TRADE IN CRISPR/GENE-EDITED WHEAT: A PARTIAL EQUILIBRIUM ANALYSIS

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MASTER OF SCIENCE

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ABSTRACT

Previous studies have analyzed how the adoption of genetically engineered or modified technologies have affected agricultural crops such as corn, soybeans, cotton, and barley without focusing on wheat. Also, given the negative impact of drought on wheat production, no studies have focused on the implications of drought tolerant (HB4) and CRISPR/gene-editing on wheat trade. To address these issues, this study employed the partial equilibrium analysis and analyzed the implications of drought tolerant (HB4) and CRISPR/gene-editing technology adoption on wheat trade under various scenarios. The study found that when Argentina, Australia, United States, Canada, and Russia adopt gene-editing wheat, all consuming countries experience a welfare gain except Japan, Korea, Belgium, Netherland, and Italy. More so, Argentina, Mexico, Nigeria, Brazil, Egypt, and Venezuela continue to consume CRISPR wheat in all scenarios. Also, all producing countries experience a gain in producer welfare.

ACKNOWLEDGEMENTS

I wish to express my heartfelt gratitude to my Committee Chairman and Advisor, Dr. Thomas I. Wahl, for his time, support, patience, and motivation in the completion of this thesis. Honestly, without him, this thesis wouldn't have come to a completion. I remain exceptionally appreciative of your encouragement. In addition, I would like to thank all NDSU Department of Agribusiness and Applied Economics faculty members and colleague students who contributed immensely in various ways to the success of this research work. Furthermore, I would like to thank the Department of Agribusiness and Applied Economics for the financial support towards my education at NDSU. I also wish to thank Mr. Albert Quayson and his wife Mrs. Doris Quayson, Anita Amoah, Esther Brown, and the entire members of Kings Love Fellowship for your support in bringing my master's degree to a successful end.

DEDICATION

This thesis is dedicated to my lovely Dad and Mom, Mr. Emmanuel Kwadwo Fosu and Mrs. Salomey Ampomah Fosu

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CHAPTER 1. INTRODUCTION

1.1. Background to the Study

Genome editing (GE), also known as gene editing, is a group of technologies that allow scientists to edit the DNA of many organisms such as plants, bacteria, and animals (National Human Genome Research Institute, 2019). These technologies permit genetic material to be added, removed, or changed at particular locations in the genome. Gene editing has been applied in many areas such as medicine, plant science, biotechnology, and agriculture. In agriculture and plant sciences, it offers the opportunity to increase the efficiency of food production by reducing losses due to disease, pests, and unfavorable weather conditions by increasing tolerance under adverse conditions (Bhalla, 2006). In addition, GE has helped to increase seed production, crop yields, and improved nutritional qualities (Bhalla, 2006; Davuluri et al., 2005; Singh et al., 2005; and Sakamoto et al., 2006). Although several methods of gene editing have been developed, CRISPR/Cas9 (Clustered Regularly Interspaced Short Palindromic Repeats and CRISPR-associated protein 9), which was introduced in 2012, is currently one of the most widely used technologies. CRISPR/Cas 9 system has replaced its predecessors such as genetic engineering, zinc-finger nucleases, and transcription activator-like effector nucleases because it is simple, efficient, and versatile (Hsu et al, 2014; Wang et al, 2017; Barrangou et al, 2016). While genetic engineering or genetic modification (GM) is the direct manipulation of an organism's genes using biotechnology, CRISPR/Cas 9 or gene-editing give scientists the ability to alter the organism's DNA.

Over the past few years, CRISPR/Cas9 system has extensively been adopted in a wide range of agricultural commodities such as wheat, rice, corn, soybean, potato, tomato and many other crops (Shan et al, 2013, Jacobs et al, 2015; Brooks et al, 2014). CRISPR/Cas 9 works by using bacteria to transcribe spacer sequences into short RNA sequences (i.e. CRISPR RNAs or crRNAs) capable of guiding the system to matching sequences of DNA (Broad Institute, 2018). Thus, when the target DNA is found, Cas9, one of the enzymes produced by the cell binds to the DNA and modifies the targeted gene (Broad Institute, 2018). CRISPR allows researchers to create new variants of a gene with improved properties (Wang et al., 2018). It can be used to induce sequence-specific genome modifications in the most widely cultivated food crop plants: rice and wheat (Shan, Wang & Gao 2014).

Unlike the genetic engineering that introduced foreign DNA into an organism to improve outcomes, CRISPR/Cas9 has multiplex genome capacity that enables it to modify many genes simultaneously. Also, the hexaploid nature of the wheat genome makes this plant an important model for studying and optimizing the genome editing system (Kim et al, 2018). Generally, genome editing encapsulates three types of sequence-specific nucleases (SSNs) namely zinc-finger nucleases (ZFNs), transcription activator-like effector nucleases (TALENs), and clustered regularly interspaced short palindromic repeat-associated endonucleases (CRISPR/Cas) (Caroll, 2011; Sun at al., 2016; & Sprink et al., 2015). All these technologies have useful functions including targeted gene knock-out and knock-in, gene replacement and activation, and DNA repair and will be widely applied in crop breeding (Lieber, 2010, Chapman et al., 2012 & Jiang et al., 2017). CRISPR/Cas9 according to scientists has a plethora of advantages over genetic modification. Although gene editing is similar to conventional breeding, plant geneticists and scientists argued that CRISPR is faster, cheaper, and more precise. Again, it is less strictly regulated than “first generation” genetic engineering. Scientists have embraced gene-editing in recent times because it is more accurate, causing fewer “off-target effects,” and allows researchers to move genes from within the species, while GM rely on genes from other species.

Since CRISPR gene editing doesn't require transgenics-the movement of genes from one species to another, scientists believe that is safer than GM because it simply removes genes or copies sequences from similar species (The Guardian 2019).

Wheat is the third most-produced cereal crop after corn and rice with a total global production of 683.15 million metric tons (International Service for the Acquisition of Agri-biotech Applications, ISAAA, 2018). China, India, the European Union (EU), United States, and Russia are the largest producers of wheat (USDA, 2018). In terms of exports, the United States is the largest exporter of wheat worldwide. Russia, Canada, Australia, Argentina, and the EU also export a significant portion of their wheat production. Mexico, Japan, Egypt, and Indonesia are the top importers of wheat followed by Algeria, Bangladesh, Brazil, the European Union, South Korea, Nigeria, and Philippines among others (USDA, 2018). Currently, the United States and China are the two largest markets for GM crops (Wong and Chan, 2016). For example, in 2014, the US grew the largest volume GM crops, followed by Brazil, and Argentina (Lucht, 2015). Also, in terms of adoption of GM crops, in 2014, soybeans, corn, and cotton accounted for about 94%, 93%, and 96% respectively of the total crop area planted (Lucht, 2015). Again, it was estimated that about 95% of imported corn and 90% of imported soybeans by China are genetically modified (Lucht, 2015). Thus, while GM corn, soybean, and cotton have been grown extensively worldwide, GM wheat, is currently not commercially produced anywhere. In Australia, genetic engineered wheat is still in the trial stage. Although seed companies have produced it, GE wheat is not grown commercially for a myriad of different reasons (LeMieux, 2018).

Li et al., (2012) opined that no transgenic wheat has been commercialized and new wheat varieties are mainly developed by conventional breeding techniques that are costly and time-consuming. One reason is the complex genetic mechanisms that go on with wheat DNA. A wheat cell has six copies of its seven chromosomes (42 chromosomes total) (LeMieux, 2018). Furthermore, the amount of wheat DNA is difficult to deal with and the multiple copies of one gene make genetic manipulation tricky (LeMieux, 2018). Other reasons that impede the development of GE wheat according to Wilson et al. (2003) are because wheat is a smaller volume crop, its relative importance of exports, the regulation policies in importing countries, competition among exporting countries, and different market systems among others.

Due to the difficulty in developing biotech wheat, several initiatives have been put in place. In 1997, Monsanto began the technical development stage of Round-UP Ready wheat (RRW). In the same year, scientists with Monsanto and academic researchers conducted a six-year field testing and the result showed that Round-UP Ready wheat performs exceptionally better under the most difficult production environments for spring wheat and offers the potential to increase yields by 5% to 15% (Monsanto 2004).

In addition, since 2007, Syngenta has been working on genetically engineered Fusarium-resistant wheat, however, the company has postponed the project because of the public concern over biotechnology (ISAAA, 2007). While GM corn and soybeans are routinely grown, they are largely used as animal feed, whereas wheat is consumed directly by human beings and faced more consumer resistance (The New York Times, 2013). As a result, consumers have raised concerns over the safety of the biotech product and hence its acceptance is subject to debate and bitter conflict around the globe (Taylor et al, 2003). Japan, South Korea, Alegria, and the EU together import more than 47 percent of United States export of spring wheat however, these countries have moved to prevent the importing GM wheat (The New York Times, 2013). Furthermore, the Global Research report, (2013) shows that the EU has prepared to begin testing shipments for the Round-Up Ready gene. The Guardian (2019) shows that CRISPR-gene editing technology will be subject to stringent health and environment review, as well as labeling requirements in the EU, but not in the United States. For example, the European court of Justice ruled in summer 2018 that gene-edited crops should be regulated as GMOs meanwhile, according to researchers, the first CRISPR-edited produce, grains, and meat are expected to reach the United States grocery market this year (The Guardian, 2019).

Consumers' perception of benefits and risks of GE food and confidence or trust in government regulatory systems are the major factors that influences their decision to accept GE food (Wilson et al., 2003 and Taylor et al., 2003). More so, in June 2008, the Western Organization of Resource Council (WORC) joined farmers, consumers, and civil society organizations in Australia, Canada, and the United States in a joint statement confirming their collective commitment to stop commercialization of biotech wheat (The United States Department of Justice, 2009). Although science has not shown empirically that GM foods are unsafe, it has not also convinced the public in some countries that GM foods are safe (Taylor et al, 2003). Kuzma and VerHage (2006) indicated that United States consumers are willing to pay 20% more to avoid GMO foods, and nearly half of the public reports actively avoiding GM ingredients and foods however, consumers may be slightly less concerned about with CRISPR gene edited products.

