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# **Why Has not Genetically Modified Wheat Been Commercialized: A Game Theoretical Perspective**

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# **Why Has not Genetically Modified Wheat Been Commercialized: A Game Theoretical Perspective**

## **Abstract**

In this paper, we investigate the reasons why Genetically Modified (GM) wheat has not been commercialized with a particular focus on how the leftward shifts of wheat demand affect social welfare changes. When wheat demand doesn't change due to the introduction of GM wheat, a presumed 10% yield increase will increase U.S. wheat producers' welfare by at least U.S.\$215 million and increase all consumers' welfare by at least U.S.\$392 million. However, a leftward shift of the demand curve, by as small as 3%, could diminish welfare gains and even result in negative welfare changes for both consumers and producers. We then explore, from a game theoretical approach, the cause-and-effect relationship between the demand side and major players' strategic reactions in the wheat market. Under certain conditions, anti-biotech special interest groups have the incentive to send messages to mislead consumers in favor of these groups' interests. Along with the fears of losing export sales because first mover disadvantages would occur to the country which first adopts GM wheat, essential decision makers—farmers and agricultural traders— would choose not to adopt GM wheat. Yet, a united front of industries along the GM food chain, as well as a coalition of international wheat exporters would help reshape the evolution of GM wheat commercialization.

*Key words:* GM wheat, game theory, special interest groups, political economy, first-mover disadvantage, welfare impact

# 1. Introduction

Although to date there is no Genetically Modified (GM) wheat in commerce, the debate around GM wheat has never stopped. Various reasons have been given in the literature to explain why GM wheat has not been adopted by farmers. An affordable segregation and traceability system must be established (Furtan, Gray, and Holzman, 2003 & 2005). Also, farmers may be concerned about the long term economic benefits because of the higher price of GM seeds and herbicide treatments (Fraley, 2013). Moreover, they would not want to lose their major export markets, especially Japan and the European Union (EU) where the approval process for new GM crops is slow and consumers are strongly opposed to consuming GM foods (Wisner, 2002; Furtan, Gray, and Holzman, 2003; Kogan, 2005; Schmitz, Schmitz, and Moss, 2005; Blue, 2010; Kalaitzandonakes, 2014).

A number of studies have also been conducted on the economic impact of GM wheat commercialization. Furtan, Gray, and Holzman (2005) use a game theory model to analyze whether or not there is a first-mover advantage for the United States and/or Canada to approve GM wheat. They assume no segregation, and thus the wheat price decreases to the lower GM wheat price after GM wheat is commercialized due to the “lemons” problem (Furtan, Gray, and Holzman, 2003). They also assume both wheat markets in the United States and Canada are homogeneous regarding GM wheat acceptance, indicating no demand shift in either country if GM wheat is adopted as is also assumed in Falck-Zepeda, Traxler, and Nelson (2000) and Price *et al.* (2003). Results show that the first-mover advantage does not exist considering the total social welfare change for biotech firms, wheat producers, and consumers together, because the optimal strategy for the United States is to approve GM wheat regardless of Canada’s decisions, while for Canada is not to approve GM wheat regardless of U.S. decisions. If only consumers’

welfare changes are considered, there is no first-mover advantage and the optimal strategy for both countries is to approve GM wheat. Berwald, Carter, and Gruère (2006) claim that Canada's stringent regulations on GM wheat are biased and caused the failure of GM adoption in the United States. Their results show that Canada would encounter a significant welfare loss if it produces only non-GM wheat while 75% of wheat produced in the United States and some developing countries is GM wheat. Johnson, Lin, and Vocke (2005) assume simultaneous commercialization of GM wheat in both Canada and the United States. They also allow segregation and demand shifts in segmented markets. As is acknowledged by the authors, their results of small net total welfare loss due to GM wheat adoption are highly dependent on presumed values of their model parameters, such as the adoption rate, consumer acceptance rates in the segmented market, cost savings, and yield increases. Besides parameters used in the model of Johnson, Lin, and Vocke (2005), Wilson *et al.* (2008) take into account of transportation costs and showed both consumer and GM wheat (hard red spring wheat) producers will gain, while consumers in countries having higher GM wheat acceptance gain more and those in countries having stricter GM food restrictions (such as Japan and the EU) gain less.

Even though these studies differ in their empirical estimates of the welfare impact of GM wheat commercialization, their assumption about consumers' demand is rather optimistic, especially with regards to consumers in those markets where tolerance thresholds are high, for instance, in the United States where there is no labeling requirement on GM foods. However, using the United States as an example, the aggregated total wheat demand (domestic demand plus foreign demand) might shift to the left in a segregated marketing channel (which has to be established for non-GM wheat farmers to sell GM free wheat (Schmitz, Schmitz, and Moss, 2005)). Consequently, the welfare impact analysis may be flawed if the leftward shift of wheat

demand, which might be the reason that GM wheat has not been commercialized, is not taken into account. If a leftward shift of the demand curve could cause aggregate welfare changes for both producers and consumers to be negative, the optimal strategy would certainly not to introduce GM wheat.

Unlike previous research focusing on the possible welfare impacts if GM wheat is introduced, we investigate reasons why GM wheat has not been introduced. In the following section of this paper, we investigate whether or not regulatory constraints on GM wheat have been harder than other commercialized GM crops by providing a background of the regulatory framework regarding Genetically Modified Organisms (GMOs) and development stages of GM wheat. Considering the demand side, a theoretical welfare impact model focusing on possible leftward shifts of aggregated wheat demand for U.S. wheat and related empirical results are provided in the third section and fourth section, respectively. In the fifth section, we discuss how the leftward shift of wheat demand relate to the strategic interactions between consumers and anti-biotech special interest groups and between wheat exporters and their international buyers. To understand the current difficulty in commercializing GM wheat, it is important to examine cause-and-effect relationship between the demand side and these players' strategic interactions. The summary and policy implications, as well as limitations and future research extensions are provided in the last section.

## **2. Background**

### **2.1. Genetically Modified Organism (GMO) regulatory framework review**

All Genetically Modified Organisms (GMOs) have to be tested through approval processes under three main regulatory agencies, namely the US department of Agriculture's Animal and Plant Health Inspection Service (APHIS), the Food and Drug Administration (FDA), the

Environmental Protection Agency (EPA). As shown in Figure 1, APHIS regulates the field trials of GMOs including planting, importation, interstate movement, or environmental release under the Plant Protection Act (PPA). By regulation (as in 7 CFR 340.1, 2013), most GM plants are classified as “regulated articles”, and the PPA requires a regulated article to receive approval from APHIS under either the notification procedure or the permit procedure before introduction<sup>1</sup> (USDA/APHIS, 2015). The biotechnology provider can send a notification to APHIS if the GM plant meets certain criteria by regulations (7 CFR 340.3, 2013) including the cloned genetic material is stably integrated into the plant genome; the genetic material does not include the complete infectious genome of a known plant pest; the plants or plant materials are shipped in a container that meets certain requirements; etc. If the notification is denied by the APHIS, the application may pursue a permit. The permit procedure requires the application to submit more information, in addition to data required by the notification procedure, describing how the field trials are conducted including processes to prevent release, the intended use and distribution, and the final disposition of the regulated article (7 CFR 340.4(b), 2013). If the permit is issued, the biotechnology applicant is then required to comply with conditions designed to ensure the regulated article remains confined and does not persist after field trials (7 CFR 340.4 (f), 2013). Failure in this stage can result in withdrawal of the permit by an inspector or the Administrator (7 CFR 340.4 (g), 2013).

Before commercial distribution, GMOs also require safety approval, known as the safety consultation process, from the Food and Drug Administration (FDA) (21 USC 348, 2016) if they are used for human food and animal feed purposes. If a plant is modified to produce substance that can prevent, destroy, repel, or mitigate a pest, it is classified as a pesticide (7 USC 136(u),

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<sup>1</sup> The introduction includes any movement into or through the U.S., or release into the environment outside an area of physical confinement (USDA, 2015).



2016). The Environmental Protection Agency (EPA) requires all pesticides to be registered under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) before they can be marketed. Before the required registration, pesticides must be tested and shown to be safe both to the environment and in food for consumption (7 USC 136a, 2016).

A regulated article may be eligible for a determination of nonregulated status if it has been tested and has shown not to pose a risk. Upon receipt of a petition, APHIS publishes a notice in the Federal Register, which specifies that public comments will be accepted during a 60-day period (7 CFR 340.6, 2013). APHIS has 180 days to approve in whole, or part, or deny the petition. If the petition is approved by APHIS, the plant will no longer be classified as a regulated article and may then be introduced into the United States without any further APHIS regulatory oversight (USDA/APHIS, 2015).

#### **[Insert Figure 1]**

Philips McDougall conducted a consultancy study for Crop Life International through a survey of cost and time involved in plant biotechnology R&D activities from six biotech companies consisting of BASF Corporation, Bayer CropScience, Dow AgroSciences, Dupont/Pioneer Hi-Bred, Monsanto Company, and Syngenta AG (Philips McDougall, 2011). The study suggests that the average dollar amount that these six companies spent on discovery, development, and authorization of a new GM trait introduced between 2008 and 2012 was \$136 million. The highest costs —51.4% of total costs or \$69.9 million—occurred in the discovery stage, and the secondary costs—25.8% of total costs or \$35.1 million— were associated with meeting regulatory requirements. On average, the cumulative time duration involving approval process starting from applying for field trials is 11.3 years before 2002, and 10.3 years between

2008 and 2012, while it is 12.9 years in 2012 (Table 1). Since these activity stages may overlap in real time, the cumulative total may be longer than the actual time spent on approval process.

