rather than encourage IP markets.

Testing Strategies in the Presence of Unapproved GM Crops

In this section, we assume a more complete state of the world where certain GM crops are produced in some exporting countries but cannot be traded to some importing countries where they have not yet received regulatory clearance for use. That is, we assume regulatory asynchronicity across countries and hence the presence of unapproved events in international trade. Under these conditions, the best responses of importers and exporters could change relative to those derived in the previous game. Importers and exporters of IP crops continue to avoid all GMOs and hence the presence of unapproved events does not change their practices in a significant way.

The circumstances for exporters and importers in commodity markets, however, change markedly. They must now account for the potential presence of unapproved GM crops in their NIP commodity shipments and prevent their entry to relevant import markets. For this reason they might have to engage in some segregation of crops and GMO testing in order to detect the potential presence of unapproved events and direct them to markets where they can be traded. In this way, commodity importers and exporters are now also exposed to measurement uncertainty associated with the use of GMO tests for unapproved GM crops. In this section, we examine the implications of such changes in the optimal testing strategies of importers and exporters and the equilibrium conditions under this new state of the world.

Game Description

This game set up will be similar to the one in section III but with a few important differences. Once again there are two types of exporters: the first type (IP-type) export IP crops whose identity have been preserved through the supply chain and have been tested for the absence of GMOs, including those which are unapproved in some markets. Accordingly, IP crop exporters certify their shipments as “non-GMO.” The second type of exporters (NIP-type) export NIP commodities. Because of the presence of unapproved GM crops in some markets they may segregate commodities that are being directed to certain import markets and test them for the presence of unapproved events at incremental marginal costs. In such markets, NIP commodity exporters face not only incremental costs but also measurement uncertainty.

It is assumed that the prices of IP non GM crops are higher than those of NIP commodities by a premium that increases with consumer willingness to pay for non-GM products. As before, the specified premium in IP markets is net of IP costs and hence it increases as such costs decrease.

There are also two types of importers. The first tests the imported shipment before accepting it and the second type does not. Importers who accept shipments that contain unapproved GM crops or IP crops that do not meet certification standards are assumed to incur losses (e.g. due to reputation effects, loss of sales and other factors). The optimal testing strategies of importers are of interest in this study and their derivation within the context of a PBE is detailed in *Appendix II.* As in the previous game, the probabilities of a shipment passing/failing a GMO test at the points of export and import, the payoff functions for both players, the beliefs for importers according to Bayes' rule as well as the equilibrium strategies for the exporters and the best response of importers are all derived and presented in A*ppendix II*. Here, we focus our discussions on the conditions for a separating equilibrium where the market stably segments into an IP non-GM and a commodity market.

Dynamics of the Game

When the dynamic game of incomplete information described above is solved, a separating equilibrium is obtained under the same three general conditions derived in the previous game, namely:

(i) $\frac{p}{R} > \frac{P(\alpha_I > \alpha_T / \alpha_E \leq \alpha_T)}{P(\alpha_I \leq \alpha_T / \alpha_E \leq \alpha_T)}$

(ii) R >0 and

(iii) $t < [1 - P(q / \alpha_E \leq \alpha_T)](Z_I - Z_{NI})$

This is not surprising since the incentives for the segmentation of the IP crop and commodity markets are similar in both games. The most significant variation in the equilibrium conditions of the two games is that testing costs, IP costs, rejection costs, and measurement uncertainty are different from the previous game as they must now account for any additional effort to segregate and test for the unapproved events as well. Generally, IP costs, testing costs, and measurement uncertainty should be only marginally different. Since rigorous IP procedures are applied across the supply chain the marginal segregation and testing for additional GM events should be relatively low. The rejection costs in the second game, however, can be drastically different. The rejection costs of any shipment which tests positive for unapproved events at the point of import will be much higher than the typical rejection costs considered in the previous game. This is because the salvage value of such shipments is zero since they are illegal and cannot be sold at any price in the specific market. Hence, they must either be destroyed or redirected to a different market, typically at great cost (Lin et al., 2003). If conditions (i) through (iii) do not hold the separating equilibrium does not exist and a pooling equilibrium may come into existence where both types of exporters converge to export commodities.

While the separating equilibrium conditions are similar in the first and second game the optimal testing strategies are not. The best response for the importers in this game is to test all the shipments whether they carry certification or not. Those who import shipments of IP crops test them for the presence of all GMOs whereas those importing commodities with no certification test the shipments for the presence of unapproved GM crops only. Accordingly there is no incentive for the NIP-type exporters to cheat by falsely claiming the absence of unapproved events. Since the best strategy of the importers is to test all commodity imports for unapproved GM crops, higher risks of rejection would exist. It is therefore in the interest of the NIP exporters to segregate and test relevant commodity streams in order to minimize the risk of exporting unapproved GM crops. Even so, because of measurement uncertainty there is still a chance that commodity shipments could be rejected. Under these circumstances the following condition must hold:

$$\text{(iv)} \qquad \frac{\Pi^{e}_{NI}}{C_{NI} + R} > \frac{P(\alpha^{U}_{I} > \alpha^{U}_{T} \,/\, \alpha^{U}_{E} \le \alpha^{U}_{T})}{P(\alpha^{U}_{I} \le \alpha^{U}_{T} \,/\, \alpha^{U}_{E} \le \alpha^{U}_{T})}$$

Condition (iv) implies that the ratio of the probability of rejection over the probability of acceptance of a NIP shipment that has been tested for unapproved events at the point of export must be less than the ratio of the exporters' profit over the sum of marginal production and rejection cost per unit of NIP commodity.