In North America, several initiatives have focused on the development of Round-UP Ready trait; however, there is extensive research on wide range of GM traits (e.g., fusarium resistance and drought resistance etc.) (Wilson et al., 2003). Several GM wheat development efforts in North America are focused on Hard Red Spring (HRS) wheat, although recent research is underway in Mexico for drought tolerance (Wilson et al., 2003). As the world is confronted with the issue of climate change, drought resistance becomes an essential trait for grain production. Argentine researchers have isolated the drought tolerance gene (HB4) from sunflowers, and have inserted it in varieties of corn, wheat, and soybeans with promising results (USDA, 2016). The major advantage of this technology is that in drought conditions HB4 wheat yields 25% more than non-GE varieties and in a good condition's yields are equivalent or even slightly better (USDA, 2016). Because Australia and Argentina both have low rainfall and periodically suffer from drought conditions, these countries are working closely to increase collaboration across agriculture. For example, recently in Victoria the wheat supply decreased by 70% due to severe drought conditions, leading to the state's loss of $300 million (ISAAA, 2018). Also, a Reuters report (2018) shows that wheat production in the east coast of Australia is expected to plummet by 11% due to extreme drought condition in the area. Similarly, AgWeb (2015) reported that continuing drought in Canada is expected to create a 12 million metric ton loss in wheat exports. In 2014, due to severe drought conditions, winter wheat production in US was estimated at 246 million bushels, 23 percent lower than the production in the previous years. Furthermore, Kansas farmers planted about 9.6 million acres of winter wheat, which was an increase in the amount planted the previous year, however, only 8.8 million bushels of these acres were harvested due to drought (National Agricultural Statistics Service, 2014). Given the negative impact of drought on wheat production, no studies have been conducted to analyze how the adoption of drought tolerant (HB4) or CRISPR/gene-editing technology affect global wheat trade. To fill these gaps in the literature, this study will seek to address several research questions.

1.2. Statement of the Problem

Numerous studies exist in the literature to investigate how the adoption of genetic engineering affect agricultural crops such as corn, soybeans, cotton, and barley among others. However, no studies have focused on how biotech adoption affects wheat trade with emphasis on exporting countries such as United States, Canada, Australia, Argentina, and Russia. The few studies on biotechnology focused on herbicide tolerant (HT), insect-resistance (BT), glyphosate resistant and to the best of our knowledge no studies have analyzed the trade implications of drought tolerant (HB4) and CRISPR/Cas 9 wheat. Furthermore, previous studies on wheat trade have focused so much on United States, Canada, and Australia and no studies have focused on Argentina and Russia. The current study seeks to fill these gaps in the literature by analyzing the trade implications of adoption of drought tolerant (HB4) and CRISPR/gene-edited wheat.

1.3. Research Questions

1. What are the effects of Argentina's drought-tolerant wheat exports on its trading partners?
2. What happens to global trade patterns if Australia adopts drought-tolerant wheat from Argentina?
3. What happens to global trade patterns if United States, Canada, Australia, and Russia adopt drought-tolerant wheat from Argentina?
4. What are the welfare effects of drought-tolerant and gene-editing wheat on producers and consumers of wheat?

1.4. Significance of the Study

The results of this study will be valuable to universities, companies, government institutions, and consumers who are interested in biotechnology and international grain trade.

Since genetic engineered (e.g. drought tolerant) and CRISPR/Cas9 are new biotechnologies, few studies have examined the trade implications of these technologies. This study will close this gap and form the basis for further research for those who may be interested in studying biotechnology and international grain trade.

1.5. Organization of the Study

The study is organized into six chapters. Chapter one is introductory, it comprises the background to the study, problem statement, research questions, significance as well as organization of the study. Chapter two presents the country overview of the global wheat markets. Chapter three presents review of relevant literature on genetic engineered wheat trade. Chapter four presents the methodological framework and techniques adopted in conducting the study. Chapter five also examines and discusses the results and main findings with reference to empirical literature. The final chapter presents the summary and conclusions of the study.

CHAPTER 2. OVERVIEW

2.1. Introduction

This section of the study presents the overview of the global wheat trade. Specifically, the section presents descriptive analysis of the major wheat exporters and their major importers. Based on the objectives of this study, the study restricted the discussion to the countries of interest such as the United States, Canada, Australia, Argentina, and Russia. These countries are known to be the global giants in wheat exports.

2.2. The United States Wheat Market

Figure 1 and 2 show the trade flow of wheat exports from the United States within the study period. From the figures, Japan is the top importer of wheat from United States followed by Mexico, Nigeria, Korea, Indonesia and Philippines. Other major importers of U.S. wheat are China, Colombia, Thailand, Brazil, and Guatemala. Japan is food-deficit, hence, their import requirements for wheat tend be stable and domestic production is not large enough to meet needs. Japan has favored wheat-based foods such as pasta, bread, noodles, and pizza etc.
In addition, the Japanese have switched to meat eating, resulting in an increased demand for feed grains.

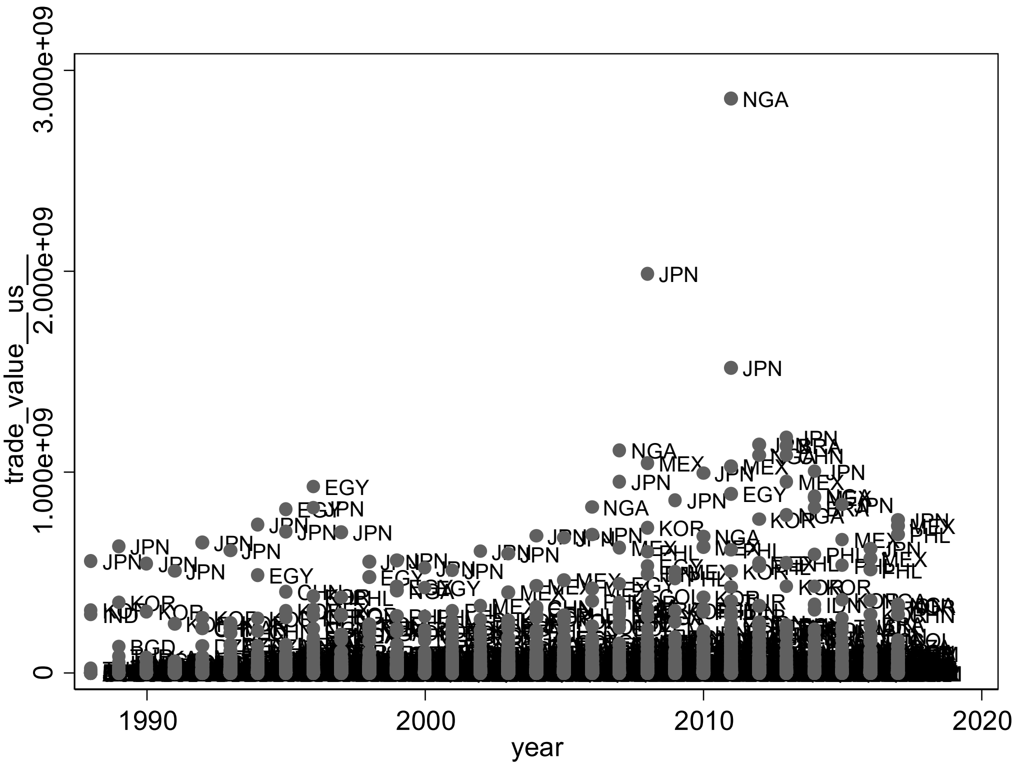

Figure 1: Scatter Plots of U.S. Wheat Exports by Destination (Trade Value ($))
Source: UN COMTRADE (2019)

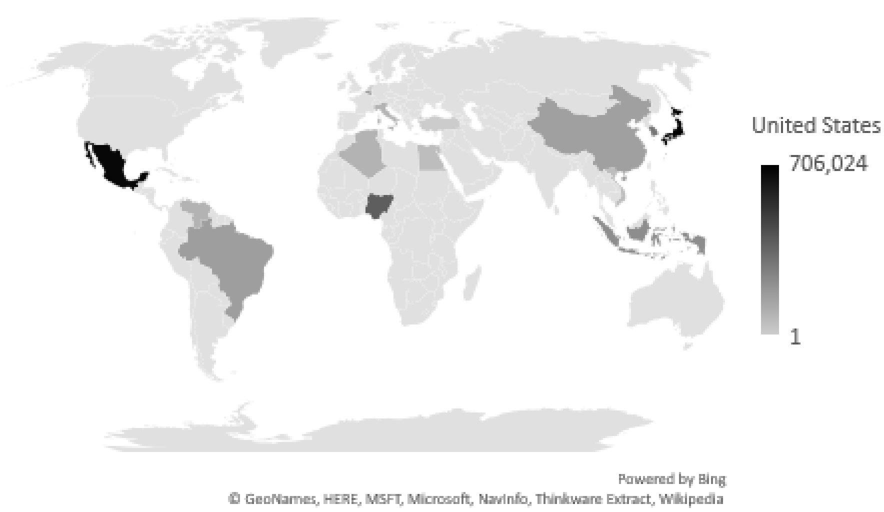

Figure 2: Wheat Trade Flow for United States, Three-year Average (2015-2017)
Source: USDA (2019)

The Figures 3 and 4 indicate that Japan and Philippines are the largest importer of Hard Red Spring (HRS) wheat from the United States, followed by China, Indonesia, South Korea, Thailand, Venezuela, Italy, and Mexico.

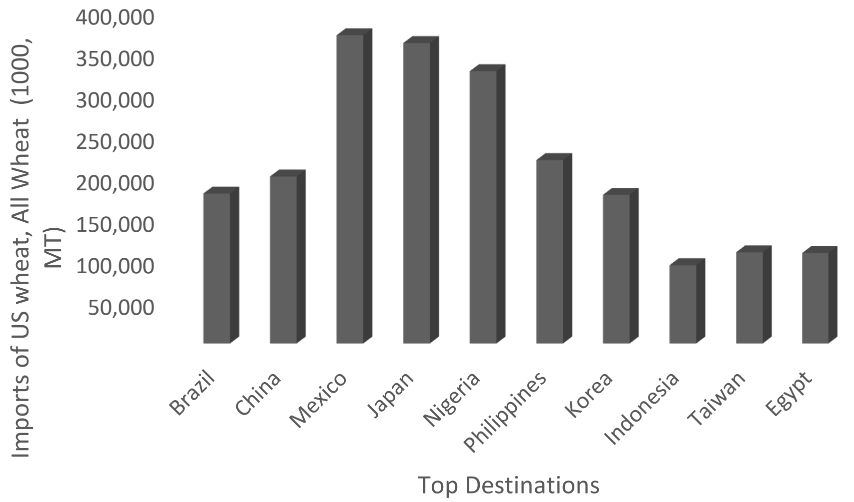

Figure 3: Top 10 Importers of United States Wheat (All Wheat), Three-year Average (2015-2017)
Source: (USDA, 2019)

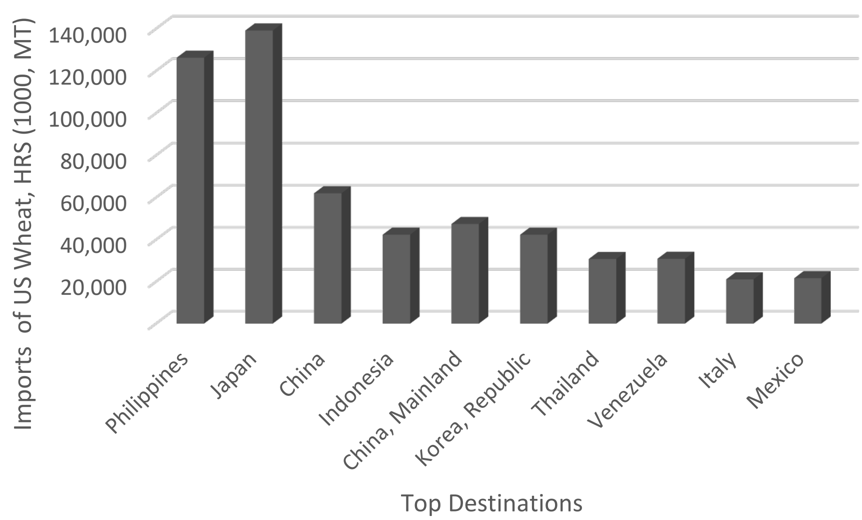

Figure 4: Top 10 Importers of United States Wheat (Hard Red Spring), Three-year Average (2015-2017)
Source: (USDA, 2019)

The Figure 5 indicates that China, Mexico and Egypt are the top importers of Soft Red Winter wheat from the United States, followed by Nigeria, Brazil, Ecuador, Peru, Dominican Republic, and Chile.