**[Insert Table 1]**

## **2.2. GM wheat development history**

Among all genetically modified (GM) wheat varieties, Monsanto's herbicide-resistant (known as Roundup Ready) wheat has been the forefront of the debate. The history of GM wheat dates back to 1997 when Monsanto Company began the development of glyphosate-resistant spring wheat, known as Roundup Ready® wheat (MON 71800). Anticipating to duplicate the economic success of earlier commercialized GM corn, soybean, and canola, Monsanto submitted applications in the United States and Canada for regulatory approval of MON 71800 in 2002. Two years later, Monsanto received the food use safety approval from the U.S. Food and Drug Administration (FDA) (FDA/CFSAN, 2004). However, by this time, regulatory applications for the new GM wheat had attracted attention of environmental activists and were starting to meet with resistance from certain wheat farmer groups (especially those with a large exposure to export markets), agrochemical manufacturers, and wheat traders (Falkner, 2009; Graff, Hochman, Zilberman, 2009). In large part due to a lack of commercial opportunities and industry alignment, Monsanto was forced to withdraw its application from the U.S. Environmental Protection Agency (EPA) and publicly declared its intention to discontinue the MON 71800 program (Falkner, 2009). On May 10, 2004, Carl Casale, Executive Vice President of Monsanto, stated that (Monsanto, 2004)

*“As a result of our portfolio review and dialogue with wheat industry leaders, we recognize the business opportunities with Roundup Ready spring wheat are less attractive relative to Monsanto's other commercial priorities. Acreage planted in the spring wheat market in the United States and Canada has declined nearly 25*

*percent since 1997, and even more in the higher cost weed control target market for this product. This technology adds value for only a segment of spring wheat growers, resulting in a lack of widespread wheat industry alignment, unlike the alignment we see in other crops where biotechnology is broadly applied..... We will continue to monitor the wheat industry's desire for crop improvements, via breeding and biotechnology, to determine if and when it might be practical to move forward with a biotech wheat product. This decision allows us to defer commercial development of Roundup Ready wheat, in order to align with the potential commercialization of other biotechnology traits in wheat, estimated to be four to eight years in the future.”*

While Monsanto immediately closed all GM wheat programs in 2005, other companies or research institutions have been developing various GM traits for wheat, including pest-resistant wheat, salt-tolerant wheat, biofortified wheat, and drought-tolerant wheat (USDA/APHIS Notification, Permit, and Petition Data, January 19, 2016). For instance, Syngenta developed a Fusarium-resistant wheat but postponed the project in 2007 (ISAAA, Pocket K No. 38: Biotech Wheat).

In 2009, Monsanto purchased WestBred—a seed company—and resumed the research in GM wheat responding to the wheat industry in Australia, Canada and the United States that calls for more investment in R&D of GM wheat research. Since then, all Monsanto’s GM wheat field trials have received permits from and been regulated by USDA/APHIS. However, unexpected GM wheat were detected on a farm in Oregon in 2013, and a year later again in a research facility in Montana. USDA immediately launched investigations after being notified the discovery of unauthorized GM wheat. Extensive testing by both USDA and Monsanto confirmed that there is no GM wheat in commerce; the two incidents are isolated even though both GM wheat varieties share the same GM trait from the original Roundup Ready wheat (MON 71800) developed by Monsanto (Table 2) (USDA/APHIS, 2014). USDA announced in December, 2015 that as of January 1, 2016, it will require GM wheat developers to apply for permits before

conducting field trials. Since the new requirement was implemented, there have been three permit applications and one notification application submitted to USDA/APHIS, all of which are pending as of January 19, 2016 (USDA/APHIS Notification, Permit, and Petition Data, January 19, 2016).

**[Insert Table 2]**

### **3. Theoretical welfare impact model**

Existing studies indicate that the key hurdle of commercializing GM wheat from the marketing perspective is rather consumers' attitudes toward GMOs than food safety concerns associated with GMOs which haven't been proven scientifically valid. Essentially, food labeling entitles final consumers to make choices out of GM versus non-GM products (Wisner, 2004; Blue, 2010; Fraley, 2009). Even if the government approves imports of GM wheat, there wouldn't be any guarantee of consumer acceptance. A simplified model, as depicted in Figure 2, can be used to illustrate how the shift of the demand curve impacts welfare changes of producers and consumers. The total demand curve for U.S. wheat is  $D$ . This demand curve aggregates the demand of all wheat varieties from both the domestic market and the foreign market. The total U.S. wheat supply curve is  $S$ . Before GM wheat is adopted,  $D$  and  $S$  represent the total demand and supply for non-GM U.S. wheat only. Assuming that the new aggregated total supply curve, which aggregates both GM wheat supply and non-GM wheat supply in the United States, shifts to  $S'$  by 10% due to the yield increase of GM wheat. If it is assumed the aggregated total demand curve for U.S. wheat does not change, then a rightward shift of the aggregated total supply curve will result in a lower aggregated wheat price. The aggregated welfare of producers and consumers increase by  $(fdeb - P_0P_1fa)$  and  $P_0P_1ba$ , respectively.

As is argued by Schmitz *et al.* (2010) and Moss, Schmitz, and Schmitz (2008), a segregated marketing channel must be established for producers to sell non-GM commodities. The model in Figure 2 allows market segregation. But for better intuitive understanding, we aggregate domestic and foreign markets. The analysis is also consistent with the aforementioned previous studies which are conducted based on segregated markets. In a segregated market, the supply curve for non-GM wheat may shift to the left due to segregation costs, but the supply curve for GM wheat shifts outward by more than 10%, resulting the initial assumption that the aggregated total supply curve shifts outwardly by 10%. With demand curves—both the demand curve for non-GM wheat and the demand curve for undifferentiated wheat—remaining unchanged, producers and consumers in non-GM wheat markets will be worse off because of segregation costs, while consumers and producers in undifferentiated markets are better off enjoying the lower price due to the cost saving biotechnology. Aggregating total welfare changes of both markets will lead to total welfare gains of  $(fdeb - P_0P_1fa)$  and  $P_0P_1ba$  for producers and consumers, respectively. Of course, if the total aggregated wheat demand curve also shifts to the right, the total welfare change for consumers and producers will increase more.

**[Insert Figure 2]**

Nevertheless, the welfare impact analysis may be flawed if it is assumed that the demand curve may shift to the left, especially when considering the large scale of consumers' anti-GMO sentiments from both the domestic U.S. market and major importing markets of U.S. wheat, such as Japan, South Korea, China, Taiwan, and the EU. A recent research survey was conducted by the Pew Research Center in cooperation with the American Association for the Advancement of Science (AAAS) using a sample of two non-overlapping groups: 2,002 adult U.S. citizens and 3,748 scientists who are all members of the AAAS. The survey was released in January 2015,

and the result indicates that among all those respondents who chose to answer, 37% of adult citizens say eating GM foods is generally safe while 57% believe GM foods are unsafe (PewResearchCenter, 2015). Besides the required labeling on GM foods, there have also been broad consumer opposition to GM foods in the aforementioned major U.S. wheat importing countries, which makes it harder to sell GM wheat. Also, studies suggest that high segregation costs, low levels of tolerance for unapproved GMO imports, as well as concerns of contamination would divert these countries' wheat import demand to markets where GM wheat is not adopted (Wisner, 2002; Blue, 2010). All these factors indicate that it is very likely that the demand curve for non-GM wheat from the United States will shift to the left after GM wheat is adopted. If the distance of the leftward shift of the non-GM wheat demand curve exceeds that of the rightward shift of the undifferentiated wheat demand curve, then the aggregated total wheat demand curve will shift to the left.

As is shown in Figure 2, if the aggregated total demand curve shifts from  $D$  to  $D'$  resulting the new equilibrium price at  $P'_0$  and the equilibrium quantity still at  $Q_0$ , then the aggregated total welfare will not change for either consumers or producers. (Here, we assume shifts of demand and supply curves are parallel. But, if the parallel shift assumption is released, one can still find the breakeven position of the new aggregated total demand curve.) A further left shift of the aggregated total demand curve will result in negative welfare changes for both consumers and producers. As shown in Figure 2, the aggregated total demand curve now is  $D''$ . The new equilibrium is  $(P_2, Q_2)$ . The producer surplus change is  $(P_2ge - P_0ad)$  and consumer surplus change is  $(hP_2g - P^{**}P_0a)$ , both of which are negative.

#### 4. Empirical welfare estimations of commercializing GM wheat

In this section, we estimate the impact of commercializing GM wheat in marketing year 2014/15.

It is assumed that the adoption of GM wheat increases wheat yield by 10%. Estimation results are obtained based on three scenarios of demand curve changes: (1) the total demand curve remains unchanged; (2) the total demand curve shifts to the position where welfare changes for both consumers and producers are zero (breakeven position)<sup>2</sup>; and (3) the total demand curve shifts to the left of the breakeven position.

The data on U.S. wheat supply and disappearance are provided in Table 3. The total U.S. production of all wheat is given in column 1 (excluding the column of marketing year). The USDA/ERS separates the domestic use of wheat into food, seed, feed and residue uses. The total disappearance is the sum of the domestic use and export. The last two columns are U.S. farm price—average price for all wheat received by U.S. farmers—and the annual world wheat price for the corresponding marketing year. We use values in the marketing year of 2014/15 as the basis in this study. The total U.S. wheat production is approximately 2.03 billion bushels and total disappearance of U.S. wheat is 2.01 billion bushels of which 1.16 billion bushels are for the domestic use and 854 million bushels are sold as exports. About 83% of all wheat consumed in the United States is considered as food wheat and the remaining 17% as non-food wheat. The average price received by wheat farmers in 2014/15 is U.S.\$ 5.99 per bushel and the average world wheat price for the same marketing year is U.S.\$ 5.91 per bushel.

**[Insert Table 3]**

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<sup>2</sup> We assume demand and supply curves are linear. In reality, these curves are most likely not linear (Schmitz, Schmitz, and Moss, 2005). However, since we are trying to illustrate how the parallel shifts of the total demand curve affect producer and consumer welfare changes due to the adoption of GM wheat, a linear curve can fully capture the sign of welfare changes and has been used in previous studies that estimate economic impact of GM wheat commercialization.

The world wheat price and the total disappearance are the actual equilibrium price and quantity at the intersection of the total U.S. wheat supply curve and demand curve (Figure 2). To estimate the monetary welfare impact of commercializing GM wheat, price elasticities of supply and demand curves also need to be specified. Harrington and Dubman (2008) estimated the price elasticity of wheat supply in the United States is 1.25 and Sumner (2005) assumed it to be 1.0. Furtan, Gray, and Holzman (2005) assumed the price elasticity of the overall U.S. and Canadian wheat supply to be 0.5. Wilson et al. (2008) used 0.263, 0.302, and 0.251 for the price elasticity of wheat supply in North Dakota, Montana, and other U.S. states, respectively. On the demand side, Hniotis, Baffes and Ames (1988) estimated the export demand for U.S. wheat is  $-0.741$ , and Harrington and Dubman (2008) estimated the price elasticities of both the export demand and the domestic nonfarm demand for U.S. wheat are  $-0.85$ . Furtan, Gray, and Holzman (2005) used  $-0.15$  for the price elasticity of the overall U.S. and Canadian wheat demand, and Wilson et al. (2008) used  $-0.5$  for the price elasticity of export demand for U.S. wheat. To be close to the middle range of the price elasticities being used in previous studies as well as to provide an upper-bound limit, we assume the price elasticities of total U.S. wheat supply to be 0.5 and 1.5, and the price elasticities of total demand for U.S. wheat to be  $-0.5$  to  $-1.5$  in this study.