Since there is no premium in NIP commodity shipments the above condition highlights that as the costs for segregating and testing for unapproved events increase the ability of commodity exporters to pass such costs onto importers is critical. In competitive import markets with alternative NIP suppliers and/or close substitute products, NIP exporters from countries producing unapproved GM crops would likely find it difficult to absorb the incremental segregation, testing and potential rejection costs and could exit the market. In import markets where NIP exporters have some market power, they might be able to increase their prices to reflect the incremental costs and uncertainty in commodity exports.

As in the IP market, the potential rejection costs of any shipment which tests positive for unapproved events at the point of import are very high due to the lack of salvage value and high destruction or redirection costs. Given condition (iv), the increased levels of potential rejection costs and the possible lack of premium to cover the segregation and testing costs for unapproved GM crops suggest that the very existence of commodity exports in the presence of measurement uncertainty from unapproved events may be quite tenuous. As measurement uncertainty increases (e.g. because of increased level of adoption of an unapproved GM crops or because of an increased number of unapproved GM crops are used) there might be a limit where commodity exports cease. This is consistent with market conditions observed in certain international trade flows confronted with the presence of unapproved events.

Consider the EU corn gluten market as an example. Corn gluten is a co-product of the corn wet milling industry and a moderately high source of protein used in ruminant feeds, pet foods, poultry and swine. Historically, US corn gluten feed exports to the EU have been fairly stable. Roughly 5 million MT valued at almost $0.5 billion were being exported from the US to the EU in the late 1990s according to data from the US Commerce Department. By 2007 US gluten feed exports to EU had fallen to under 0.6 million MT, or almost 10% of the normal level of exports. Much of the deterioration in the US exports owes to the production of GM crops in the US which were not approved for use in the EU, first the Bt10 event and subsequently the DAS-59122-7 or Herculex event. The first significant drop in US exports of corn gluten feed occurred in 2005 when the EU began requesting certificates assuring the absence of Bt 10 in corn gluten shipments. Then in 2007, three separate US cargoes which had tested negative for Herculex in the US tested positive upon arrival in EU ports and led to a 40% drop in US exports within the year. A large portion of the relatively small US corn gluten exports to the EU now are directed to the IP non-GM market.

Synthesis of the Results and Concluding Comments

A number of conclusions can be drawn from the preceding analysis about the impacts of measurement uncertainty in GMO testing on the behavior of importers and exporters in IP non-GM and in commodity markets. While GMOs are credence goods (Giannakas and Fulton, 2002) their presence can be analytically tested and hence informational asymmetries as in McCluskey (2000) do not arise. Similarly, while there are markets where IP non-GM crops receive premium prices, asymmetries between buyers and sellers do not result in “markets for lemons” because of the availability of analytical testing. But while analytical GMO testing limits certain informational asymmetries it also involves measurement uncertainty which also affects behavior. In this context, dynamic games of incomplete information as those I have used in this analysis are useful for examining the behavior of importers and exporters and the various factors that might affect the efficiency and performance of their exchanges.

The first general result from my analysis is that not all GMO measurement uncertainties are created equal. Measurement uncertainty for approved GMOs affects the IP non-GM markets alone but measurement uncertainty for unapproved GMO events affects all markets, imposes larger rejection costs and can deter even commodity trade. Hence, the potential deadweight loss associated with the increased costs, higher prices or potential loss of exchange from measurement uncertainties in GMO testing created from the presence of unapproved events in the market is generally more significant.

Our analysis also indicates that the relative size of IP, segregation, testing and rejection costs, the premiums offered in the IP markets and measurement uncertainty all have direct impacts on the emergence of separating equilibriums and their stability. Yet, these figures tend to vary from one supply chain to another; they vary by crop and region; they vary with underlying supply and demand conditions; and they often influence one another. For instance, the more stringent the IP procedures are the higher the IP costs and the lower measurement uncertainty would tend to be (Kalaitzandonakes, Maltsbarger and Barnes, 2001). Similarly, the more extensive testing is performed (i.e. more samples taken, at more points of exchange in the supply chain), the higher the testing costs and the lower the measurement uncertainty would tend to be (Wilson, Dahl and Jabs, 2007).

Because of this link between IP effort, costs and measurement uncertainty, my analysis shows that when IP and testing costs increase in IP crop markets, the separating equilibriums and the market segmentation become more robust.[6] This result, however, holds only when IP premiums increase as well.[7] Hence, when IP exporters have market power and/or when consumer willingness to pay for non-GMO products (Lusk et al., 2005, Noussair et al., 2004, Matsumoto, 2006) is high, market segmentation is strengthened. When premiums are not responsive or capped at low levels, then increasing IP and testing costs make the market segmentation weak. Hence, under certain market conditions strategies that seek to strengthen the presence of IP non-GM markets by reducing measurement uncertainty via expanded sampling regimes (e.g. Paoletti et al., 2006) could in fact have the opposite effect.

Alternatively, technical solutions like standardization of GMO testing methods and protocols which would tend to reduce measurement uncertainty without increasing

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[6] From the payoff functions 1 and 3 of the I-type exporter in appendix II, it follows that as the marginal cost of IP-type exporter (C_I) increases due to an increase in identity preservation and testing costs, the probability that the shipment is accepted at both the point of import and export increases as the measurement uncertainty is reduced. Under these conditions the payoff of the IP-type exporter who certifies the shipment as 'does not contain GMOs' increase and the payoff of the IP-type exporter who does not certify the shipment is reduced suggesting that the separating equilibrium becomes more robust.