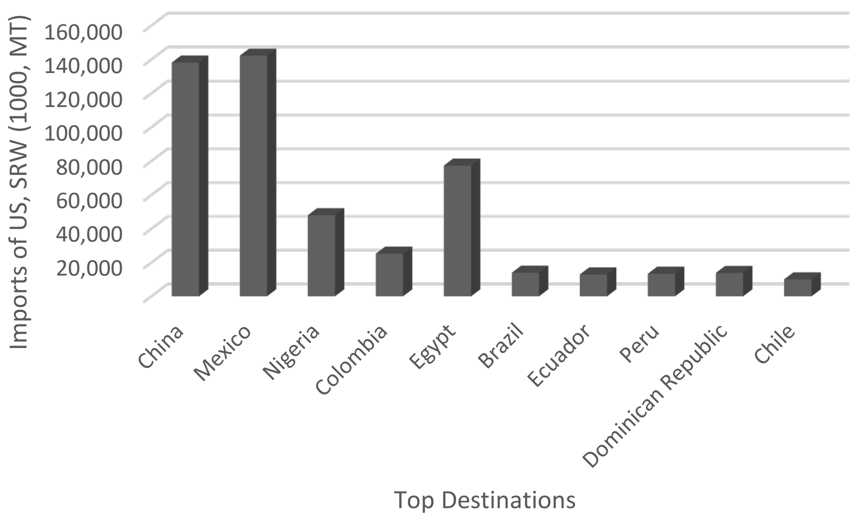

Figure 5: Top 10 Importers of United States Wheat (Soft Red Winter), Three-year Average (2015-2017)
Source: (USDA, 2019)

The Figure 6 indicates that Nigeria is the top importer of Hard White wheat from the United States, followed by Colombia, Taiwan, Malaysia, and Mexico. Nigeria is the top importer of U.S. Hard White wheat. Thus, Nigeria's population is rising and presently stands at 190 million. The country's glowing population put increased pressure on its demand for breads and noodles and hence increased demand for wheat.

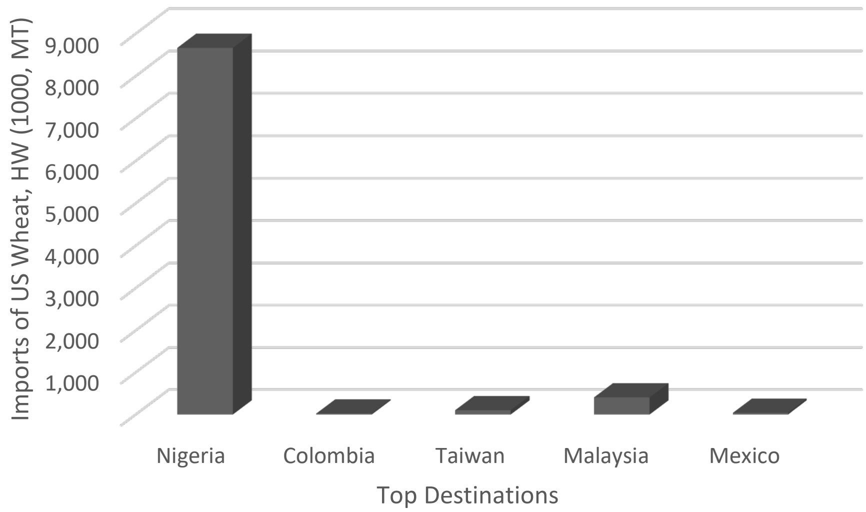

Figure 6: Top Importers of United States Wheat (Hard White), Three-year Average (2015-2017)
Source: (USDA, 2019)

In addition, Philippines, Japan, and South Korea are the top importers of soft white wheat from the United States. Other major importers of soft white wheat include Indonesia, Yemen, Thailand, China, Chile, Taiwan, and Mexico (see Figure 7).

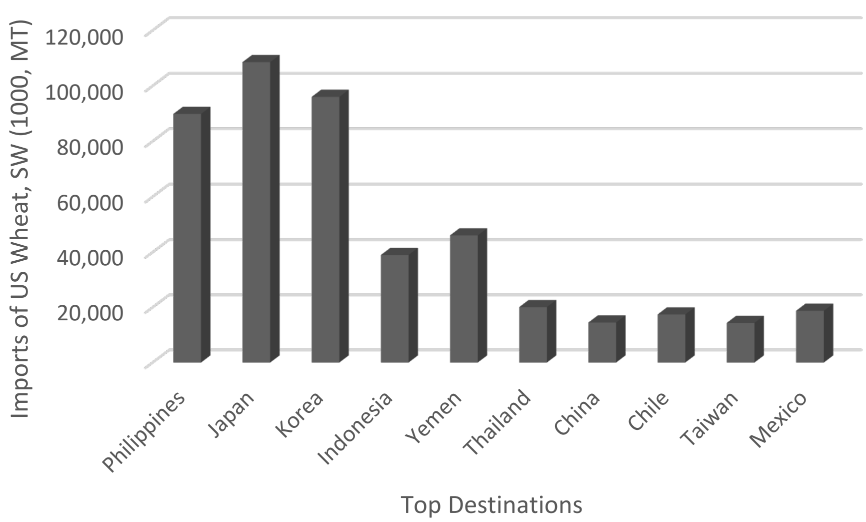

Figure 7: Top 10 Importers of United States Wheat (Soft White), Three-year Average (2015-2017)
Source: (USDA, 2019)

Again, Italy is the largest importer of Durum Wheat from U.S. followed by Algeria, Nigeria, Venezuela, the Netherlands, Guatemala, Chile, Belgium, Panama, and German.

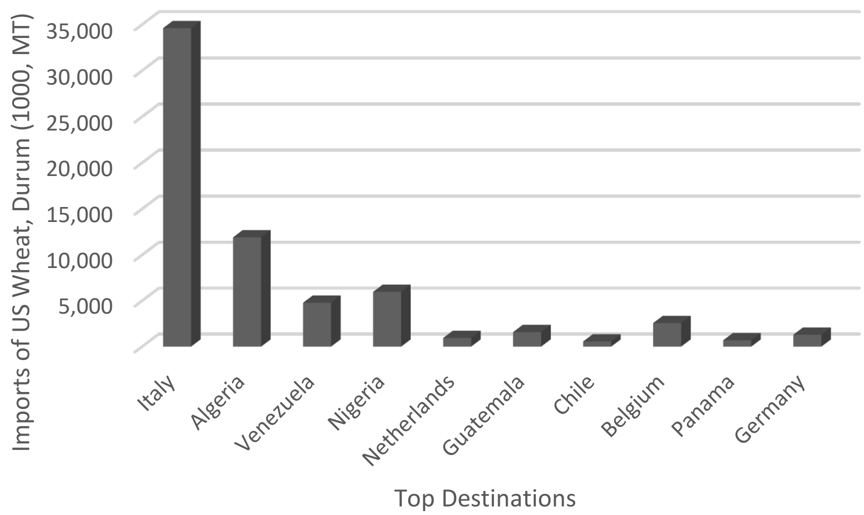

Figure 8: Top 10 Importers of United States Wheat (Durum), Three-year Average (2015-2017)
Source: (USDA, 2019)

2.3. The Canadian Wheat Market

The Canadian wheat market is predominantly spread across the importing countries, although the majority of export goes to the Asia, Africa, and Oceania (see Figure 9 and 10). Indonesia and Japan are the top importers of Canadian wheat followed by United States, Mexico, Algeria, Nigeria, Venezuela, Brazil, and China (see Figure 9 and 10). Wheat imported from Canada is used for making cakes, pastry, cereal, crackers, biscuits, and filling etc. Figure 11 indicates that apart from Japan, all the other trading partners of Canada are emerging and developing economies. This suggest that Canadian trade policies on wheat export should focus largely on these countries.