Estimates of welfare changes due to the introduction of GM wheat are provided in Table 4. When the wheat demand remains unchanged but the wheat supply responds to the 10% yield increase from adopting GM wheat, consumers of U.S. wheat (including both domestic U.S. consumers and foreign consumers) gain from U.S.\$ 391 million to U.S.\$ 1.20 billion, and U.S. wheat producers gain from U.S.\$ 215 million to U.S.\$ 1.29 billion. However, along with the total demand curve shifting leftwards, these welfare gains will gradually diminish. When the price elasticities of demand and supply equal, a same 10% leftward parallel shift of the total demand



curve will reduce these welfare gains to be zero. If the price elasticity of U.S. wheat supply is 0.5 and the price elasticity of the total demand for U.S. wheat is  $-1.5$ , a 29.6% leftward parallel shift of the total demand curve will diminish the welfare gains of both consumers and producers. If the price elasticity of U.S. wheat supply is 1.5 and the price elasticity of the total demand for U.S. wheat is  $-0.5$ , a 3.3% leftward parallel shift of the total demand curve will diminish welfare gains for both consumers and producers. If the total demand curve for U.S. wheat shifts leftwards beyond the breakeven position, welfare changes for both consumers and producers become negative. Consequently, adopting GM wheat is not a wise option for either wheat farmers or consumers.

## **5. Strategic interactions between major players in the wheat market**

Furtan, Gray, and Holzman (2005) apply a game theoretical framework to determine if there is a first-mover advantage for the United States and Canada to approve GM wheat. The following analysis is also from a game theoretical perspective, but we focus on the cause-and-effect relationship between the wheat demand after GM wheat commercialization and wheat players' strategic interactions.

### **5.1. Consumers versus anti-biotech special interest groups**

Graff, Hochman, and Zilberman (2009) pointed out that the growing tension centering on GMOs is rather a political outcome. Opponents of GMOs provide and publicize bad news about GMOs, while supporters promote good news. Consumers then make decisions by weighting the evidence based on trust in various groups. Various scientific organizations have stated that GMOs are safe as their conventional counterparts (a partial list of these organizations is presented in Table 2A in the appendix), but a majority of consumers from numerous of polls are not aware of these scientific statements considering the safety of GMOs. Thus, a question would arise: knowing the

vast amount of scientific evidence, can special interest groups purposely mislead consumers to make inappropriate decisions in favor of their rent seeking activities (Schmitz et al., 2010)? This has not been answered by previous literature.

Game theory models are commonly used to explain strategic relationships between decision makers. Bullock (2015) used game theory models explaining why making trade negotiations more transparent could result in more misinformation. As is in Bullock (2015), the game played by citizens and trade negotiators is actually a cheap talk game, a type of signaling game where the message sender's type is private information to her/him thus unknown to the message receiver. Employing a similar game theory structure as is in Bullock (2015), we model the strategic interactions between consumers and anti-GMO special interest groups (Figure 3). Nature moves first by determining the probability of GMOs being not good with probability  $p$ , and being good with probability  $(1 - p)$ . The Special Interest Group (SIG) has private information of what Nature says about GMOs, and then it sends a message indicating either "GMOs are good" or "GMOs are not good" to the consumer. The payoff functions are: SIG gets 1 if the consumer votes for "GMOs are not good", and loses the spin cost if it chooses to spin the message. The consumer gains 1 if he votes properly—if Nature says "GMOs are not safe" and the consumer votes for "GMOs are not safe"; vice versa—but loses the inspection cost if he chooses to inspect. When SIG sends the message to the consumer, it may spin or not spin the message. So the consumer doesn't know if the message he received is spun or not. For instance, when the consumer receives "GMOs are not safe", he doesn't know if he is at ① or at ②.

To get the consumer's payoff when he chooses to inspect, it is reasonably assume that it is more likely for him to vote properly. In other words, if the consumer chooses to inspect, the probability of the consumer voting against GMOs when Nature says "GMOs are not good"

equals the probability of the consumer voting in favor of GMOs when Nature says “GMOs are good”, and it is greater than 0.5. We denote this probability as  $s > 0.5$ . When the consumer chooses not to inspect, he behaves based on his beliefs. In this model, we assume two sets of the consumer’s beliefs when he doesn’t inspect: (1) no matter what SIG says, GMOs are not good with probability  $p$ ; (2) if SIG says GMOs are not good, then GMOs are not good with probability 1, and if SIG says GMOs are good, then GMOs are good with probability 1. A perfect Bayes-Nash equilibrium requires not only sequential rationality (each player acts optimally given his beliefs) but also consistent beliefs (the message receiver recognizes the incentives the sender has to mislead him when he updates his posterior beliefs in response to the sender’s observed behavior)<sup>3</sup>.

Starting with the consumer’s first set of beliefs, the extensive form of the Bayesian game between the consumer and SIG is shown in Figure 4. Consistent with these beliefs, the consumer’s expect payoff from choosing to inspect regardless of what SIG says is

$p(s - c_i) + (1 - p)(s - c_i) = s - c_i$ . His expected payoff from choosing not to inspect regardless

of what SIG says is  $p \cdot p + (1 - p) \cdot (1 - p) = p^2 + (1 - p)^2$ . Thus, if  $s - c_i > p^2 + (1 - p)^2$ , the

consumer will inspect regardless of what SIG says. Since the consumer will inspect, SIG is

always better off when it says what Nature says (meaning not to spin the message) since

$s > (s - c_s)$  and  $(1 - s) > (1 - s - c_s)$ . On the other hand, if  $s - c_i < p^2 + (1 - p)^2$ , the consumer

will not inspect regardless of what SIG says. Since the consumer will not inspect, SIG is still

always better off when it says what Nature says since  $p > (p - c_s)$ . Therefore, the perfect Bayes-

Nash equilibrium is

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<sup>3</sup> More details about signaling games can be found in Harrington, Joseph. Games, strategies and decision making. Macmillan. Worth Publishers, New York (2009).

***SIG's strategy:*** *Never spin the message.*

***The consumer's strategy:*** *Ignore what SIG says.*

***The consumer's beliefs:*** *Regardless of what SIG says, GMOs are not good with probability  $p$ .*

In this equilibrium, messages from SIG does not contain any information, meaning the message sender SIG does not influence the receiver's behavior.

**[Insert Figure 4]**

The interesting issue is whether there is also an equilibrium in which messages actually contain information thus can affect receiver's behavior. Now we consider the following scenario for a separating perfect Bayes-Nash equilibrium based on the second set of consumer's beliefs (Figure 5):

***SIG's strategy:*** *Signal "GMOs are not good" if and only if Nature says "GMOs are not good"; signal "GMOs are good" if and only if Nature says "GMOs are good"*

***The consumer's strategy:*** *Follow SIG's messages and not inspect.*

***The consumer's beliefs:*** *If SIG says "GMOs are not good", then assign probability 1 to "GMOs are not good". If SIG says "GMOs are good", then assign probability 1 to "GMOs are good".*

We need to find out when this equilibrium exists. First of all, it is apparent that the consumer's beliefs are consistent. Given that SIG only signals what Nature says, the consumer's strategy is clearly optimal. Suppose Nature says "GMOs are not good", then SIG will choose to signal "GMOs are not safe" since the consumer's strategy is to not inspect SIG's message and  $1 > -c_s$  which is indeed true. The problematic scenario is when Nature says "GMOs are safe", for SIG to choose "GMOs are safe", it would lead to  $(1 - c_s) < 0$  which is indeed not possible because the

spin cost cannot be greater than 1. Therefore, this is not a perfect Bayes-Nash equilibrium since SIG's strategies are not optimal when Nature says "GMOs are good".

**[Insert Figure 5]**

Therefore, there is only one perfect Bayes-Nash equilibrium in which SIG's messages are not informative and it has no incentive to mislead the consumer. However, if the consumer's inspection costs are high ( $c_i > s$  in Figure 5) and the consumer does not draw inferences from SIG's strategy to update his beliefs, it can be easily notice that his dominant strategy is not to inspect, and thus the optimal strategy for SIG is "always signal GMOs are not good" since  $1 > -c_s$  and  $1 - c_s > 0$ . Though this consequence—SIG's strategy is always "GMOs are not good"; the consumer's strategy is to not inspect; the consumer has the second set of beliefs— is not a perfect Bayes-Nash equilibrium since consumers' beliefs are not consistent with SIG's optimal strategy, it indicates when the consumer's strategy is dominated by not inspecting due to his high inspection cost, SIG has the incentive to mislead the consumer as long as the consumer does not adjust his beliefs based on SIG's observed actions.

The above game theoretical analysis indicates that anti-GMO special interest groups will try to increase consumers' inspection costs in order to mislead consumers if they can influence consumers' perspectives on GMOs. One way to increase consumers' inspection costs is to send them more messages, thus it is less possible (or more expensive) for consumers to inspect every message (Bullock, 2015). Researchers, such as Lusk (2013), suggest to encode product information into a barcode so that if consumers are interested to inspect, they can check the barcode for more information.

## **5.2. Wheat importers versus wheat exporters**

Wheat is one of the commodities where the world largest exporters are competing for market shares. For decades, nearly 90% of total world wheat exports have been dominated by the United States, Canada, Australia, the EU, Argentina, and the former Soviet Union (including three major wheat exporters: Russia, Ukraine, and Kazakhstan). Nevertheless, the profiles for the United States and Australia, the historically two largest wheat exporters, are rather gloomy in terms of continuously decreasing export shares with sharp fluctuations. For the United State, due to increased planting flexibility and low returns compared to competing crops such as soybean and corn, U.S. wheat production and export shares in the world market have been downward trending since 1981/82 (Figure 6a). In contrast, wheat exports of the EU, Russia, and Ukraine have been steadily increasing since 2000/01 (Figure 6b). In the marketing year of 2013/14, the U.S. share of world wheat exports was 19.41%, while the EU share increased to 19.73% becoming the world largest wheat exporter (Figure 6c).