[7] We can examine the impact of the premium received by IP crops on the equilibrium by analyzing the condition (given in footnote 10, Appendix II) that should be satisfied in order for 'Certification(C)' to dominate the 'No Certification (NC)'strategy. From this analysis I can infer that as the premium decreases the equilibrium becomes weaker and as the premium approaches zero the equilibrium no longer stands. On the other hand, if the premium for IP non-GM crops increases, the equilibrium becomes more robust.

the variable costs of IP and commodity markets. Based on the results of my analysis, these would tend to universally improve market separation, trade and the overall efficiency of market exchange. Achieving standardization of GMO testing methods and protocols appears difficult for the moment as numerous technical issues remain and there is no obvious international forum/organization to facilitate adoption of such standards could be imposed through industry or government action. In the absence of imminent standardization, some governments have resorted to certifying the accuracy of laboratories through GMO ring trials while reporting the size of measurement uncertainty in those trials to increase market transparency about relevant exchange risks (e.g. see USDA/GIPSA Proficiency Program and the International Seed Testing Association Proficiency Test Program).

A number of private and public institutional arrangements have also been considered for managing GMO testing measurement uncertainty and reducing market inefficiency. Private institutional arrangements include use of insurance schemes and third party certification systems (Golan, Kuchler and Mitchell, 2000). With such arrangements measurement uncertainty is typically not reduced. Instead, risks are shared at some cost to facilitate trade. The results of my analysis therefore suggest that depending on the amount of uncertainty absorbed by third parties and the level of the added costs, these private institutional arrangements may or may not have much of an impact in the market. While third party certification services are actively offered by GMO testing and other certification firms, insurance schemes that pool rejection risks and spread associated costs have so far proven difficult to establish.

A few government policies have also been proposed for improving market efficiency in the presence of GMO testing measurement uncertainty, chief among them the use of adventitious presence (AP) thresholds. As AP thresholds increase, measurement uncertainty as well as IP and testing costs would tend to decline (Kalaitzandonakes and Magnier, 2004). Based on our analysis, these effects would tend to universally improve market segmentation, trade and the overall efficiency of market exchange. While such policies would tend to improve market efficiency for non-GM markets, they would likely have little impact in the case of unapproved events as AP allowances for unapproved event are not typically made (often referred to as "zero tolerance standard"). Based on our analysis, this suggests that the most significant source of market instability would likely be removed only through synchronicity in the regulatory approvals of new GM events across all major markets. Alternatively, self-imposed restraints by innovators stopping short of introducing unapproved events in the market may also achieve the same outcome. In all, our analysis provides a framework for examining in a structured fashion the incentives, tensions, and relative effectiveness of alternative technical, institutional and market solutions to the problem of measurement uncertainty in GMO testing and its impacts on trade.

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Appendix I

Notations:

- P_I = Price paid to the exporter for each unit of IP crop
- P_{NI} = Price paid to the exporter for each unit of NIP commodity. Since identity preservation systems are costly to operate and exporters need be to be compensated accordingly, I assume that $P_I > P_{NI}$. Accordingly, the premium p paid for the IP crop is p= $P_I - P_{NI}$
- Z_I = Price paid by the end user in the importing country for each unit of IP crop.
- Z_{NI} = Price paid by the end user for each unit of NIP commodity.
- C_I = Marginal cost to produce and identity preserve each unit of IP crop
- C_{NI} = Marginal cost to produce each unit of NIP commodity. Since identity preservation system incurs costs to operate, we assume $C_I > C_{NI}$
- R = Rejection cost of a shipment is rejected at point of import
- t = Testing cost per unit of crop
- $\Pi_I^m = Z_I - P_I$ = Importer's profit when a unit of IP crop is imported and sold.
- $\Pi_{NI}^m = Z_{NI} - P_{NI}$ = Importer's profit when a unit of NIP commodity sold.
- $\Pi_I^e = P_I - C_I$ = Exporter's profit when a unit of IP crop is exported.
- $\Pi_{NI}^e = P_{NI} - C_{NI}$ = Exporter's profit when a unit of NIP commodity is exported.

Probabilities of the shipment passing the tests at the point of import and export:

- α_E = GMO content of shipment (% of total) at point of export
- α_I = GMO content of shipment (% of total) measured at point of import

- α_T = Threshold limit below which the shipment is "non-GM"
- Probability that the IP shipment passes the test at point of export = $P(\alpha_E \le \alpha_T)$
- Probability that NIP shipment passes the test at point of import = $P(\alpha_I \le \alpha_T)$
- Probability that the shipment of IP crop fails the test at the point of export = $1 - P(\alpha_E \le \alpha_T) = P(\alpha_E > \alpha_T)$
- Probability that the shipment of NIP commodity fails the test at point of export = $1 - P(\alpha_I \le \alpha_T) = P(\alpha_I > \alpha_T)$
- Probability that the shipment of IP crop passes the test at the point of import given that it had passed the test at the point of export $P(\alpha_I \le \alpha_T / \alpha_E \le \alpha_T)$
- Probability that the shipment of IP crop does not pass the test at the point of import though it had passed the test at the point of export $P(\alpha_I > \alpha_T / \alpha_E \le \alpha_T)$
- Probability that the importer gets IP crop given that he does not test the shipment, but it has passed the test at point of export = $P(q / \alpha_E \le \alpha_T)$
- Probability that the importer does not get IP crop given that he does not test the shipment but it has passed the test at point of export = $1 - P(q / \alpha_E \le \alpha_T)$

Payoffs for the exporter:

1. IP crop, certification from the exporter and testing by the importer:

$$Y_E(IP, C, T) = [P(\alpha_I \le \alpha_T / \alpha_E \le \alpha_T)(P_I - C_I) + P(\alpha_I > \alpha_T / \alpha_E \le \alpha_T)(P_{NI} - C_I - R\ )]$$

The first part of the payoff denotes the payoff of the exporter when the shipment passes the test both at the point of import and export. The second part of the payoff indicates that when the importer rejects the shipment, the exporter gets the price of the NIP commodity (salvage value) although he incurs IP costs C_I.