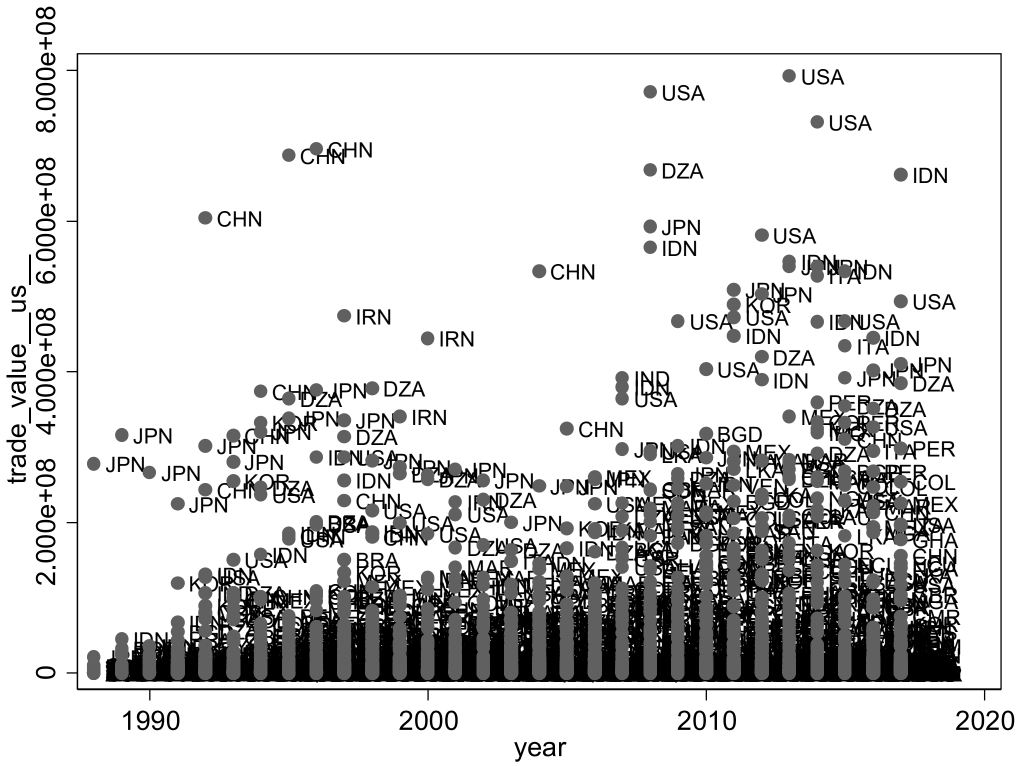

Figure 9: Scatter Plots of Canada’s Wheat Exports by Destination (Trade Value ($))
Source: UN COMTrade, (2019)

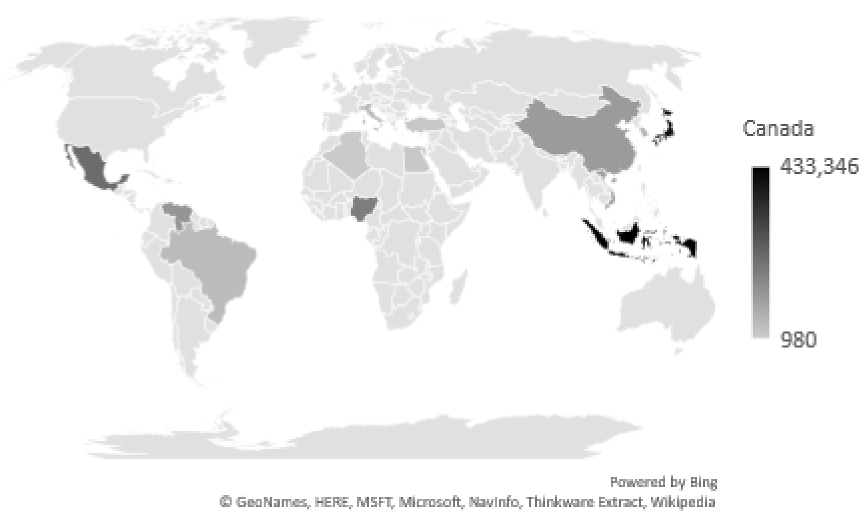

Figure 10: Wheat Export Trade Flow for Canada, Three-year Average (2015-2017)
Source: Canada Grain Commission (2019)

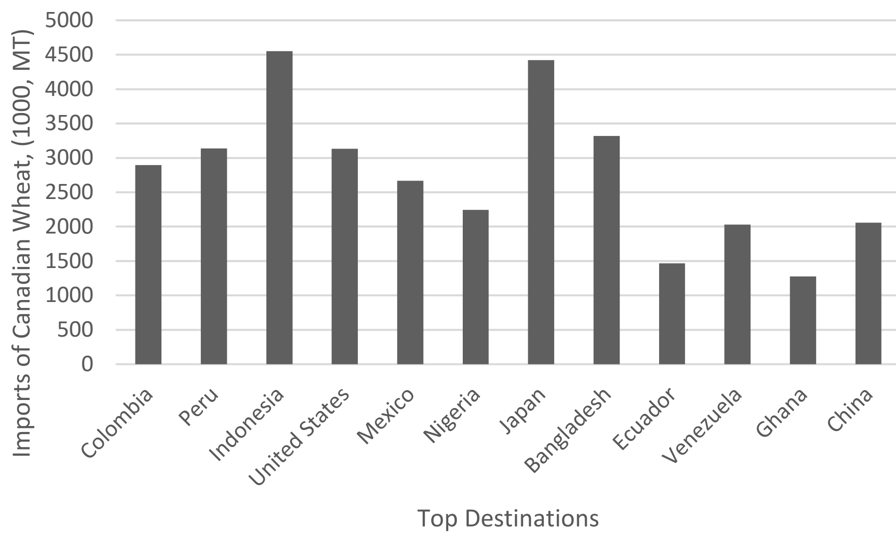

Figure 11: Top Destination Canadian Wheat (All Wheat), Three-year Average (2015-2017)
Source: Canadian Grain Commission (2019)

The Figure 12 shows the market for Canadian durum wheat. It can be observed that Algeria is leading importer of durum wheat from Canada, followed by Italy and Morocco. Other top importers of Canadian durum wheat are US, Japan, Turkey, and Vietnam. Most countries in North Africa such as Morocco, Algeria, and Tunisia have unfavorable climate conditions (i.e. dry land and variable yields) leading to low production of food grains. The unfavorable climate conditions in North Africa has contributed or translated into increasing demand for durum wheat from Canada. Italy also purchases durum wheat from Canada for making pasta. However, in recent years, Italy's imports from Canada has plummet with the fear that Canada's durum wheat has been contaminated with glyphosate herbicide.

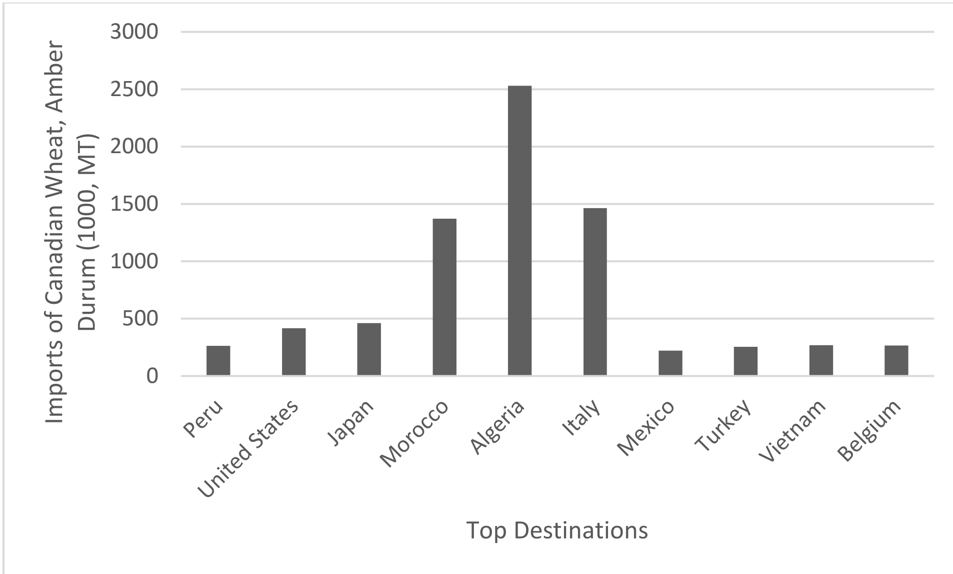

Figure 12: Top Destination Canadian Wheat (Durum Wheat), Three-year Average (2015-2017)
Source: Canadian Grain Commission (2019)

2.4. The Australia Wheat Market

Figure 13 shows the global wheat trade for Australia overtime. The Figure shows that wheat exports from Australia is widely spread across the trading partners. In addition, it can be observed that Indonesia recorded the highest wheat import from Australia. Japan, India, South Korea, and Vietnam also imports a large amount of wheat from Australia. Increased demand for Australia's wheat from Indonesia might be due to the fact the Indonesia is close to Australia and therefore cost of transporting wheat will be low. In addition, Indonesia continues to have increased population and more westernized in their food consumption. As a result, the country's demand for Australian wheat is expected to increase. More so, Indonesia's middle class is expanding, and this is expected to drive Australia's wheat export.

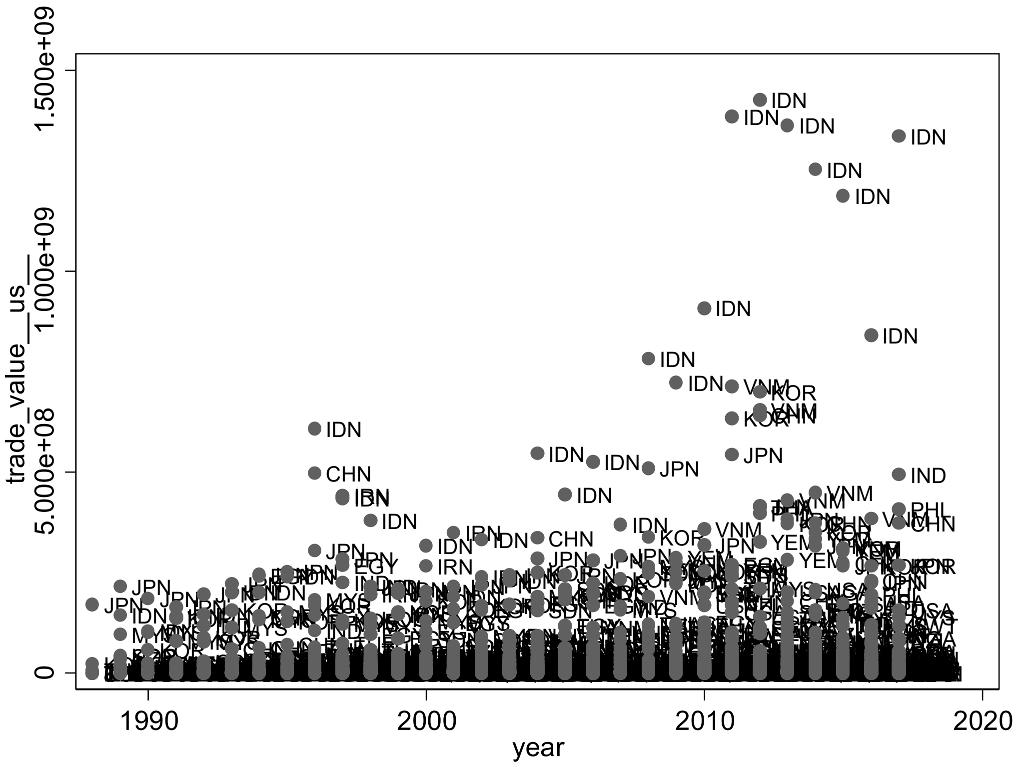

Figure 13: Scatter Plots of Australia's Wheat Exports by Destination (Trade Value ($))
Source: UN COMTRADE (2019)

Figure 14: Wheat Export Trade Flow for Australia, Three-year Average (2015-2017)
Source: ABARES (2019).