While the world wheat export market is dominated by only a few countries, there are many wheat importers scattered all over the world. As is shown in Figure 6d, the developing world account for the majority of world wheat imports. These regions include Middle East (Iran and Iraq), North Africa (Egypt, Algeria, and Morocco), Sub-Saharan Africa (Nigeria, Republic of South Africa, Sudan, and Kenya), Southeast Asia (Indonesia, Philippines, and Vietnam), South America (Brazil and Mexico), and South Asia (Afghanistan, Bangladesh, and Pakistan). Developed countries including Japan, South Korea, and some countries in the EU also account for a large share of world wheat imports. It should be noticed that the EU, China, and India are the top three wheat producers, however, their domestically produced wheat are mainly for

domestic consumption and their wheat imports are very small compared to other countries as mentioned above (Figure 6d).

**[Insert Figure 6a, 6b, 6c, and 6d]**

Facing the decreasing wheat planting acreages and shrinking export markets especially for the United States and Australia, the first GM wheat trait (herbicide resistant) initiated by Monsanto in 1997 was considered as an alternative method to lessen wheat farmers' weed control stress by reducing the use of chemical pesticide and thus it could improve farmers' economic benefits. Although U.S. farmers producing primarily for domestic market have remained open-minded about the potential commercial benefits of GM wheat, GM wheat commercialization received strongly oppositions from North American wheat export interests, particularly from the former Canadian Wheat Board because Canadian farmers are more dependent on export markets and they fear to lose the modest growing opportunity at that time (Figure 6b) (Falkner, 2009; Wisner, 2002). Due to the failure of building a consensus among North American wheat farmers, Monsanto announced to delay the GM wheat development in May 2004. While some wheat groups still continue to oppose GM wheat commercialization, a majority of wheat industries in the United States, Canada, and Australia signed a trilateral agreement in 2009 to promote GM wheat commercialization (Wheat Biotechnology Commercialization, 2014). From a game theoretical perspective, this cartel formation is a necessary approach at the moment to move forward towards GM wheat commercialization considering the *first-mover disadvantage*: no player can gain by committing to move first; the other player will obviously exploit the knowledge of the previous move.

The top ten wheat consumers of the five biggest wheat exporters consisting of the United States, Canada, Australia, the EU, and Russia as well as these five exporters' strategic

relationships in terms of export market competitions are shown in Table 5 and Figure 7, respectively. The United States shares with Canada the same important export destinations including Mexico, Japan, and Indonesia, total of which account for about 25% of major U.S. export markets while about 28% of Canadian export markets; Canada shares with Australia the same export destinations majorly including Indonesia and Japan, which in total account for about 13% of major Canadian export markets while about 28% of major Australian export markets; The United States shares with Australia the same export destinations including Japan, Indonesia, China, Philippines, and South Korea, total of which account for over 30% of major U.S. export markets while over 45% of major Australian export markets. Finally, the three exporters share the same markets of Mexico, Japan, and Indonesia. Among these shared destinations, Mexico and Philippines are the only two countries where there are no labeling requirements on GM foods. It is obvious that the first mover towards GM wheat will encounter a vast loss of export markets. The competition from the EU and Russia was considered as a threat to the GM wheat cartel formed by the United States, Canada, and Australia. However, Egypt and Yemen are the only two major destinations that they shared with the GM wheat promotion cartel, while there is no labeling requirement in either Egypt or Yemen at the moment. Therefore, as long as the segregation system can be established to assure the non-GM buyers that they can buy cheaper non-GM wheat than switching to the EU or Russia (taking into account of transaction and transportation costs), then this GM wheat promotion cartel is desirable.

**[Insert Table 5]**

**[Insert Figure 7]**



## Conclusions

In this paper, we have emphasized, using a welfare impact model, that the large uncertainty from the demand side is perhaps the main reason that GM wheat has not been commercialized. If the aggregated demand shifts to the left, welfare gains for both consumers and producers could diminish and even become negative. From a game theoretical perspective, we show that anti-GM wheat special interest groups, who realized reducing consumers' demand is the essential key to block GM wheat, would try to mislead consumers in favor of their rent seeking activities. With regard to the trilateral agreement promoting GM wheat commercialization between the United State, Canada, and Australia, we investigate the underlying reasons why this cartel formation is needed to promote GM wheat through examining the strategic relationship between major players in the world wheat market.

This paper can be further extended in the following aspects. First, a more specific model distinguishing domestic demand from foreign demand would show consumer surplus changes for both consumer in the United States and consumers abroad. In this paper, domestic demand and foreign demand are aggregated, and thus our estimates of consumer surplus are the sum of U.S. consumer surplus and foreign consumer surplus. Second, in our model, we do not take into account of segregation costs, which could further impact both GM wheat demand and non-GM wheat demand. For instance, if segregation costs in the United States are too high, non-GM wheat demand from the United States would be further reduced. Third, it would be interesting to show the empirical welfare impacts if GM wheat is concurrently commercialized in the United State, Canada, and Australia, and whether or not the cartel is the optimal solution.

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## Appendix:

Table 1A. Definition of activity stages

Activity Stage	Definition
<b>I. Early Discovery “Hits”</b>	<b>Activity:</b> Preliminary screening and identification of genetic sequences with the potential to deliver the trait of interest. May involve screening genetic libraries, knowledge-based in silico genome searches, random activation tagging, gene sequence shuffling, etc. <b>Output to the next Activity Stage:</b> genetic sequence “hits”.
<b>II. Late Discovery “Leads”</b>	<b>Input:</b> genetic sequences <b>Activity:</b> Use one or more surrogate model plant system assays (e.g, Arabidopsis, micro-crop), normally with one or two utility promoter cassettes, to evaluate the hits in order to determine which hits may be capable to deliver the trait of interest. This is considered to represent “proof of concept”. <b>Output:</b> Genetic sequence “leads”
<b>III. Construct Optimization</b>	<b>Activity:</b> Lead genetic sequences are combined with different promoter sequences selected for their pattern of constitutive, temporal or tissue-specific expression required to optimize gene expression and gene product accumulation in order to achieve the trait of interest. The target crop is transformed and evaluated under greenhouse and/or field conditions. To evaluate each construct conclusively in plants may be characterized per construct for the trait of interest

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and no negative agronomic effects. **Output:** Genetic constructs (coding sequence(s) and markers) “leads”

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**IV. Commercial Event  
Production & Selection**

**Activity:** The Lead genetic constructs are used to product commercial-quality events which are pre-screened using various forms of molecular characterization to eliminate complex or multiple insertions. These events may go through a preliminary evaluation in the greenhouse or nursery as T0 or T1 plants for the trait of interest depending on the complexity of the trait. The numbers may vary depending on the transformation methodology used.

**Output:** Commercial-quality events “leads”

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**V. Introgression, Breeding  
& Wide-Area Testing**

**Activity:** The lead commercial quality events are introgressed into the most elite germplasm to produce sufficient quantities of seed for product-quality hybrids or varieties for evaluation under normal and/or managed field conditions to confirm the trait of interest, to ensure no negative impact of the trait on key performance attributes, yield or grain quality, and to evaluate potential interactions of the event and trait in key product germplasm in multiple environments both alone and with other events. These field evaluations will likely happen over 3-5 years. **Output:** Commercial quality event(s) to regulatory science

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**VI. Regulatory Science**

**Activity:** Conduct all regulatory science studies and data generation in the field, greenhouse, growth chambers and laboratories (internal and external contract research organizations) to fully characterize the event insertion and to confirm the food, feed and environmental safety of products containing the event and representing the trait. The field evaluations may require two seasons to produce the data and prepare the comprehensive data package required for submissions to obtain cultivation and import approvals. **Output:** Regulatory packages to submit for commercial event(s)

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**VII. Registration & Regulatory Affairs**

**Activity:** The staffing resources required to prepare, submit and manage to approval the submissions in 1-2 countries/jurisdictions for cultivation approval and in 5-7 countries/jurisdictions for import approval. Normally 12-15 different agencies. **Output:** Submissions made and approvals obtained for commercial sale and grain production.

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Source: Phillips McDougall (2011)

Table 2A. A partial list of organizations that have commented on genetically modified crops (including links)

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- [American Association for the Advancement of Science](#): “The science is quite clear: crop improvement by the modern molecular techniques of biotechnology is safe.”
- [American Medical Association](#): “There is no scientific justification for special labeling of genetically modified foods. Bioengineered foods have been consumed for close to 20 years, and during that time, no overt consequences on human health have been reported and/or substantiated in the peer-reviewed literature.”
- [The United States National Academy of Sciences](#): “Environmental effects at the farm level have occurred as a result of the adoption of GE crops and the agricultural practices that accompany their cultivation. The introduction of GE crops has reduced pesticide use or the toxicity of pesticides used on fields where soybean, corn, and cotton are grown.”
- [World Health Organization](#): “No effects on human health have been shown as a result of the consumption of GM foods by the general population in the countries where they have been approved.”
- [The United States National Academy of Sciences](#): “To date, no adverse health effects attributed to genetic engineering have been documented in the human population.”