2. IP crop, certification from the exporter and no testing by the importer:

$$Y_E(IP, C, NT) = P_I - C_I = \Pi_I^e$$

The importer does not test the shipment and trusts the claim of the exporter.

3. IP crop, no certification by the exporter and testing by the importer:

$$Y_E(IP, NC, T) = P_{NI} - C_I = \Pi_I^e - p$$

The exporter does not certify the shipment even though it has been identity preserved, the importer tests the shipment and pays P_{NI} (i.e., “even if he gets IP crop”).

4. IP crop, no certification from the exporter and no testing by the importer:

$$Y_E(IP, NC, NT) = P_{NI} - C_I = \Pi_I^e - p$$

5. NIP commodity, certification by the exporter and testing by the importer:

$$Y_E(NIP, C, T) = P_{NI} - C_{NI} - R = \Pi_{NI}^e - R$$

The exporter attempts to cheat, but the importer tests the shipment.

6. NIP commodity, certification by the exporter and no testing by the importer:

$$Y_E(NIP, C, NT) = P_I - C_{NI} = \Pi_{NI}^e + p$$

The exporter cheats and the importer pays the price of IP crop without testing.

7. NIP commodity, no certification by the exporter and testing by the importer:

$$Y_E(NIP, NC, T) = P_{NI} - C_{NI} = \Pi_{NI}^e$$

The importer tests the shipment but pays the price of the NIP commodity.

8. NIP commodity, no certification by the exporter and no testing by the importer:

$$Y_E(NIP, NC, NT) = P_{NI} - C_{NI} = \Pi_{NI}^e \quad .$$

Payoffs for the importer:

9. IP crop, certification from the exporter and testing by the importer:

$$Y_M(IP,C,T) = [P(\alpha_I \le \alpha_T / \alpha_E \le \alpha_T)(Z_I - P_I - t) - P(\alpha_I > \alpha_T / \alpha_E \le \alpha_T)(t)]$$
$$= [P(\alpha_I \le \alpha_T / \alpha_E \le \alpha_T)(\Pi_I^m)] - t$$

If the shipment passes the test, the importer can sell at the price of IP crop, otherwise the importer incurs only the testing expenditure as the shipment is rejected.

10. IP crop, certification from the exporter and no testing by the importer:

$$Y_M(IP,C,NT) = [P(q / \alpha_E \le \alpha_T)(\Pi_I^m) + (1 - P(q / \alpha_E \le \alpha_T))(\Pi_{NI}^m - p)]$$

The importer does not test and accepts the shipment as certified. In the case the exporter cheats or erroneously certifies the shipment as "non-GMO" the importer pays P_I but can sell the shipment to the end user only at Z_{NI}.

11. IP crop, no certification from the exporter and testing by the importer:

$$Y_M(IP,NC,T) = [P(\alpha_I \le \alpha_T / \alpha_E \le \alpha_T)(\Pi_I^m - p - t) + P(\alpha_I > \alpha_T / \alpha_E \le \alpha_T)(\Pi_{NI}^m - t)]$$

The first part of the equation indicates the importer pays P_{NI} and sells at price Z_I. The second part of the equation indicates that the importer does not reject the shipment if it fails the test and pays P_{NI}.

12. IP crop, no certification from the exporter and no testing by the importer:

$$Y_M(IP,NC,NT) = [P(q / \alpha_E \le \alpha_T)(\Pi_I^m + p) + (1 - P(q / \alpha_E \le \alpha_T)\Pi_{NI}^m]$$

The importer does not test and pays P_{NI} for the non-certified shipment.

13. NIP commodity, certification from the exporter and testing by the importer:

$$Y_M(NIP,C,T) = -t$$

The exporter tries to cheat, but the importer tests and incurs expenditure.

14. NIP commodity, certification from the exporter and no testing by the importer:

$$Y_M(NIP,C,NT) = Z_{NI} - P_I = \Pi_I^m - p$$

The importer pays P_I for the commodity since the exporter provides certification and the importer does not perform any test.

15. NIP commodity, no certification from the exporter and testing by the importer:

$$Y_M(NIP, NC, T) = Z_{NI} - P_{NI} - t = \Pi_{NI}^{M} - t$$

The importer tests the shipment even though the exporter sends the true signal.

16. NIP commodity, no certification from the exporter and no testing by the importer:

$$Y_M(NIP, NC, NT) = Z_{NI} - P_{NI} = \Pi_{NI}^{m}$$

The importer pays P_{NI} and there is no chance that the commodity is IP crop.

Finding a Separating Perfect Bayesian Equilibrium (PBE)

We identify a PBE for our game by following the steps (i)-(iii) below.