2.5. The Argentina Wheat Market

Argentina is one of the major wheats producing and exporting nations. The country's major export market for wheat is Brazil followed by Algeria, Vietnam, China, Egypt, and Nigeria. That is, research suggest that about 95% of Brazil's wheat is imported from Argentina (The Brazil Business, 2013). This is also evidenced by the Figures 15 and 16. Some reasons why Brazil imports large amounts of wheat from Argentina include proximity, no tariffs on wheat from Argentina and because they are both members of the Mercosur South American Customs' Union.

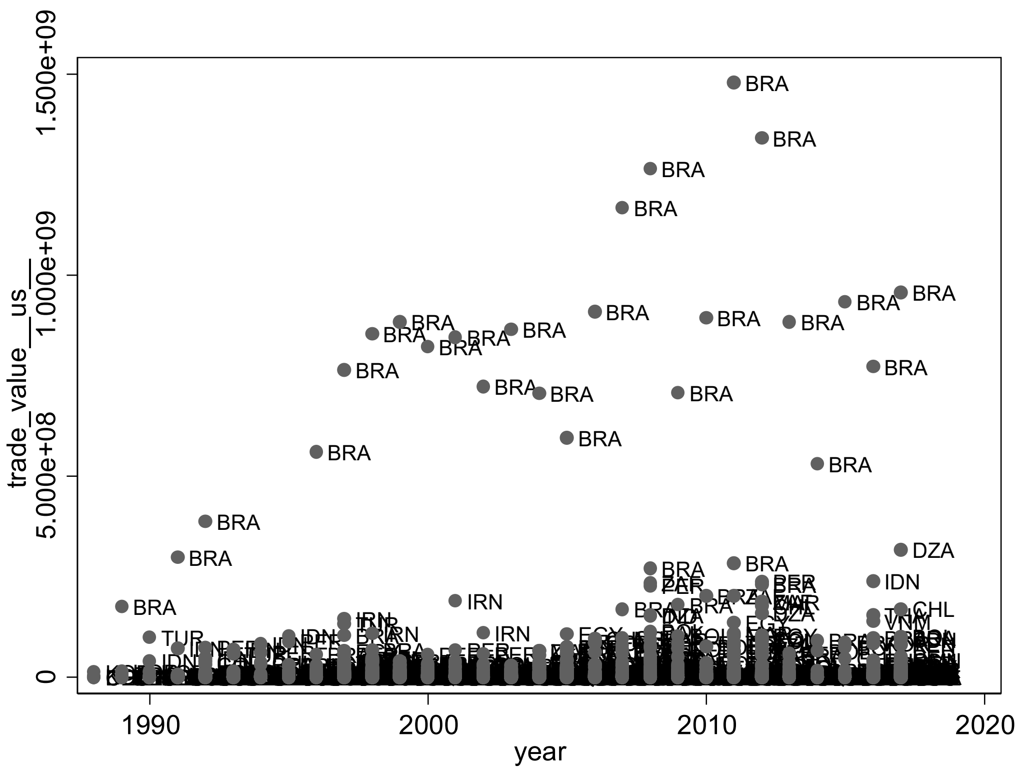

Figure 15: Scatter Plots of Argentina's Wheat Exports by Destination (Trade Value ($))
Source: UN COMTRADE (2019)

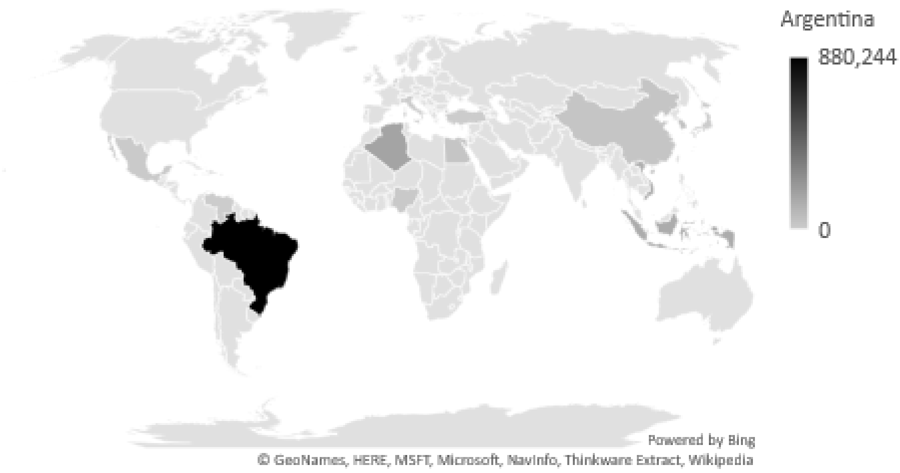

Figure 16: Wheat Export Trade Flow for Argentina, Three-year Average (2015-2017)
Source: UNCOMTRADE (2019)

2.6. The Russian Wheat Markets

Russia's top export market is Egypt, followed by Turkey, Nigeria, Indonesia, Vietnam, and Mexico etc. (see Figure 19). For example, in 2016, Russia won the contracts to export 120,000 tons of wheat to Egypt. Among the factors that have contributed to increased exports of the country's wheat are the adoption of a low-price strategy, the depreciation of the Russian Ruble, favorable weather conditions as well as high government investment in agriculture. Also, contributing to high wheat demand by Egypt is their recent membership in the Russia-led Eurasian free trade zone. This has made it possible for Egypt to trade with Russia and other Eurasian nations such as Armenia, Belarus, and Kazakhstan. Egypt is the most populous country in the Arab World and hence the country's import large of amount of wheat is one of the main energy sources in terms of daily calorie intake (FAO, 2015).

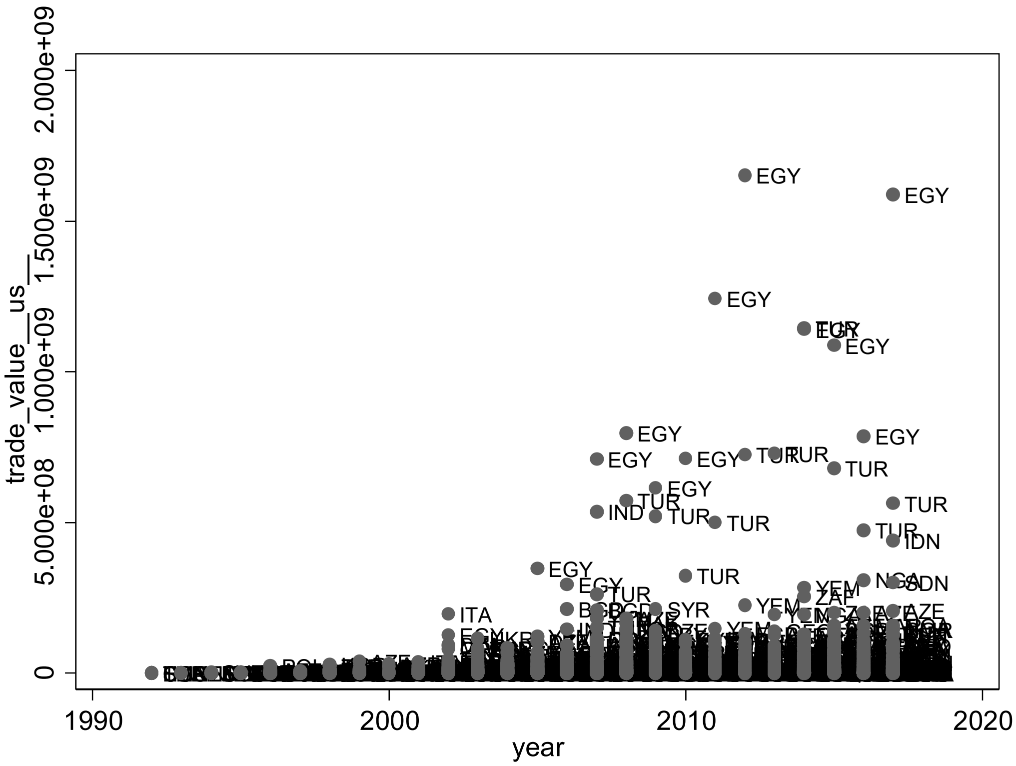

Figure 17: Scatter Plots of Russia's Wheat Export by Destination (Trade Value ($))
Source: UN COMTRADE (2019)

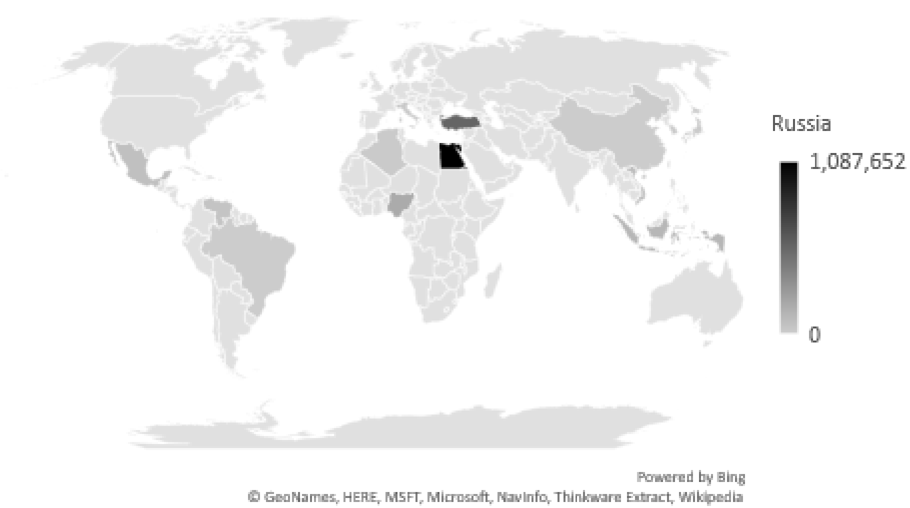

Figure 18: Wheat Export Trade Flow for Russia, Three-year Average (2015-2017)
Source: UN COMTrade (2019)

CHAPTER 3. LITERATURE REVIEW

3.1. Introduction

Numerous studies have examined how biotechnology adoption impact on agricultural crops such as corn, soybeans, canola, barley and cotton. However, few studies have examined the implication of biotechnology adoption on wheat trade. The few studies that have applied biotechnology in agricultural crops focused mainly on the herbicide tolerant (HT), insect-resistance (BT), glyphosate resistant and no studies have examined the implication of drought tolerant (HB4) and CRISPR/Cas9 or genome editing system on wheat and its implication for trade. This chapter presents the relevant empirical literature on genetic engineered/CRISPR/Cas9 wheat trade. The first section explores the empirical literature on genetic engineered and CRISPR/Cas9 technology and the global wheat markets. The second section examines empirical literature on the application of the CRISPR/Cas9 genome editing technique in wheat.