- [American Phytopathological Society](#): “The American Phytopathological Society (APS), which represents approximately 5,000 scientists who work with plant pathogens, the diseases they cause, and ways of controlling them, supports biotechnology as a means for improving plant health, food safety, and sustainable growth in plant productivity.”
- [American Society for Cell Biology](#): “Far from presenting a threat to the public health, GM crops in many cases improve it. The ASCB vigorously supports research and development in the area of genetically engineered organisms, including the development of genetically modified (GM) crop plants.”
- [American Society for Microbiology](#): “The ASM is not aware of any acceptable evidence that food produced with biotechnology and subject to FDA oversight constitutes high risk or is unsafe. We are sufficiently convinced to assure the public that plant varieties and products created with biotechnology have the potential of improved nutrition, better taste and longer shelf-life.
- [American Society of Plant Biologists](#): “The risks of unintended consequences of this type of gene transfer are comparable to the random mixing of genes that occurs during classical breeding... The ASPB believes strongly that, with continued responsible regulation and oversight, GE will bring many significant health and environmental benefits to the world and its people.”
- [U.S. Food and Drug Administration](#): “FDA is confident that the bioengineered foods on the United States market today are as safe as their conventional counterparts.”
- [Health Canada](#): “Health Canada is not aware of any published scientific evidence demonstrating that novel foods are any less safe than traditional foods.”
- [Society of Toxicology](#): “Scientific analysis indicates that the process of GM food production is unlikely to lead to hazards of a different nature than those already familiar to toxicologists. The level of safety of current GM foods to consumers appears to be equivalent to that of traditional foods.”
- [International Seed Federation](#): “The development of GM crops has benefited farmers, consumers and the environment... Today, data shows that GM crops and foods are as safe as their conventional counterparts: millions of hectares worldwide have been cultivated with GM crops and billions of people have eaten GM foods without any documented harmful effect on human health or the environment.”
- [Council for Agricultural Science and Technology](#): “Over the last decade, 8.5 million farmers have grown transgenic varieties of crops on more than 1 billion acres of farmland in 17 countries. These crops have been consumed by humans and animals in most countries. Transgenic crops on the market today are as safe to eat as their conventional counterparts, and likely more so given the greater regulatory scrutiny to which they are exposed.”

- [Society for In Vitro Biology](#): “The SIVB supports the current science-based approach for the evaluation and regulation of genetically engineered crops. The SIVB supports the need for easy public access to available information on the safety of genetically modified crop products. In addition, the SIVB feels that foods from genetically modified crops, which are determined to be substantially equivalent to those made from crops, do not require mandatory labeling.”
- [American Dietetic Association](#): “It is the position of the American Dietetic Association that agricultural and food biotechnology techniques can enhance the quality, safety, nutritional value, and variety of food available for human consumption and increase the efficiency of food production, food processing, food distribution, and environmental and waste management.” (<http://1.usa.gov/12hvWnE>) **Update:** The American Dietetic Association (ADA) has become The Academy of Nutrition and Dietetics (AND). While the above statement reflected the ADA’s position the president of AND has stated that AND is currently neutral and has no position on GMOs.
- [Federation of Animal Science Societies](#): “Meat, milk and eggs from livestock and poultry consuming biotech feeds are safe for human consumption.”
- [Consensus document on GMOs Safety](#) (14 Italian scientific societies): “GMOs on the market today, having successfully passed all the tests and procedures necessary to authorization, are to be considered, on the basis of current knowledge, safe to use for human and animal consumption.”
- [“Transgenic Plants and World Agriculture”](#) – Prepared by the Royal Society of London, the U.S. National Academy of Sciences, the Brazilian Academy of Sciences, the Chinese Academy of Sciences, the Indian National Science Academy, the Mexican Academy of Sciences, and the Third World Academy of Sciences: “Foods can be produced through the use of GM technology that are more nutritious, stable in storage, and in principle health promoting – bringing benefits to consumers in both industrialized and developing nations.”
- [French Academy of Science](#): “All criticisms against GMOs can be largely rejected on strictly scientific criteria.”
- [International Society of African Scientists](#): “Africa and the Caribbean cannot afford to be left further behind in acquiring the uses and benefits of this new agricultural revolution.”
- [Union of German Academies of Sciences and Humanities](#): “Food derived from GM plants approved in the EU and the US poses no risks greater than those from the corresponding conventional food. On the contrary, in some cases food from GM plants appears to be superior with respect to health.”
- [International Council for Science](#): “Currently available genetically modified crops – and foods derived from them – have been judged safe to eat, and the methods used to test them have been deemed appropriate.”

Table 1. Duration of each activity stage in a GMO plant approval process

Table 1. Duration of each activity stage in a GMO plant approval process

Category	Event sold before 2002		Event sold between 2008-2012		Required to complete each stage in 2011	
	Months	% share	Months	% share	Months	% share
<b>Introgression breeding &amp; wide-area testing</b>	40	29.63%	37.2	30.19%	42	27.18%
<b>Regulatory science</b>	50.5	37.41%	37.2	30.19%	47	30.42%
<b>Registration &amp; regulatory affairs</b>	44.5	32.96%	48.8	39.61%	65.5	42.39%
<b>Total cumulative time</b>	135 (11.3 yr)		123.2 (10.3		154.5 (12.9 yr)	

Source: Phillips McDougall (2011). Note the definition of each category/stage is detailed in Table 1A in the Appendix.

Table 2. Two incidents involving the detection of GE wheat in the United States

Table 2. Two incidents involving the detection of GE wheat in the United States

	<b>Oregon</b>	<b>Montana</b>
<b>Location</b>	A single field on a single farm	A research facility (SARC) where authorized regulated field trials for GM wheat occurred between 2000 and 2003.
<b>Time of discovery and USDA investigation</b>	The Oregon farmer sent the GM wheat sample to an Oregon State University scientist and the samples were received on April 30, 2013. The scientist notified USDA on May 3, 2013. USDA launched the investigation immediately on May 3, 2013.	The research facility (SARC) at Montana notified USDA the discovery of GM wheat on July 14, 2014. USDA launched the investigation immediately on July 14, 2014.
<b>GM wheat variety information</b>	A hybrid that includes genetic material from other types and varieties of wheat, along with a GE glyphosate-resistant wheat trait (Roundup) developed by Monsanto.	Contains the GE glyphosate-resistant wheat trait (Roundup), but less genetically diverse and more similar to known varieties of wheat.
<b>USDA/APHIS investigation result</b>	While both GE wheat varieties share the same GE trait, the GE wheat detected in Oregon appears to be an isolated incident and did not originate from the field trials conducted in Montana. Up to date, APHIS has no evidence of GE wheat in commerce.	

Source: USDA/APHIS, 2014

Table 3. U.S. Wheat statistics, 1989/90-2014/15 (supply and use in millions of bushels, price in U.S.\$/bushel)

Table 3. U.S. Wheat statistics, 1989/90-2014/15 (supply and use in millions of bushels, price in U.S.\$/bushel)

Mkt year (Jun/May)	Production	Food	Feed and Residue	Seed	Domestic Use	Export	Total disappearance	U.S. Farm price	World wheat price
1989/90	2,037	749	139	104	992	1,232	2,224	3.72	4.42
1990/91	2,730	790	482	93	1,365	1,069	2,435	2.61	3.22
1991/92	1,980	789	244	98	1,132	1,282	2,414	3.0	4.04
1992/93	2,467	835	194	99	1,128	1,354	2,481	3.24	3.90
1993/94	2,396	872	272	96	1,240	1,228	2,467	3.26	3.80
1994/95	2,321	853	345	89	1,287	1,188	2,475	3.45	4.18
1995/96	2,183	883	154	103	1,140	1,241	2,381	4.55	5.69
1996/97	2,277	891	308	102	1,301	1,002	2,302	4.30	5.02
1997/98	2,481	914	251	92	1,257	1,040	2,298	3.38	3.88
1998/99	2,547	910	391	80	1,381	1,046	2,427	2.65	3.23
1999/00	2,296	929	279	92	1,300	1,086	2,386	2.48	2.93
2000/01	2,228	950	300	79	1,330	1,062	2,392	2.62	3.37
2001/02	1,947	926	182	83	1,192	962	2,154	2.78	3.36
2002/03	1,606	919	116	84	1,119	850	1,969	3.56	4.28
2003/04	2,344	912	203	80	1,194	1,158	2,352	3.40	4.21

2004/05	2,157	910	181	78	1,168	1,066	2,234	3.40	4.08
2005/06	2,103	917	157	77	1,151	1,003	2,154	3.42	4.50
2006/07	1,808	938	117	82	1,137	908	2,045	4.26	5.43
2007/08	2,051	948	16	88	1,051	1,263	2,314	6.48	9.07
2008/09	2,512	927	268	78	1,273	1,015	2,288	6.78	7.19
2009/10	2,209	919	142	68	1,129	879	2,008	4.87	5.57
2010/11	2,163	926	85	71	1,081	1,291	2,373	5.70	7.72
2011/12	1,993	941	159	76	1,176	1,051	2,227	7.24	7.89
2012/13	2,252	951	365	73	1,389	1,012	2,401	7.77	9.04
2013/14	2,135	955	228	77	1,260	1,176	2,436	6.87	7.85
2014/15	2,026	958	120	81	1,159	854	2,014	5.99	5.91

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Data Source: Wheat Data Yearbook Tables (Updated on Jan. 13, 2016), USDA/ERS. The world wheat price is the monthly average of weekly prices for US No. 2, Hard Red Winter, FOB U.S. Gulf of Mexico, as reported by the International Grain Council on Thursday of each week.

<http://www.indexmundi.com/commodities/?commodity=wheat>.



Table 4, Empirical estimates of welfare effect of GM wheat commercialization

Supply elasticity $E_s$	0.5						1.5					
	-0.5			-1.5			-0.5			-1.5		
Demand elasticity $E_d$												
Supply change	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
Demand change	0	-10%	-20%	0	-29.6%	-40%	0	-3.3%	-10%	0	-10%	-20%
Current price $P_0$	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91
Current consumption $Q_0$	2014	2014	2014	2014	2014	2014	2014	2014	2014	2014	2014	2014
New equilibrium price $P_1$	5.33	4.71	4.15	5.61	4.71	4.43	5.65	5.53	5.34	5.72	5.53	5.32
New equilibrium quantity $Q_1$	2114	2014	1905	2160	2014	1960	2060	2014	1906	2112	2014	1910
Non-GM cutoff or lowest price $d$	2.8	2.8	2.8	2.8	2.8	2.8	1.93	1.93	1.93	1.93	1.93	1.93
GM cutoff or lowest price $e$	1.6	1.6	1.6	1.6	1.6	1.6	1.55	1.55	1.55	1.55	1.55	1.55
Quantity at cutoff price $Q^A$	1560	1560	1560	1560	1560	1560	—	—	—	—	—	—
$P^{**}$	17.85	17.85	17.85	9.88	9.88	9.88	17.85	17.85	17.85	9.87	9.87	9.87
$P^*$	—	16.65	15.45	—	8.68	8.3	—	17.47	16.6	—	9.49	9.08
$\Delta CS$ (million U.S.\$)	1197.12	0	-1260.33	626.1	0	-205.19	529.62	0	-1292.8	391.97	0	-396.92
$\Delta PS$ (million U.S.\$)	1294.44	0	-1139.70	1901.03	0	-576.77	215.14	0	-395.99	395.66	0	-407.51

Note: The unit for price is U.S.\$/bushel; for quantity is million bushels.