(i) Assignment of strategies and derivation of the beliefs

There are only two possibilities for separating strategies for the Exporter. One possibility is that the IP-type Exporter chooses C and NIP-type Exporter chooses NC. The second possibility is that the IP-type Exporter chooses NC and NIP-type Exporter chooses C. But in our case C strictly dominates NC[8] for IP-type exporter[9] so if a

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[8] The following condition should be satisfied $\frac{p}{R} > \frac{P(\alpha_I > \alpha_T / \alpha_E \leq \alpha_T)}{P(\alpha_I \leq \alpha_T / \alpha_E \leq \alpha_T)}$ in order for Payoff 1 to be greater than Payoff 3. From the above condition, the ratio of probability of acceptance and probability of rejection of an IP crop shipment given it has already been tested by the exporter should be less than the ratio of premium for a unit of IP crop and rejection costs per unit of shipment. Payoff 2 is greater than Payoff 4 by an amount equal to the premium for I-type crop. From these two results we can conclude that C strictly dominates NC.

[9] We can prove that Payoffs 1 and 2 are respectively greater than Payoffs 3 and 4.

separating PBE exists then the IP-type Exporter will systematically play C while the NIP-type Exporter will systematically play NC. We can specify the belief of importer as

$$\sigma_E(t) = \begin{cases} \text{C if type = IP} \\ \text{NC if type = NIP} \end{cases}$$

Now let μ (t_i / A) be the probability that the Importer assigns to type i after observing action A. If Importer observes that the Exporter chooses C, he assigns probability 1 to type IP. If he observes Exporter choosing NC, he assigns probability 1 to type NIP. These beliefs are consistent with Bayes' rule for both information sets that are reached with positive probability along the equilibrium path. To simplify, I assume that probabilities of IP-type, and NIP-type exporters are equal[10]: P (IP) =P (NIP) = 1/2.

We just established that,

P(C / IP) = 1; P (NC / IP) = 0 ; P(C / NIP) = 0 ; P (NC / NIP) = 1

So, by applying Bayes' theorem, we obtain

μ (IP / C)[11] = 1 ; μ (NIP / C) = 0 ;   μ (IP / NC) = 0 ; μ (NIP / NC)= 1

(ii) Best Response for Importer:

When Exporter chooses C:

- Importer's expected profit from choosing (T) in response to Exporter choosing (C):

EU_I (T, C) = μ (IP / C) * Y_M(T, C; IP) + μ (NIP / C) * Y_M (T, C; NIP) =

$$[P(\alpha_I \le \alpha_T / \alpha_E \le \alpha_T)(\Pi_I^m - t) - P(\alpha_I > \alpha_T / \alpha_E \le \alpha_T)(t)] = \Pi_I^m - t$$

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[10] Even if the probabilities are not equal, the results do not change when we apply Bayes' theorem.

[11] By applying Bayes' theorem, we get:

$$\mu(IP/C) = \frac{P(C/IP)P(C)}{P(C)} = \frac{P(C/IP)P(I)}{P(C/IP)P(IP) + P(C/NIP)P(NIP)} = \frac{1(0.5)}{1(0.5)+0(0.5)} = 1$$

This payoff function can be also written as $\Pi_I^m - t$ as the importer receives the profit of IP-type shipment from a replacement shipment if the first fails the test. So, with a probability of 1, he receives the profit of IP-type crop and incurs testing expenses with the same probability.

- Importer's expected profit from choosing (NT) in response to exporter choosing (C):

  EU_I (NT, C) = μ (IP / C) * Y_M (NT, C; IP) + μ (NIP/ C) * Y_M (NT, C; NIP) =

  $[P(q/\alpha_E \le \alpha_T)(\Pi_I^m) + (1 - P(q/\alpha_E \le \alpha_T))(\Pi_{NI}^m - p)]$

  From expected profit derived above we obtain the first condition for a PBE to hold:

  EU_I (T, C) > EU_I (NT, C) if $t < [1 - P(q/\alpha_E \le \alpha_T)](Z_I - Z_{NI})$.

So the best response of the importer if the exporter chooses to certify is ***BR_I (C) = T***.

When Exporter chooses NC:

- Importer's expected profit from choosing (T) in response to Exporter choosing (NC):

  EU_I (T, NC) = μ (IP/ NC) * Y_M (T, NC; IP) + μ (NIP / NC) * Y_M (T, NC; NIP) =

  $\Pi_{NI}^m - t$

- Importer's exp. profit from choosing (NT) in response to exporter choosing (NC):

  EU_I (NT, NC) = μ (IP / NC) * Y_M (NT, NC; IP) + μ (NIP / NC) * Y_M (NT, NC; NIP) = Π_{NI}^m

We readily obtain that EU_I (NT, MC) > EU_I (T, MC) as there is no additional benefit of testing the shipment by the importer. So, he is left with the same kind of the commodity whether or not he tests the shipment. Consequently 'testing' is not a best response and the best response of Importer, if Exporter chooses NC = ***BR_I (NC) = NT.***

(iii) Checking deviations

We can confirm that the equilibrium is a PBE only if neither type of Exporter has an incentive to deviate. We know that IP-type Exporter will not deviate as C strictly dominates NC. The NIP-type Exporter follows the assigned strategy as long as the payoff it yields is at least as high as the one he would get if he deviated.

In our case, the NIP-type's payoff along the equilibrium path is Π^{e}_{NI} . If he deviated and choose C instead of NC, the Importer would choose T since his beliefs continue to be as above. Therefore, if R>0, the payoff of Exporter of type NIP from deviating is $Y_E(NI,C,T) = \Pi^{e}_{NI} - R$, which is smaller than the payoff from following the equilibrium. In the situation when neither type of exporter deviates, it can be proved that there exists a ***separating PBE***,[12] which is as follows:

$$\sigma_E(t) = \begin{cases} \text{C, if type = IP} \\ \text{NC, if type = NIP} \end{cases}$$

$$\sigma_I(E, \mu(E)) = \begin{cases} \text{Test, if E = C} \\ \text{No Test, if E = NC} \end{cases}$$

Note 1: The game was also checked for the existence of a pooling equilibrium (i.e. both the types of exporters will be choosing C), but no such equilibrium was found on the basis of the conditions derived.