3.2. Literature Review on Genetic Engineered and CRISPR/Cas9 Wheat Trade

Using a quantitative model, Johnson, et al., (2005) investigated the economic and welfare impacts of commercializing herbicide-tolerant, biotech wheat in North America. To do this, a transgenic variety of spring wheat was proposed for deregulation. The main issue of study was to find out whether, and under what conditions, the economic benefits from transgenic wheat could be outweighed by economic costs. The analysis of the study also sought to address the distribution of costs and benefits among producers, consumers, and US taxpayers. The analysis also gave specific attention to the impact on consumers in non-biotech and biotech market segments, and consumers in the United States and other consumers across the world. In addition, the analysis assumed that commercialization of biotech wheat could result to a small net loss to total economic welfare. The findings of study show that if biotech wheat were commercialized and widely adopted by spring wheat producers, a dual marketing system for wheat would have to emerge. In addition, marginal costs of segregation and identity preservation would eventually be borne by producers and consumers of non-biotech wheat, as has occurred in the cases of non-biotech corn and soybeans.

In their paper, Taylor, et al., (2003) employed a spatial equilibrium model to evaluate the trade impacts associated with GM wheat introduction along with several assumed post-GM adoption scenarios. The principal objective of the study was to estimate the impact of the introduction of GM wheat on United States, the North Dakota wheat industry, and the Canadian wheat market. Other objectives of the study were to estimate price levels, producer benefits, trade flow changes, and changes in consumer benefits. To do this, the study developed a model for HRS wheat and HRW wheat. The HRS wheat was divided into non-GM and GM categories. The study also divided United States into three producing regions and Canada was divided into the four western provinces. There were 26 importing countries and the rest of the world region. Findings from the study revealed that total trade volume of exported hard wheat changes little bit under the various scenarios. Also, since import demand is inelastic, changes in imports remain relatively constant with small changes in price, however there was a change in trade flows. Again, when GM wheat was introduced, the countries restricting GM wheat import non-GM wheat from other sources resulting in little change in volume or price. The study found that when GM wheat is produced, both total producer and consumer welfare increase slightly, if segregation is successful.

More so, using global data from more than one decade of field trials and surveys, Finger et al., (2011) employed the meta-analysis and analyzed the effects of farm-level costs and benefits of GM crops yields, seed costs, pesticide costs, management, labor cost, and gross margins. The results of the study found compared to conventional crops, GM crops lead to yield increases and reductions in the costs of pesticide application, whereas seed costs are usually substantially higher. Based on the findings, the study concluded that the adoption of GM crops leads on average to a higher economic performance, which is also underlined by the high adoption rates for GM crops in several countries. However, the kind and magnitude of benefits from GM crops are very heterogeneous between countries and regions, mainly due to differences in pest pressure and pest management practices. Thus, countries with poor pest management practices benefited most from a reduction in yield losses, whiles other countries benefited from cost reductions.

Also, in Canada, the University of Saskatchewan analyzed the optimal time to license GM-HT wheat. Furtan, et al. (2003) developed an empirical model that incorporates the stochastic effects of price and the environmental costs on the optimal time to license GM-HT wheat. The results of estimated model show that direct production benefit realized by the adopters of GM-HT wheat varieties is between $14.93 and $8.72 per acre. As calculated by Holzman, the benefits are because of improved crop yields and a reduction in the costs.

In the context of developing countries, Gruère, et al. (2007) used a multi-country, multi-sector computable general equilibrium model to study the potential effects of introducing GM food crops in Bangladesh, India, Indonesia, and the Philippines in the presence of trade-related regulations of GM food in major importers. Their study focused on GM field crops such as rice, wheat, maize, soybeans, and cotton resistant to biotic and abiotic stresses, such as drought-resistant rice. In addition, the study built on previous international simulation models by improving the representation of the productivity shocks associated with GM crops, and by using an improved representation of the world market, accounting for the effects of GM food labeling policies in major importers and the possibility of segregation for non-GM products going toward sensitive importing countries. The simulations results indicated that the gains associated with the adoption of GM food crops largely exceed any type of potential trade losses these countries may incur. Adopting GM crops also allows net importing countries to greatly reduce their imports. The study also found that segregation of non-GM crops can help reduce any potential trade loss for GM adopters. Lastly, the study found that the opportunity cost of segregation is much larger for sensitive importing countries than for countries adopting new GM crops.

3.3. Literature Review on CRISPR/Cas9 Application in Wheat

This section of the literature review highlights the relevant empirical literature on the application of biotechnology (CRISPR/Cas9) genomic editing system in wheat. The rationale behind this section is to give a better understanding of the scientific ideas behind the CRISPR technology and how it is applied to agricultural crops such as wheat. In their recent study at Rothamsted Research, Martignago (2017) applied CRISPR/Cas9 in rice and wheat. They observed that regenerating plants through genome edited protoplast was more complicated and time consuming in wheat than in rice or other food crops. Therefore, in order to obtain better and more promising results, they had to build a wheat specific vector and take away any putative splicing site. To reinforce the vector structure the wheat codon was also adjusted, and a red fluorescein protein was attached at C-terminal and a specific Ribonucleic acid (RNA) expression cassette was also produced. To prove the presence of the Cas9 wheat gene, in the embryos, the IIB protein served as an indicator for the presence of then gene in the nuclei of the embryos of interest.

Zhang *et al*., (2016) on their work on efficient and transgene-free genome editing in wheat through transient expression of CRISPR/Cas9 RNA, they reported two simple and efficient genome-editing techniques in which plants were regenerated from callus cells transiently expressing CRISPR/Cas9 introduced as RNA. The transient expressing-based genomic-editing system was believed to be highly efficient and specific for producing transgene-free and homozygous wheat mutants in the T0 generation. Their work demonstrated that transient expression of CRISPR/Cas9 RNA in wheat callus cells can efficiently induce targeted and transgene-free mutant. In addition, they successfully obtained homozygous mutants with no detectable transgenes in hexaploid bread wheat. The results of the study suggested that newly developed genome-editing techniques are likely effective for both wheat species and are genotype-independent.

In a similar study, Wang et al., (2016) investigated how to optimize multiplex CRISPR/Cas9-based genome editing for wheat. The results of the study suggested that for designing functional short guide RNA (gRNAs) for wheat genome editing, bioinformatics algorithms should take into consideration the polyploid nature of its genome. Also, the transient expression assay provides an effective alternative for screening many gRNAs and selecting optimal constructs for editing multiple targets in the wheat genome. Furthermore, their study established that the tRNA processing system of wheat can generate mutagenic guide RNA (gRNA) molecules from a polycistronic gene construct assembled using multiple gRNAs separated by the transfer RNA (tRNA) spacers.

Kim et al., (2018) applied a CRISPR/Cas9 genomic editing system in wheat protoplast to conduct the targeted editing of stress-responsive transcription factor genes, wheat dehydration responsive element binding protein 2 (TaDREB2), and wheat ethylene responsive factor 3 (TaERF3). The targeted genomic editing of TaDREB2 and TaERF3 were attained transient expression of gRNAs and Cas9 protein in wheat protoplast. Restriction enzyme digestion assay, T7 endonuclease assay, and sequencing were used to confirm the effectiveness of mutagenesis in wheat protoplast. The findings from the study showed that CRISPR/Cas9 system can easily be established on wheat protoplast and it has a huge potential for targeted manipulation of the wheat genome for crop improvement purposes.

In conclusion, it was observed that even though a lot of work have been conducted as far as biotechnology and agriculture crops are concerned. Most of these studies focused on agricultural crops such as corn, soybeans, canola, barley, and cotton and only few studies have examined the implication of biotechnology on wheat. Also, the few studies that applied biotechnology in agriculture crops have focused mainly on the herbicide tolerant (HT), insect-resistance (BT), glyphosate resistant and no studies so far have examined the implication of drought tolerant (HB4) and CRISPR/Cas9 genome editing system on wheat and its implication for trade. It was also observed almost all the work on CRISPR/Cas9 have been conducted in the plant science (i.e. plant pathology) department and no studies have applied CRISPR/Cas9 in an applied economics department. This study seeks to fill up these gaps that exist in the literature.

CHAPTER 4. METHODOLOGY

4.1. Introduction

This chapter describes the research method employed used in the study. It entails the analytical model used. In addition, the source of data used, and the various scenarios employed for the analysis are discussed.

4.2. The Analytical Model

To assess the effects of trade implications of drought-tolerant (HB4) and CRISPR/Cas9 wheat, a spatial equilibrium model was employed. The spatial equilibrium model is a multi-region partial equilibrium model which links producers and consumers from different locations or countries (Bouët, 2016). The choice of this model is justified because it enables us to evaluate the impact of CRISPR wheat on supply and demand, consumer and producer surpluses as well as world welfare (Bouët, 2016). All wheat for major trading partners will be modeled. Again, wheat, excluding durum will be divided into GE and non-GE alternatives. The study adopts the spatial equilibrium model employed by Taylor, et al. (2003).

The objective function of the spatial equilibrium model is to maximize total consumer and producer surplus less transportation costs (Taylor et al. 2003). Because the model is an implicit price model, it sums the integrated inverse demand functions quantity consumed in all importing countries less the sum of the integrated inverse supply functions and quantity produced in all exporting countries, and the sum of transportation costs from producing regions to consuming regions plus cost saving to produce GM wheat (Taylor et al., 2003). The objective function of the study is specified by equation (1).

$$\sum_i \left(\frac{\left(Q_i^d\right)^2}{2b_i} - \frac{a_i Q_i^d}{b_i} \right) - \sum_i \left(\frac{\left(Q_j^s\right)^2}{2f_j} - \frac{e_j Q_j^s}{f_i} \right)$$

$$- \sum_i \sum_j q_{j,i}^s trans_{i,j} - \left(\sum_i \left(\frac{Q_i^d - d_i}{f_i} \right) * Q_i^d * def_i * sev_i \right) + \sum_j GE^S q_j^s \qquad (1)$$

Where

i =subscript denoting all wheat excluding durum consuming region;

j =subscript denoting all wheat excluding durum producing region;

a_i = intercept term of import demand equation for region i;

b_i =price coefficient of import demand equation for region i;

e_j =intercept term of export supply equation for region j;

f_i = price coefficient of export supply equation for region j;

Q_j^s = export supply from region j;

Q_i^d = import demand from region i;

$trans_{i,j}$ = transportation cost of from producing region j to consuming region i;

$q_{j,non}^s$ and $q_{j,ge}^s$ = quantity of non-GE and GE protein produced in region j;

$q_{i,non}^d$ and $q_{i,ge}^d$ = quantity of non-GE and GE protein consumed in region i;

def_i = risk of default on loans for consuming region i;

sev_i = severity of loan default for consuming region i;

GE^S = production cost savings for GE wheat production.