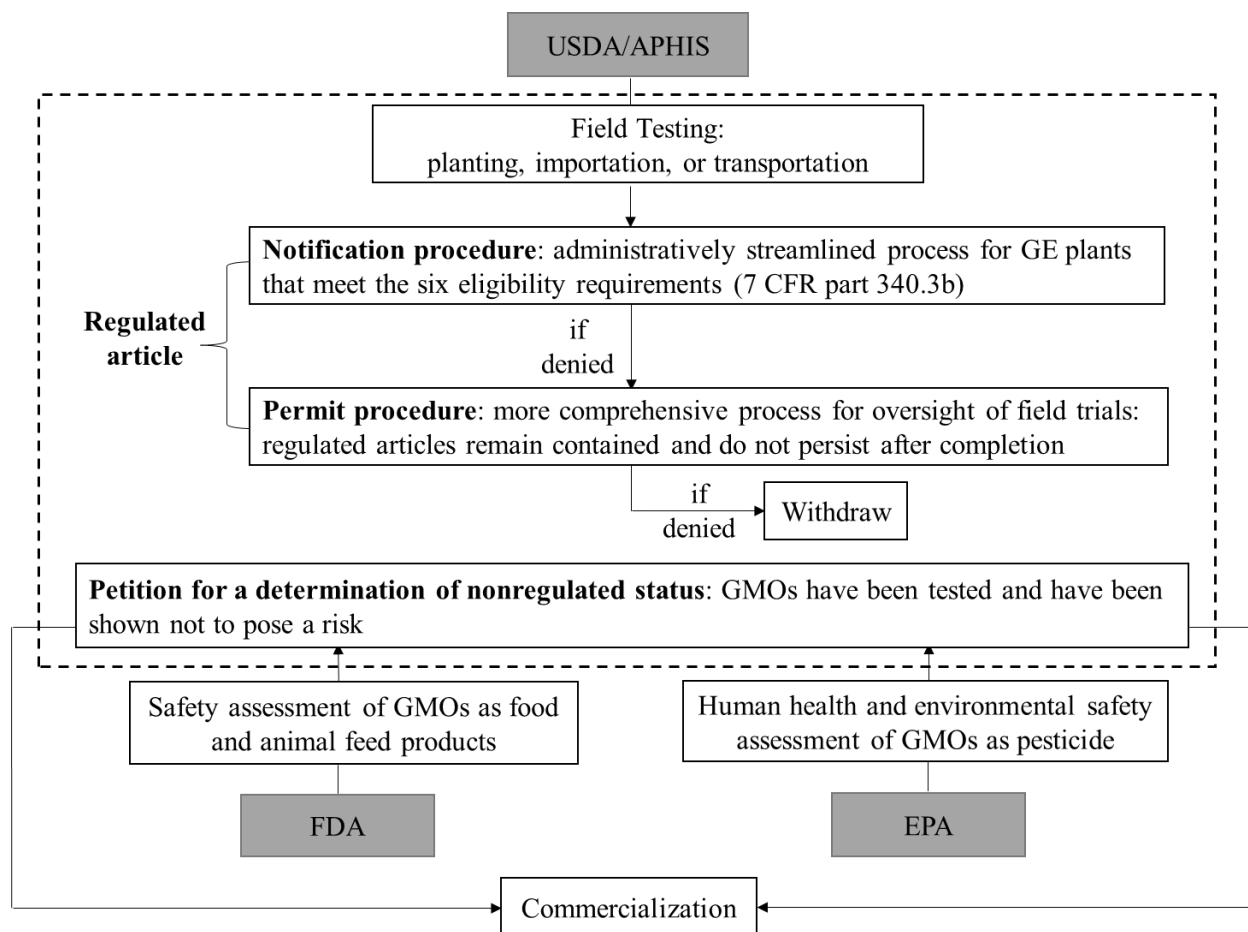
Source: Market year of Jun2014-May2015, the world wheat yearly average price is \$5.91per bushel. The current consumption is quantities of domestic use plus export. Table 1 of the Wheat Data Yearbook Tables, USDA/ERS; calculations are from authors.

Table 5. Wheat export shares by destination (based on average export quantities from 2010 to 2014)

Table 5. Wheat export shares by destination (based on average export quantities from 2010 to 2014)

United States		Canada		Australia		EU-28		Russia	
Japan	11.46%	United States	13.89%	Indonesia	21.29%	Algeria	23.25%	Egypt	27.40%
Nigeria	10.56%	Japan	7.92%	Vietnam	9.15%	Morocco	10.40%	Turkey	17.04%
Mexico	10.54%	Indonesia	5.55%	Korea, South	7.51%	Egypt	9.51%	Yemen	4.60%
Philippines	6.93%	Italy	5.27%	China	6.36%	Iran	8.01%	Iran	4.51%
Korea, South	5.29%	Venezuela	5.17%	Japan	6.06%	Saudi Arabia	6.04%	Israel	3.11%
Brazil	4.88%	Mexico	4.80%	Malaysia	4.86%	Libya	3.36%	Azerbaijan	2.91%
Egypt	4.85%	Bangladesh	4.52%	Iraq	4.74%	Tunisia	3.19%	Georgia	2.86%
China	4.34%	Peru	3.99%	Yemen	4.53%	Yemen	2.41%	Kenya	2.78%
Taiwan	3.47%	Colombia	3.72%	Philippines	4.38%	Cuba	2.40%	Libya	2.57%
Indonesia	2.60%	Sri Lanka	3.70%	Thailand	3.65%	Cote d'Ivoire	2.29%	South Africa	1.99%
ROW	35.08%	ROW	41.48%	ROW	27.46%	ROW	29.14%	ROW	30.24%

Data Source: United Nations Commodity Trade Statistics, United Nations Statistics Division



Source: USDA/APHIS (2015); Fernandez-Cornejo *et al.* (2014)