Note 2: Even if a third type of exporter, e.g., who exports a substitute commodity was added to the game, there will be no change in the results shown above.

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[12] Given the following three conditions: (i) $\dfrac{p}{R} > \dfrac{P(\alpha_I > \alpha_T / \alpha_E \leq \alpha_T)}{P(\alpha_I \leq \alpha_T / \alpha_E \leq \alpha_T)}$

(ii) R>0 and (iii) $t < [1 - P(q / \alpha_E \leq \alpha_T)](Z_I - Z_{NI})$

Appendix II

Notations: Same as in Appendix I

Probabilities of the shipment passing the tests at the point of import and export:

Note: Probabilities given below are in addition to the ones listed in Appendix I

- α_I^U = Unapproved GMO content of shipment (% of total) at point of import
- α_E^U = Unapproved GMO content of shipment (% of total) at point of export
- α_T^U = Threshold limit of the unapproved events
- Probability of the shipment does not pass the test for unapproved events at the point of export = $1 - P(\alpha_E^U \leq \alpha_T^U) = P(\alpha_E^U > \alpha_T^U)$
- Probability that shipment is tested for unapproved events only and is accepted by the importer = $P(\alpha_I^U \leq \alpha_T^U / \alpha_E^U \leq \alpha_T^U)$
- Probability of the shipment does not pass the test for unapproved events at the point of import = $1 - P(\alpha_I^U \leq \alpha_T^U) = P(\alpha_I^U > \alpha_T^U)$
- Probability that shipment is tested for unapproved events and is not accepted by the importer = $P(\alpha_I^U > \alpha_T^U / \alpha_E^U \leq \alpha_T^U)$
- Probability that the importer gets shipment without unapproved events even if he does not test the shipment which however has passed the test at the point of export = $P(q / \alpha_E^U \leq \alpha_T^U)$
- Probability that the importer does not get shipment without unapproved events if he does not test the shipment but it has passed the test at point of export = $1 - P(q / \alpha_E^U \leq \alpha_T^U)$

Payoffs for the exporter:

The following payoff functions are relevant for this game:

1. IP crop, certification from the exporter and testing by the importer:

$$Y_E(IP,C,T) = [P(\alpha_I \leq \alpha_T / \alpha_E \leq \alpha_T)(P_I - C_I) + P(\alpha_I > \alpha_T / \alpha_E \leq \alpha_T)(P_{NI} - C_I - R\ )]$$

The first part of the function denotes the payoff of the exporter when the shipment passes the test at both the points of import and export. The second part of the payoff indicates that when the importer rejects the shipment, the exporter gets paid the NIP commodity price even though he incurs identity preservation costs C_I .

2. IP crop, certification from the exporter and no testing by the importer:

$$Y_E(IP,C,NT) = P_I - C_I = \Pi_I^e$$

The importer does not test the shipment and trusts the claim of the exporter.

3. IP crop, no certification by from exporter and testing by the importer:

$$Y_E(IP,NC,T) = P_{NI} - C_I = \Pi_I^e - p$$

The exporter does not certify the shipment even though it has been identity preserved and the importer tests and pays only P_{NI} even if as he receives IP shipment.

4. IP crop, no certification from the exporter and no testing by the importer:

$$Y_E(IP,NC,NT) = P_{NI} - C_I = \Pi_I^e - p$$

Same as above from the exporter's perspective except the importer not testing.

5. NIP commodity, certification by the exporter and testing by the importer:

$$Y_E(NIP,C,T) = P_{NI} - C_{NI} - R = \Pi_{NI}^e - R$$

The exporter attempts to cheat and certifies the shipment as IP crop. The importer tests the shipment and rejects it leading to rejection costs for the exporter.

6. NIP commodity, certification by the exporter and no testing by the importer:

$$Y_E(NIP, C, NT) = P_I - C_{NI} = \Pi^e_{NI} + p$$

The exporter cheats and the importer pays the IP premium without testing.

7. NIP commodity, no certification by the exporter and testing by the importer:

$$Y_E(NIP, NC, T) = [P(\alpha^U_I \leq \alpha^U_T / \alpha^U_E \leq \alpha^U_T)(P_{NI} - C_{NI}) + P(\alpha^U_I > \alpha^U_T / \alpha^U_E \leq \alpha^U_T)(P_{NI} - C_{NI} - R)]$$

The exporter segregates and tests the shipment for the presence of unapproved events. He exports the shipment on the belief it does not contain unapproved events but does not certify it as IP crop. The exporter bears the costs of rejection in the case that the importer tests the shipment and finds unapproved events.

8. NIP commodity, no certification by the exporter and no testing by the importer:

$$Y_E(NI, NC, NT) = P_{NI} - C_{NI} = \Pi^e_{NI}$$

The importer does not test the shipment and pays accordingly.

Payoffs for the importer:

9. IP crop, certification from the exporter and testing by the importer:

$$Y_M(IP, C, T) = [P(\alpha_I \leq \alpha_T / \alpha_E \leq \alpha_T)(Z_I - P_I - t) - P(\alpha_I > \alpha_T / \alpha_E \leq \alpha_T)(t)]$$
$$= [P(\alpha_I \leq \alpha_T / \alpha_E \leq \alpha_T)(\Pi^m_I)] - t$$

In case the shipment passes the test, the importer can sell at the price of IP crop and incurs testing expenses. If he rejects, he incurs only the testing expenditure.