The first term in equation (1) is the summation of consumer surplus over all importing countries, the second term is the summation of producer surplus over all exporting countries, the third term is the sum of all transportation costs for both GE and non-GE wheat from exporting to importing countries, the fourth term indicate the welfare loss from loan defaults. The last term is the sum of all GE savings in each producing region.

To equate supply and demand for both GE and non-GE wheat, balance constraints are imposed. This is shown by equation (2)

$$q_{j,i}^{s} = q_{j,i}^{d} \forall_{i,j} \tag{2}$$

Also, total production and consumption are expressed by (3) and (4)

$$Q_{j}^{s} = \sum_{i} q_{j,i}^{s} \forall_{j} \; ; \tag{3}$$

$$Q_{j}^{d} = \sum_{i} q_{j,i}^{d} \forall_{i} \; ; \tag{4}$$

Given that price is implicit in this model, prices consumer paid, and price received by producers must be imputed as the inverse of the demand and supply functions, both evaluated post-optimality (Taylor et al., 2003).

4.3. Data

The study solely relies on secondary data. Due to limited available data for wheat exports by classes especially for Argentina, Australia, and Russia, the study used aggregated wheat data in the analysis. Specifically, the study used a three-year average data covering the period of 2015 to 2017. The model includes five producing and exporting regions including the United States, Canada, Australia, Argentina, and Russia (see Appendix A-F). Major wheat importing countries in the study include Algeria, Belgium, Brazil, Indonesia, Egypt, Italy, Netherlands, Korea, Mexico, Turkey, Other Asia, Nigeria, Vietnam, China, Japan, Venezuela, and the Rest of the World (ROW). Data were sourced from UNCOM Trade, ABARES, and USDA etc. Stata (version 14.2) and GAMS software packages were used for the analysis.

Table 1 shows the production, consumption, and export of all wheat in United States, Canada, Australia, Argentina, and Russia. United States, Argentinian, and Russian data were gleaned from the USDA, FAS reports, Canadian data was obtained from Statistics Canada, and Australian data was collected from ABARES. A three-year average of the production, consumption, and exports for years 2015/2016, 2016/2017, and 2017/2018 was used to reduce weather abnormalities, and to avoid the small production numbers in Australia and Argentina due to inclement drought situations in these countries. The price paid by consumers was calculated using the weighted average of the amount of exports from each producing region multiplied by the respective price in that region, with addition of the transport costs.

Table 1: Production, Consumption, Export, and Price of Wheat, Three-year Average 2015 to 2017 (Metric tons)

Production Region	Production	Consumption	Export	Price ($/MT)
United States	55,440	31,174	24,154	224.66
Canada	29,929	27,722	19,948	244.33
Australia	25,198	7,545	30,536	220.67
Argentina	15,900	5,700	11,675	200.33
Russia	72,855	40,666	31,284	187.00

Source: USDA (2019), ABARES (2019)

Due to differences in soil types and climate condition, wheat produced in each producing region differs from the other countries. From Table 1, it can be observed that Russia is the largest wheat producer of the five exporters followed by United States, Canada, Australia, and Argentina. In the United States, spring wheat is mostly grown in North Dakota (49%), followed by Montana (13%), Minnesota (13%), and South Dakota (10%) etc. Also, US winter wheat is mostly grown in Kansas (23%), Oklahoma (7%), Washington (7%) and North Dakota (2%) etc.

Again, in Canadian wheat is mostly produced in Saskatchewan (48%) followed by Alberta (31%) and Manitoba (14%) etc. Wheat production in Australia is concentrated in Western Australia (38%), followed by New South Wales (31%) and South Australia (17%) among others. In Argentina, wheat is produced in Buenos Aires (44%), followed by Cordoba (20%), and Santa Fe (17%) among others. More so, in Russia, wheat is mostly grown in the Southern (29%), followed by Central (20%), Volga (16%), Siberia (16) etc. (see Appendix A-G).

Table 2: World Export of Wheat (Kg/ Metric Ton), Three-year Average (2015-2017)

Origin	United States	Canada	Australia	Argentina	Russia	Total Import
Destination			Kg/Metric Ton			
Algeria	432	21	0	904	73	1,430
Belgium	19	29	0	1	0	50
Brazil	848	171	0	4,311	0	5,330
Indonesia	897	1,668	4,231	745	477	8,019
Korea	1,113	182	1,070	246	97	2,708
Mexico	2,679	863	0	33	333	3,909
Other Asia	914	4	212	1	0	1,131
Netherlands	0	11	0	10	30	52
Nigeria	1,439	700	427	67	958	3,591
Vietnam	220	439	1,550	711	526	3,446
Egypt	205	40	263	158	6,064	6,729
China	692	426	1,312	0	6	2,437
Italy	320	145	2	0	71	538
Japan	3,027	1,569	933	0	25	5,554
Turkey	0	47	0	0	2,847	2,895
Venezuela	367	470	0	0	192	1,029

Source: UNCOM Trade, 2019

Table 3: World Export of Wheat ($/ Metric Ton), Three-year Average (2015-2017)

Origin	United States	Canada	Australia	Argentina	Russia	Total Import
Destination			$/Metric Ton			
Algeria	85,264	4,728	0	172,752	11,858	274,602
Belgium	158,344	7,929	17	412	0	166,702
Brazil	158,344	35,973	0	880,244	0	1,074,560
Indonesia	218,638	433,346	1,077,876	137,073	111,774	1,978,706
Korea	302,329	47,304	273,147	44,218	16,938	683,937
Mexico	682,716	204,383	0	6,536	64,014	957,649
Other Asia	199,047	980	53,306	171	20	253,524
Netherlands	2	3,251	0	2,797	8,741	14,791
Nigeria	379,940	168,226	1,051,712	13,190	174,437	1,787,506
Vietnam	51,831	95,076	366,828	126,338	81,756	721,828
Egypt	51,549	9,376	68,517	28,925	1,087,652	1,246,018
China	151,023	105,397	303,804	28,925	1,522	590,670
Italy	81,838	37,189	569	0	16,848	136,444
Japan	706,024	395,419	234,778	0	4,703	1,340,923
Turkey	1	11,765	59	0	549,669	561,495
Venezuela	87,182	117,532	0	0	41,783	246,497

Source: UNCOM Trade, 2019

Table 4: Export Price of Wheat ($/Metric Ton), Three-year Average (2015-2017)

Origin	United States	Canada	Australia	Argentina	Russia
Destination		$/Metric Ton			
Algeria	197	225	0	191	162
Belgium	249	269	343	347	0
Brazil	187	210	0	204	0
Indonesia	244	260	255	184	234
Korea	272	260	255	180	175
Mexico	255	237	1,581	198	192
Other Asia	218	260	251	194	191
Netherlands	343	295	351	272	289
Nigeria	264	240	246	196	182
Vietnam	236	216	237	178	155
Egypt	251	232	261	184	179
China	218	247	232	0	162
Italy	256	257	242	0	237
Japan	233	252	252	0	190
Turkey	3,772	248	237	0	193
Venezuela	237	250	0	0	217

Source: USDA, ABARES, and Canadian Grain Commission

Table 5 presents the estimated export supply equations for the four producing and exporting countries. We assumed supply elasticities that were used to estimate the parameters for export supply equations. These elasticities were taken from Taylor et al., (2003). Due to difficulty in obtaining calculated elasticities of supply for Russia and Argentina, we assumed the supply elasticities of Russia and Argentina are similar to Canada and Australia respectively. That is, we assumed that these countries share some similarities in terms of climatic environment and agricultural production. Export supply equations for each producing country is specified as follows:

$$Q_j^s = \alpha_j + \beta_j . P_j^{rec} \tag{5}$$

Where j is the exporting or producing country, Q_j^s is the quantity supply by exporting countries, α_j is the intercept parameter, β_j is price coefficient, and P_j^{rec} is the price received by exporting countries.

Table 5: Calculated Elasticities and Export Supply Parameters for Producing Regions

Producing Region	Elasticities	Alpha (α_j)	Price Coefficient (β_j)
US	0.21	43797.6	51.822
Canada	0.31	19128.18	35.173
Australia	0.31	5206.05	0.077
Argentina	0.31	50269.95	120.776
Russia	0.31	501.53	2.748E-4

Source: Taylor et al., (2003)

Table 6 shows the estimated import demand equations for importing countries. Assumed elasticities were used to estimate the parameters of the demand equations for each of the importing countries. The elasticities of demand for Algeria, Belgium, Brazil, Indonesia, Egypt, Italy, Netherlands, Korea, Mexico, Turkey, Other Asia, Nigeria, Vietnam, China, Japan, Venezuela, and the Rest of the World (ROW) were taken from Taylor et al., (2003) and (Swannack, 2004). Also, the elasticity of demand for all the countries were inelastic suggesting that quantity demanded for wheat by the importing countries are unresponsive to price changes. Price and consumption data were also gleaned from the USDA grain and feed annual report. The import demand equations for each importing country are specified as follows:

$$Q_i^d = \alpha_i - b_i . P_i^{paid} \tag{6}$$

Where i stands for each country, Q_i^d is quantity demanded for each importing country, α_i is intercept for each country, b_i is the demand elasticity for each country, P_i^{paid} is the price paid by each importing country.