Figure 1. Safety regulatory process regarding GMOs in the United States

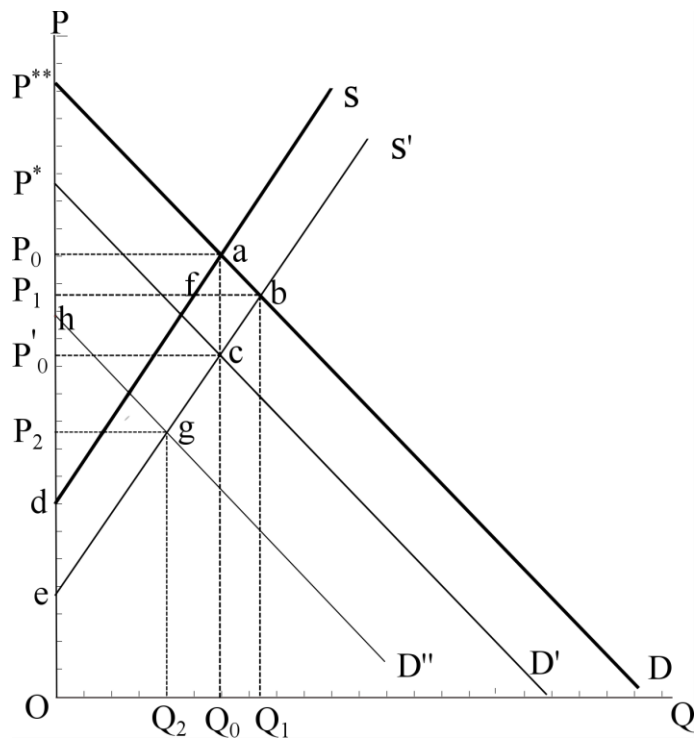


Figure 2. Economic impact of GM wheat adoption

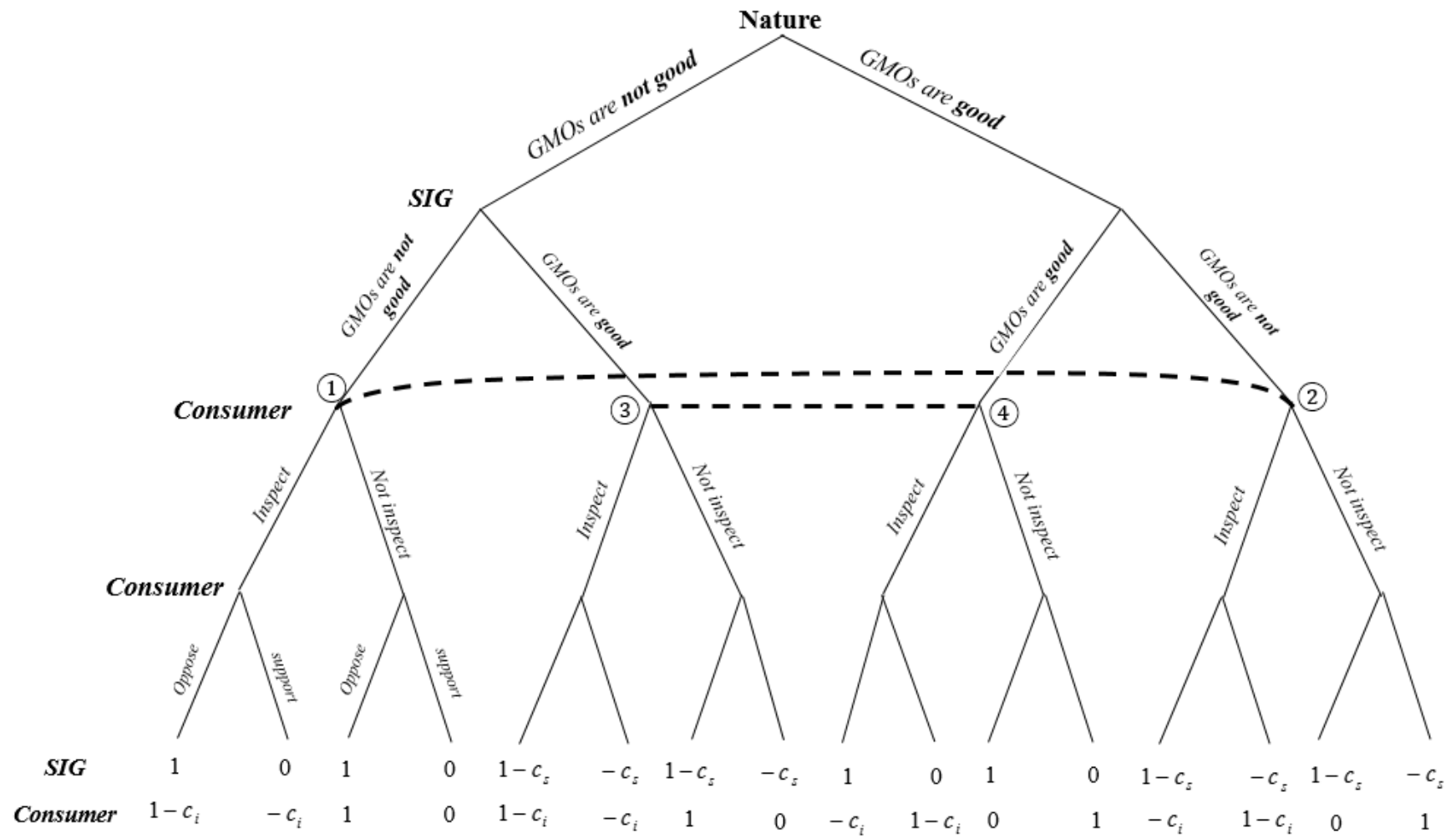


Figure 3. The strategic game between consumers and the anti-biotech Special Interest Groups (SIGs)

Note:  $c_s$  = Special interest groups' spin costs which is normalized such that  $0 < c_s < 1$ ;

$c_i$  = Consumers' inspection cost which is normalized such that  $0 < c_i < 1$

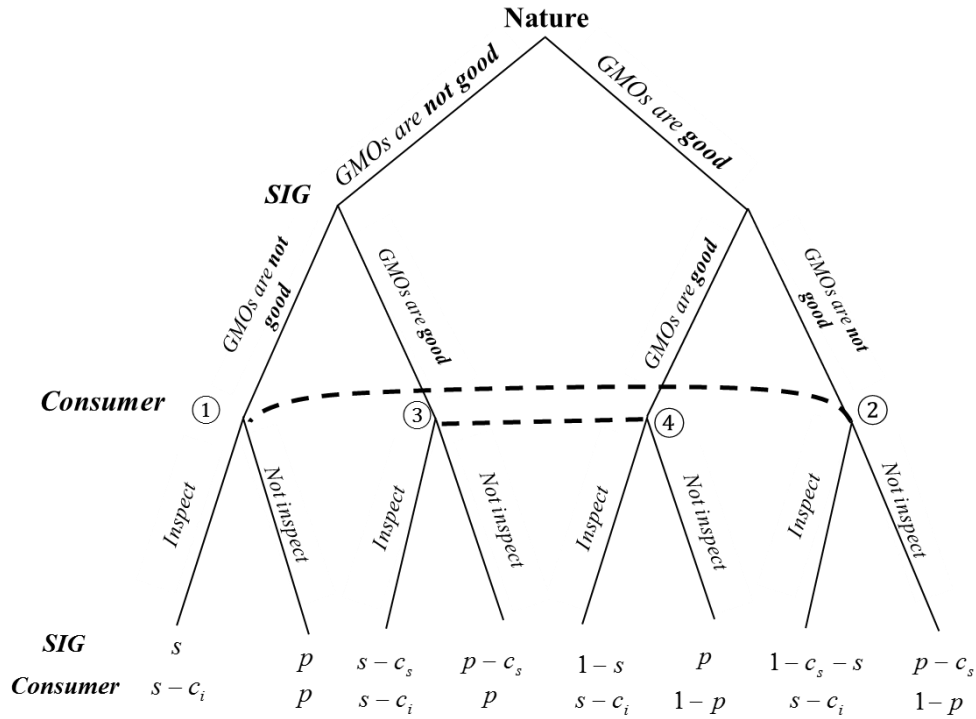


Figure 4. The consumer uses his prior beliefs in deciding how to behave when he doesn't not inspect.

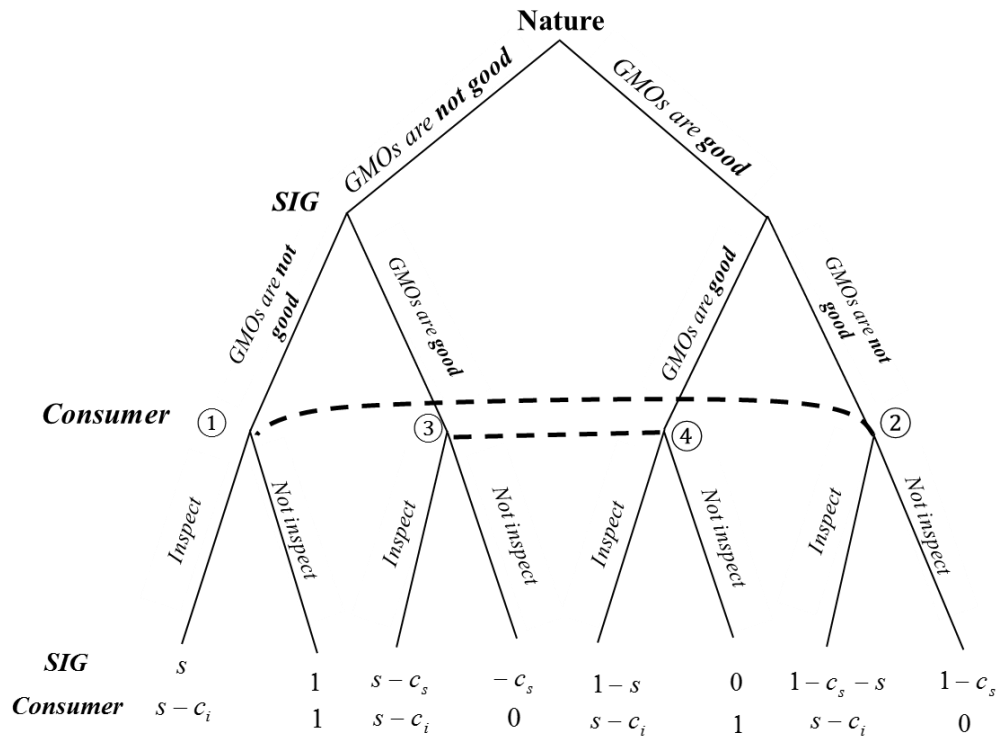
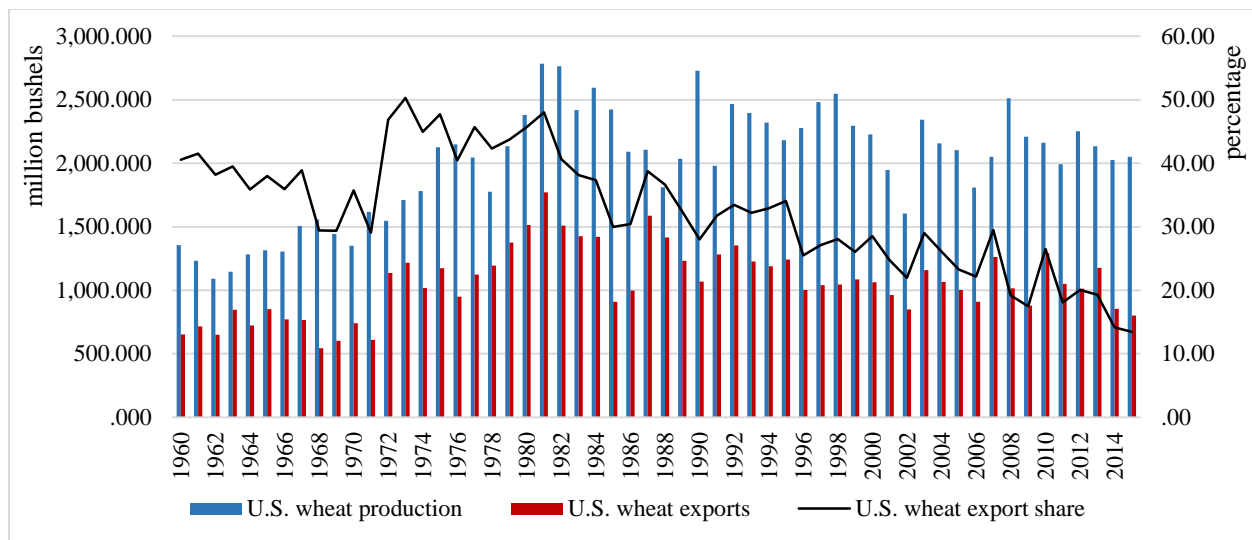
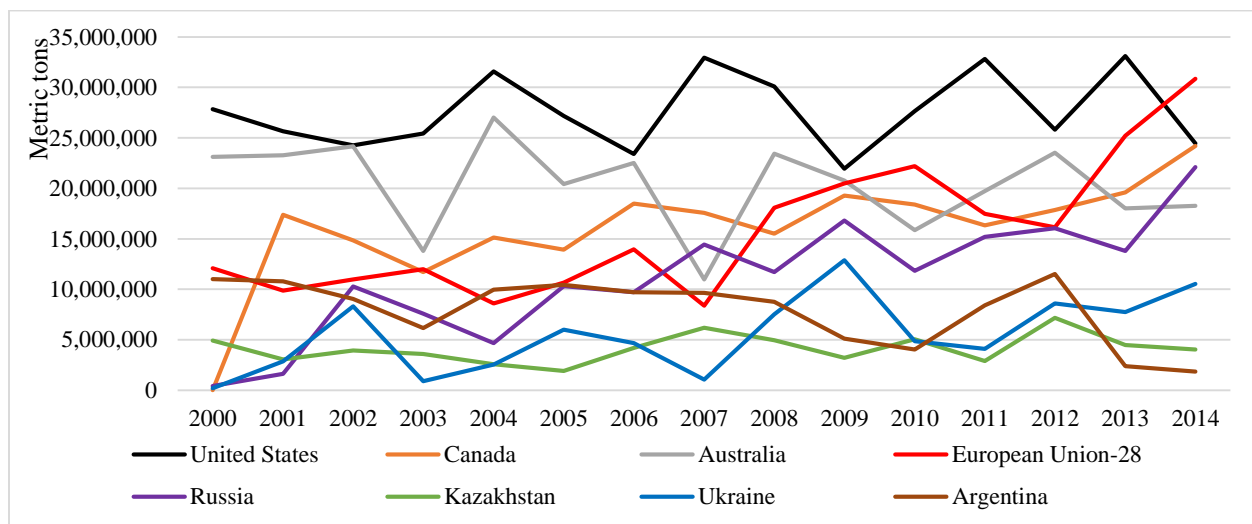