10. IP crop, certification from the exporter and no testing by the importer:

$$Y_M(IP, C, NT) = [P(q / \alpha_E \leq \alpha_T)(\Pi^m_I) + (1 - P(q / \alpha_E \leq \alpha_T))(\Pi^m_{NI} - p)]$$

Since the importer accepts without testing, he may receive an IP crop only with some probability. When he does not test, the importer pays P_I but can sell only at Z_{NI}.

11. IP crop, no certification from the exporter and testing by the importer:

$$Y_M(IP, NC, T) = [P(\alpha_I \le \alpha_T / \alpha_E \le \alpha_T)(\Pi_I^m - p - t) + P(\alpha_I > \alpha_T / \alpha_E \le \alpha_T)(\Pi_{NI}^m - t)]$$

The first part of the equation indicates the importer pays P_{NI} and sells the commodity at price Z_I when the commodity passes the test. The second part of the equation shows that the importer does not reject even if it fails the test and pays P_{NI} .

12. IP crop, no certification from the exporter and no testing by the importer:

$$Y_M(IP, NC, NT) = [P(q / \alpha_E \le \alpha_T)(\Pi_I^m + p) + (1 - P(q / \alpha_E \le \alpha_T)\Pi_{NI}^m]$$

The importer does not test the shipment and pays P_{NI} for all shipments. In the absence of testing, there is still a chance that the importer obtains IP crop.

13. NIP commodity, certification from the exporter and testing by the importer:

$$Y_M(NIP, C, T) = [P(\alpha_I \le \alpha_T / \alpha_E^U \le \alpha_T^U)(\Pi_I^m - t) - P(\alpha_I > \alpha_T / \alpha_E^U \le \alpha_T^U)(t)]$$

If the importer accepts the shipment, he pays the premium for IP. If he tests and rejects the shipment, he incurs only the testing expenditure.

14. NIP commodity, certification from the exporter and no testing by the importer:

$$Y_M(NIP, C, NT) = [P(q / \alpha_E^U \le \alpha_T^U)(\Pi_I^m) + (1 - P(q / \alpha_E^U \le \alpha_T^U))(-P_I)]$$

The importer pays P_I for all shipments, but has little chance of receiving IP crop.

15. NIP commodity, no certification from the exporter and testing by the importer:

$$Y_M(NIP, NC, T) = [P(\alpha_I^U \le \alpha_T^U / \alpha_E^U \le \alpha_T^U)(\Pi_{NI}^m - t) - P(\alpha_I^U > \alpha_T^U / \alpha_E^U \le \alpha_T^U)(t)]$$

The importer tests the shipment for unapproved events. If the importer finds unapproved events, he rejects the shipment and incurs only testing expenditures.

16. NIP commodity, no certification from the exporter and no testing by the importer:

$$Y_M(NIP, NC, NT) = [P(q / \alpha_E^U \le \alpha_T^U)(\Pi_{NI}^m) + (1 - P(q / \alpha_E^U \le \alpha_T^U))(-P_{NI})]$$

The importer does not test the shipment for unapproved events. He pays P_{NI} as claimed by the exporter, but he incurs loss equal to P_{NI} if the shipment contains unapproved events and is rejected by the end user.

Finding a Separating Perfect Bayesian Equilibrium (PBE)

We identify a PBE for our game by following the steps (i)-(iii) below.

(i) Assignment of strategies and derivation of the beliefs

There are only two possibilities for separating strategies for the Exporter. One possibility is that IP-type Exporter chooses C and NIP-type Exporter chooses NC. The second possibility is that the IP-type Exporter chooses NC and NIP-type Exporter chooses C. But since C strictly dominates NC[13] for IP-type exporter[14] if a separating PBE exists then the IP-type Exporter will systematically choose C while the NIP-type Exporter will choose NC. We can summarize the belief of the importer as follows:

$$\sigma_E(t) = \begin{cases} \text{C if type = IP} \\ \text{NC if type = NIP} \end{cases}$$

Now let $\mu(t_i / A)$ be the probability that the Importer assigns to type i after observing action A. If Importer observes that the Exporter chooses C, he will assign

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[13] The following condition should be satisfied $\frac{p}{R} > \frac{P(\alpha_I > \alpha_T / \alpha_E \leq \alpha_T)}{P(\alpha_I \leq \alpha_T / \alpha_E \leq \alpha_T)}$ in order for Payoff 1 to be greater than Payoff 3. From the above condition, the ratio of probability of acceptance and probability of rejection of an IP shipment given it has already been tested by the exporter should be lesser than the ratio of premium for a unit of IP and rejection costs per unit of shipment. The Payoff 2 is more than Payoff 4 by an amount equal to the premium for IP crops. From these two results we can say that C strictly dominates NC.

[14] We can prove that Payoff 1 and 2 are respectively greater than Payoffs 3 and 4.

probability 1 to type IP. If he observes Exporter choosing NC, he will assign probability 1 to type NIP. These beliefs are consistent with Bayes' rule as both the information sets are reached with positive probability along the equilibrium path. Again for simplification, I assume that the probabilities of I-type, and NI-type exporters are equal[15] : P (IP) = P (NIP) = 1/2.