Figure 5. The consumer follows the message from the sender (SIG)



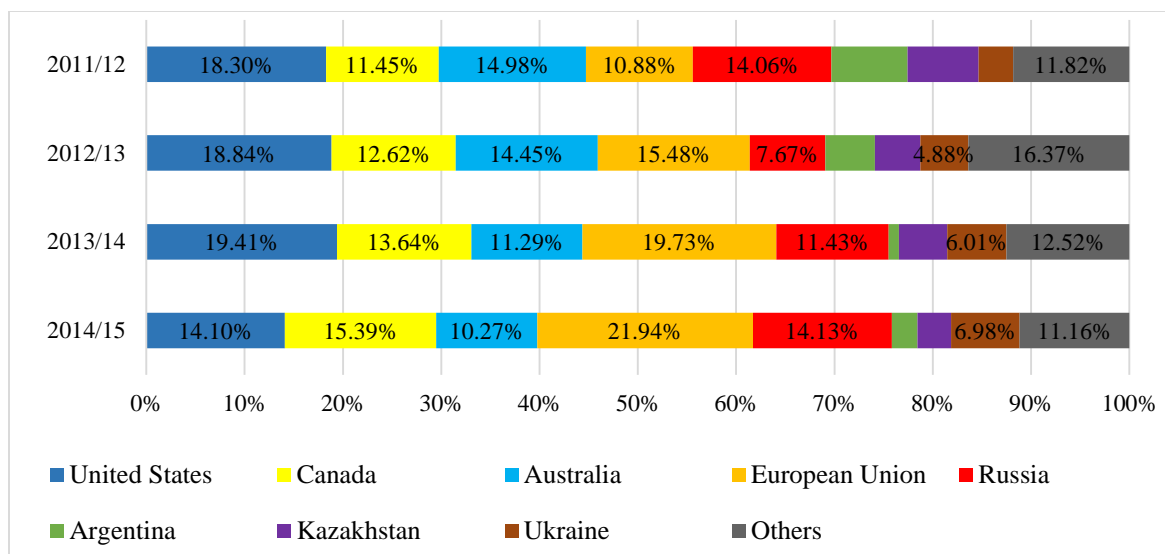
Data Source: USDA, Foreign Agricultural Service

Figure 6a. U.S. wheat production, exports, and export shares, 1960/61-2014/15



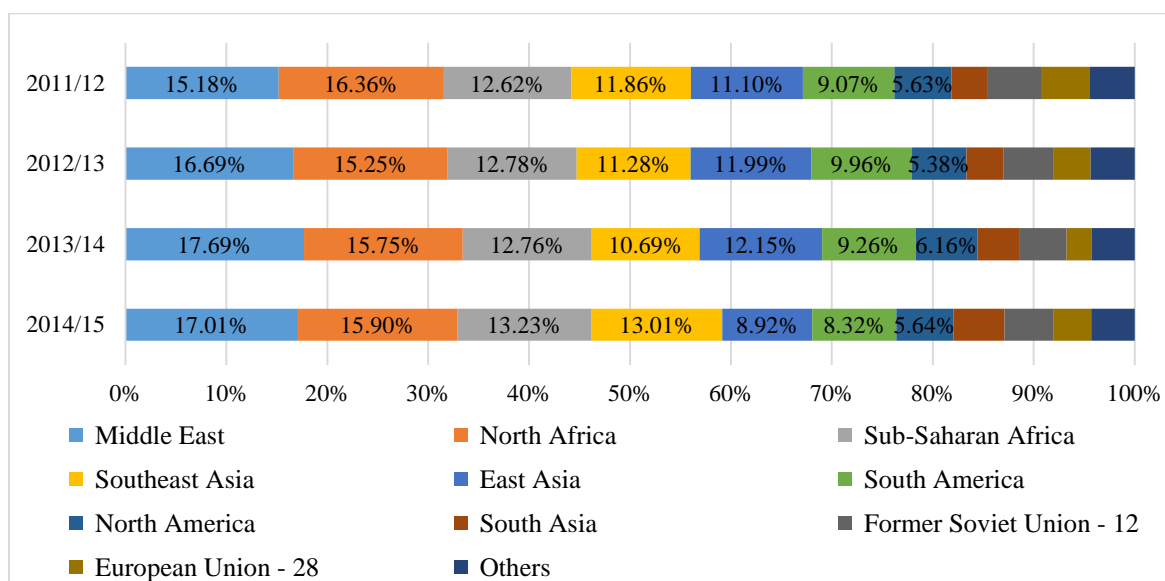
Data Source: United Nations Commodity Trade Statistics, United Nations Statistics Division

Figure 6b. Wheat exports overview by countries, 2000-2014



Data Source: United States Department of Agriculture, Foreign Agricultural Service, Production, Supply and Distribution

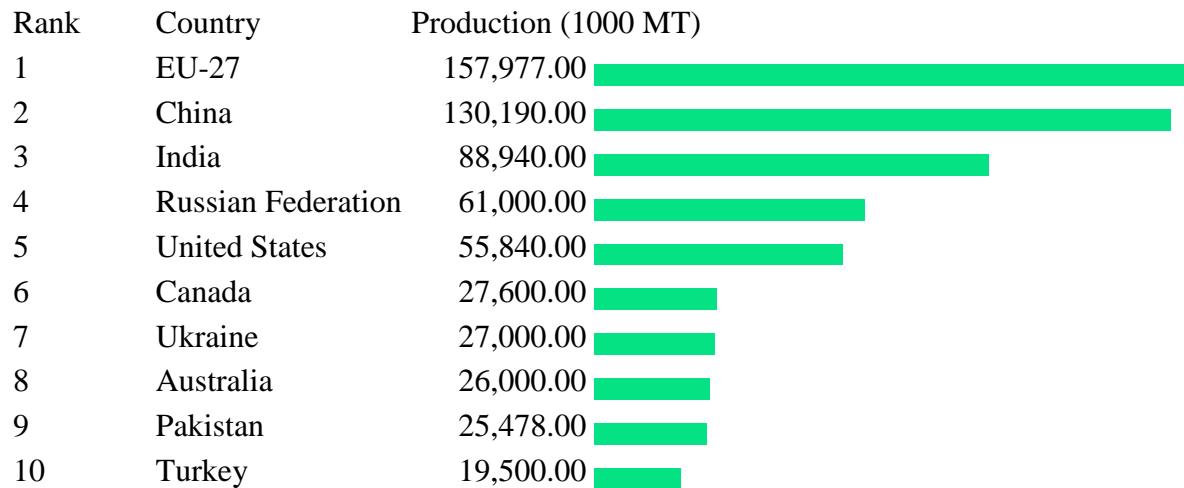
Figure 6c. Market share of major wheat exporters



Data Source: United States Department of Agriculture, Foreign Agricultural Service, Production, Supply and Distribution

Figure 6d. Market share of major wheat exporters





Data Source: Index Mundi, <http://www.indexmundi.com/agriculture/?commodity=wheat&graph=production>

Figure 6d. Major wheat producers in year 2015

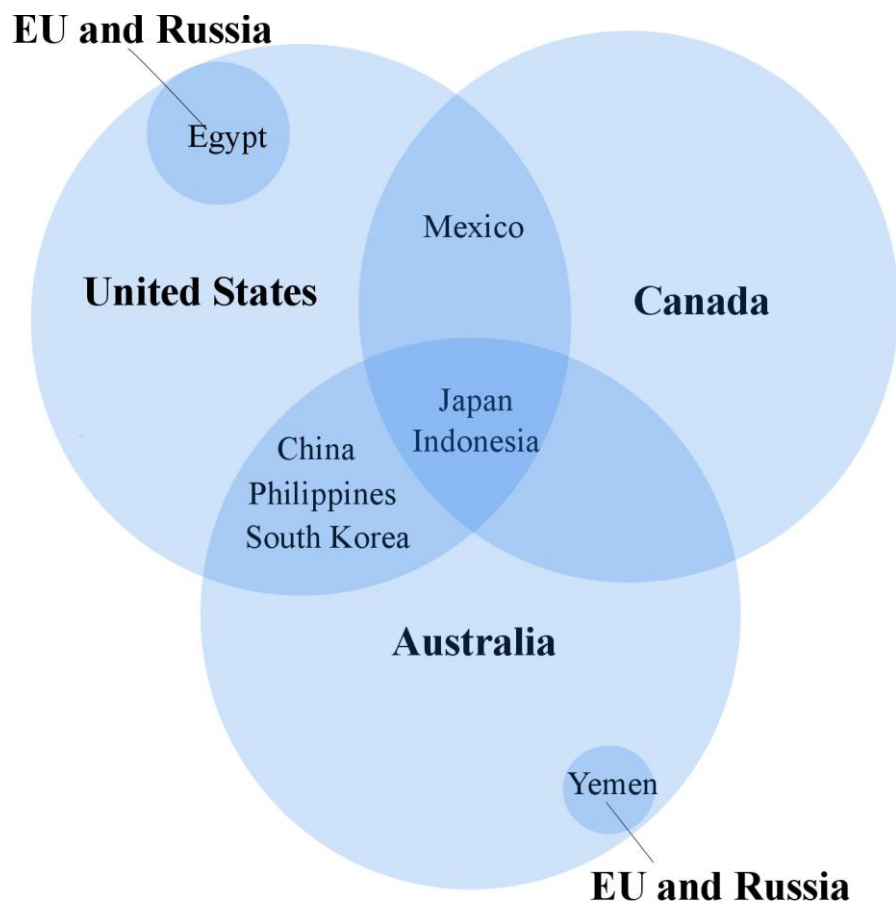


Figure 7. Market competitions among major wheat exporters