We just established that,

$$P(C / IP) = 1; \;\; P(NC / IP) = 0 \; ; P(C / NIP) = 0 \; ; P(NC / NIP) = 1$$

By applying Bayes' theorem, I obtain

$$\mu(IP / C)^{16} = 1 \; ; \mu(NIP / C) = 0 \; ; \mu(IP / NC) = 0 \; ; \mu(NIP / NC) = 1$$

(ii) Best Response for Importer:

When Exporter plays C:

- Importer's expected profit from choosing (T) in response to Exporter choosing (C): :

$$EU_I(T, C) = \mu(IP / C) * Y_M(T, C; IP) + \mu(NIP / C) * Y_M(T, C; NIP) =$$

$$[P(\alpha_I \le \alpha_T / \alpha_E \le \alpha_T)(\Pi_I^m - t) - P(\alpha_I > \alpha_T / \alpha_E \le \alpha_T)(t)] = \Pi_I^m - t$$

This payoff function can be also written as $\Pi_I^m - t$ as the importer receives the IP Premium from a second shipment if the first one fails the test. So, with a probability of 1, he will get the profit of IP crop and will incur testing expenses with the same probability.

- Importer's expected profit from choosing (NT) in response to Exporter choosing (C):

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15 Even if the probabilities are not equal to each other, there will not be a change in the results Bayes' theorem is applied.

16 By applying Bayes' theorem, we get:

$$\mu(IP / C) = \frac{P(C / IP)P(C)}{P(C)} = \frac{P(C / IP)P(IP)}{P(C / IP)P(IP) + P(C / NIP)P(NIP)} = \frac{1(0.5)}{1(0.5) + 0(0.5)} = 1$$

EU_I (NT, C) = μ (IP / C) * Y_M (NT, C; IP) + μ (NIP/ C) * Y_M (NT, C; NIP) =

$[P(q/\alpha_E \le \alpha_T)(\Pi_I^m) + (1 - P(q/\alpha_E \le \alpha_T)(\Pi_{NI}^m - p)]$

From the above it follows,

EU_I (T, C) > EU_I (NT, C) if $t < [1 - P(q/\alpha_E \le \alpha_T)](Z_I - Z_{NI})$

So, the Best Response of Importer, if Exporter chooses 'Contains' = ***BR_I (C) = T***.

When Exporter chooses NC:

- Importer's expected profit from choosing (T) in response to Exporter choosing (NC):

EU_I (T, NC) = μ (IP / NC) * Y_M (T, NC; IP) + μ (NIP / NC) * Y_M (T, NC; NIP) = $[P(\alpha_I^U \le \alpha_T^U / \alpha_E^U \le \alpha_T^U)(\Pi_{NI}^m - t) - P(\alpha_I^U > \alpha_T^U / \alpha_E^U \le \alpha_T^U)(t)]$

- Importer's expected profit from choosing (NT) in response to Exporter's choice(NC):

EU_I (NT, NC) = μ (IP / NC) * Y_M (NT, NC; IP) + μ (NIP / NC) * Y_M (NT, NC; NIP) =

$[P(q/\alpha_E^U \le \alpha_T^U)(\Pi_{NI}^m) + (1 - P(q/\alpha_E^U \le \alpha_T^U))(-P_{NI})]$

From the above, EU_I (T, NC) > EU_I (NT, NC) if

$t < Z_{NI}[P(\alpha_I^U \le \alpha_T^U / \alpha_E^U \le \alpha_T^U) - P(q/\alpha_E^U \le \alpha_T^U)] + P_{NI}[1 - P(\alpha_I^U \le \alpha_T^U / \alpha_E^U \le \alpha_T^U)]$.

The exporter procures NIP-type commodity, confirms absence unapproved events through testing, but does not provide certification. But the exporter can also cheat claiming no presence of unapproved events without testing or segregating the shipment. The best alternative for the importer is then to test the shipment even though he incurs additional testing expenditure. So, the Best Response of Importer, if Exporter chooses NC = ***BR_I (NC) = T***.

(iii) Checking deviations

We can confirm the equilibrium as a PBE only if neither type of Exporter has an incentive to deviate. We know that IP-type will not deviate as C strictly dominates NC. The Exporter type NIP will follow the assigned strategy as long as the payoff it yields is at least as high as the one he would get if he deviated.

NI-type's payoff along the equilibrium path = Y_E (NIP, NC, NT) = Π^e_{NI}

If he deviated and chose C instead, the Importer's beliefs would continue to be as above, and seeing C chosen and that the Exporter is of IP-type with probability 1, and would therefore choose T. Therefore, if R>0, the payoff of Exporter of type NIP from deviating is $Y_E(NI,C,T) = \Pi^e_{NI} - R$, which is smaller than the payoff from following the equilibrium. In this situation when neither type of exporter deviates, the proposition given above will be a *separating PBE*,[17] which is as follows:

$$\sigma_E(t) = \begin{cases} C, & \text{if type} = IP \\ NC, & \text{if type} = NIP \end{cases}$$

$$\sigma_I(E, \mu(E)) = \text{Test}, \text{ if } E = C \text{ or } NC$$

Note 1: The game was also checked for the existence of a pooling equilibrium (i.e. both the types of exporters will be choosing C), which could not be confirmed.

Note 2: It should be noted that even if we add a third type of exporter, e.g., one who exports a substitute commodity, there be no change in the results shown above.

[17] Given the conditions below: (i) $\frac{p}{R} > \frac{P(\alpha_I > \alpha_T / \alpha_E \leq \alpha_T)}{P(\alpha_I \leq \alpha_T / \alpha_E \leq \alpha_T)}$

(ii) R>0 and (iii) $t < [1 - P(q / \alpha_E \leq \alpha_T)](Z_I - Z_{NI})$