Table 6: Calculated Elasticities and Parameters for Consuming Region Demand Equations

Importing Countries	Elasticities	Price	Consumption	Alpha (α_i)	Beta ((b_i)
Mexico	-0.11	235	7,400	6,586	-3.46383
Japan	-0.006	485	6,400	6,362	-0.07918
Nigeria	-0.001	211.45	4,097	4,093	-0.01937
Korea	-0.11	254.25	4,318	3,843	-1.86802
China	-0.016	325	121,667	119,720	-5.98974
Indonesia	-0.11	309	8,950	7,966	-3.18608
Algeria	-0.001	207.89	10,317	10,306	-0.04963
Belgium	-0.012	243	4,615	4,560	-0.22792
Brazil	-0.3	196.2	11,733	8,213	-17.9409
Other Asia	-0.02	209.5	5,135	5,032	-0.49021
Netherlands	-0.012	237.2	4,615	4,560	-0.2335
Vietnam	-0.11	209.5	3,725	3,315	-1.95585
Egypt	-0.001	218.4	19,633	19,614	-0.0899
Italy	-0.012	235.5	4,615	4,560	-0.23518
Turkey	-0.02	358	17,800	17,444	-0.99441
Venezuela	-0.291	240.35	1,237	877	-1.49728
United States	-0.5	211.33	31,174	46,761	-73.77
Canada	-0.5	255	27,722	41,583	-54.36
Australia	-0.5	231.33	7,545	11,317	-16.31
Argentina	-0.3	261	5,700	7,410	-6.55
Russia	-0.012	205	40,666	41,154	-2.38
ROW	-0.02	238.25	166,548	163,217	-13.981

Source: USDA Grain and Feed Annual Report, Taylor et al., (2003)

The transportation cost matrix between exporters and importers was developed using the least-cost method. The transportation costs were calculated for each origin-destination route, and the least-cost was used. The transportation matrix is presented in Table 7. Transportation costs data for United States, Canada, Australia, Argentina, and Russia were obtained from the Thomson Reuters dry freight rates panamax grain (2019) and USDA Grain Transportation report. Also, because previous studies have not examined the countries such as Argentina and Russia, it was difficult to obtain all the shipping data especially for Russia, so the study used the sea route and distance between the origin port and the destination port and calculated the nautical miles for the countries that their shipping cost data were not available. Transport data between US and Mexico, Canada and Mexico were calculated using rail rates, which these data are higher than those obtained from the ocean freight. This is because rail transportation shipment is more direct and faster than ocean transportation. The rates were measured in US dollars/metric ton. Tariffs data for all importing countries were measured in average percent and were sourced from the World Trade Organization (WTO). This is also shown in Table 7.

Table 7: Transportation Costs, Port-to-Port from Exporting Countries to Importing Countries, Three-year Average 2015-2017 ($/Metric Ton) and Tariffs for Importing Countries

Origin	United States	Canada	Australia	Argentina	Russia	Tariffs
Destination	$/MT	$/MT	$/MT	$/MT	$/MT	% (AVE)
Mexico	74.25	124.75	16.86	27.67	19.43	9
Japan	44.72	37.28	12.83	51.60	21.92	34
Other Asia	46.08	39.48	19.05	42.25	16.60	10
Nigeria	21.78	44.69	16.86	24.80	12.02	14
Korea	17.05	35.35	12.83	43.39	20.40	187
China	43.44	36.57	17.84	37.28	20.51	23
Indonesia	51.59	46.48	19.05	46.91	14.54	8
Brazil	34.11	46.26	16.86	23.38	15.97	15
Algeria	21.78	44.69	16.86	26.52	4.49	32
Belgium	27.20	43.61	26.77	24.16	8.36	13.8
Netherlands	27.20	43.61	26.72	17.31	8.54	13.8
Vietnam	51.59	46.48	19.05	42.25	16.60	17.6
Egypt	30.47	45.91	17.38	31.84	8.26	15
Italy	27.20	43.61	25.63	27.87	3.30	13.8
Turkey	31.47	61.22	23.92	30.81	6.37	40.2
Venezuela	25.94	44.40	24.42	19.72	14.64	13.5
United States	0.00	24.14	51.59	34.11	27.20	3.1
Canada	24.14	0.00	46.48	46.26	43.61	20.40
Australia	51.59	46.48	0.00	16.86	16.85	1.10
Argentina	34.11	46.26	16.86	0.00	16.86	10.90
Russia	27.20	43.61	19.86	16.86	0.00	9.59
ROW	31.70	44.69	16.86	31.9	15.28	36.89

Source: Thomson Reuters Dry Freight Rates Panamax Grains (2019),
Taylor et al., (2003), and WTO (2019)

Recently, a lot of wheat sales from United States, Canada, Australia, Argentina, and Russia are on cash to their customers-Algeria, Belgium, Brazil, Indonesia, Egypt, Italy, Netherlands, Korea, Mexico, Turkey, Other Asia, Nigeria, Vietnam, China, Japan, and Venezuela. The work of Taylor et al., (2003) assumed that adoption of GM technology by US, Canada, Australia, Argentina, and Russia may shift their export from traditional "cash" consumers, to "credit" customers and it is expected that some of these importers may default on the loans. These expected loan losses are computed before GM adoption and after GM adoption. The estimated values on the likelihood and severity of loan default are taken from Diersen and Sherrick (2000) and Taylor et al., (2003). These figures are listed in Table 8.

Table 8: Probability of Default and Severity of Default on Export Loans for All Consumers

Destination	Default	Severity
Mexico	0.038	0.031
Japan	0.000	0.000
Nigeria	0.054	0.004
Korea	0.009	0.002
China	0.000	0.000
Indonesia	0.023	0.105
Algeria	0.054	0.004
Belgium	0.000	0.000
Brazil	0.042	0.040
Other Asia	0.042	0.040
Netherland	0.000	0.000
Vietnam	0.042	0.040
Egypt	0.054	0.004
Italy	0.000	0.000
Turkey	0.042	0.040
Venezuela	0.042	0.040
United States	0.000	0.000
Canada	0.000	0.000
Australia	0.000	0.000
Argentina	0.042	0.040
Russia	0.000	0.000
ROW	0.042	0.040

Source: Taylor et al., (2003) and Diersen and Sherrick (2000)

As can observed from Table 6, the developed countries such as Belgium, Italy, and Netherland do not present that risk. However, less developed and emerging countries such as Egypt, Nigeria, Korea, Mexico, Turkey, Indonesia, Venezuela, and Brazil among others have some risk of default.

4.4. Model Assumptions and Scenarios

Following the work of Swannack (2004) and Taylor et al., (2003), the study analyzed six scenarios and a baseline. The baseline assumed a current market where there is no GE wheat production. Scenarios 1 assumes that Argentina is the only country producing GE wheat and that Japan, Korea, Belgium, the Netherlands, and Italy do not import GE wheat. Before producers adopt this new technology, there must be some perceived benefits or incentives (Swannack 2004). That is, the evaluated production cost saving is included for both producers to serve as an incentive for producers to grow GE wheat. Scenario 2 assumes that Argentina and Australia are the only countries producing GE wheat and that, Japan, Korea, Belgium, the Netherlands, and Italy only import non-GE wheat. Scenario 3 assumes that Argentina and Australia are the only producers of GE wheat and that, Korea, Belgium, the Netherlands, Italy will only import non-GE wheat. In scenario 4 it is assumed that Argentina, Australia, and US are the only producers of GE wheat and that Korea, Belgium, the Netherlands, and Italy will only import non-GE wheat. Scenario 5 assumes that Argentina, Australia, the US, Canada, and Russia are the only producers of GE wheat and that Korea, Belgium, the Netherlands, and Italy will only import non-GE wheat. The final scenario (6) assumes there are no restrictions on production and imports of GE or non-GE wheat. Following Swannack (2004) and Taylor et al, (2003) a segregation fee of $2.33 per metric ton was used for this study. The Table 9 presents the summary of the six scenarios.

Table 9: Explanation of the Various GE Wheat Scenarios

Baseline	No GE wheat production	
Scenario 1	Only Argentina produced GE wheat	Japan, Korea, Belgium, Netherland, and Italy import only non-GE wheat
Scenario 2	Only Argentina and Australia produced GE wheat	Japan, Korea, Belgium, Netherland, and Italy import only non-GE wheat
Scenario 3	Only Argentina and Australia produced GE wheat	Korea, Belgium, Netherland, and Italy import only non-GE wheat
Scenario 4	Only Argentina, Australia, and US produced GE wheat	Korea, Belgium, Netherland, and Italy import only non-GE wheat
Scenario 5	Only Argentina, Australia, US, Canada, and Russia produced GE wheat	Korea, Belgium, Netherland, and Italy import only non-GE wheat
Scenario 6	No restriction on production or imports	

CHAPTER 5. RESULTS AND DISCUSSIONS

5.1. Introduction

This chapter presents the results obtained from the analysis of data used for the study. The study first presents the results on the trade flows emanating from the various scenarios. The study also presents the results on the producers' welfare, consumers' welfare, and total welfare due to GE wheat trade. Lastly, the results on estimated price for GE and non-GE wheat and sensitivity analysis are presented.

5.2. Results of the Trade Flows from the Various Scenarios

Table 10 presents the trade flows from producing countries to importing countries for the baseline. The baseline assumes there is no GE wheat production or export and therefore all importing countries imports only non-GE wheat. The trade flows from baseline results differ from the real-life situation due to two main reasons. First is the issue of corner solution associated with spatial equilibrium analysis. Second, since this study did not consider wheat classes and uses aggregated data, it is difficult to capture all the trade flows for some countries such as United States and Canada which produce several classes of wheat. The baseline results show that Japan imports non-GE wheat from Australia. Mexico, Nigeria, Belgium, Brazil, Netherlands, and Venezuela import from Argentina. China, import from Canada and Russia while Korea, Indonesia, Algeria, Belgium, Vietnam, Egypt, Italy, and Turkey all import from Russia. The rest of the world (ROW) countries import non-GE wheat from US, Argentina, and Australia. Furthermore, the rest of the world countries are the largest importers of non-GE wheat accounting for about 30% of the total wheat imports and the United States is the largest exporter to these countries followed by Argentina and Australia. China is the next largest importer after the rest of the world with imports accounting for about 23.58% of the total trade with the major trading partners being Russia and Canada. China imports high quality wheat from Canada and low quality or protein wheat from Russia and this is seen in the large import value from Russia. Russia and Argentina have the largest trading partners with most of their trading partners being African and Asia countries.

Table 10: Trade flows From Producing Countries to Importing Countries (Baseline)

Producing Countries	Consuming Countries	Type	Amount ($)
United States	United States	non	88,047
United States	ROW	non	299,432
Canada	Canada	non	86,328
Canada	China	non	98,550
Canada	Other Asia	non	14,119
Australia	Australia	non	21,502
Australia	Japan	non	17,711
Australia	ROW	non	139,713
Argentina	Argentina	non	16,817
Argentina	Mexico	non	20,317
Argentina	Nigeria	non	11,311
Argentina	Belgium	non	5,075
Argentina	Brazil	non	29,491
Argentina	Netherland	non	12,737
Argentina	Venezuela	non	3,383
Argentina	ROW	non	14,636
Russia	Russia	non	112,196
Russia	Korea	non	10,195
Russia	China	non	238,103
Russia	Indonesia	non	25,245
Russia	Algeria	non	28,477
Russia	Belgium	non	7,662
Russia	Vietnam	non	9,945
Russia	Egypt	non	54,201
Russia	Italy	non	12,735
Russia	Turkey	non	49,308

Baseline: No GE wheat production

Table 11 presents the trade flows from Scenario 1. The Scenario 1 assumed that Argentina is the only country producing GE wheat and that, Japan, Korea, Belgium, the Netherlands, and Italy import only non-GE wheat. It can be observed that Japan is still importing non-GE wheat from Australia, Korea and Italy are still importing from Russia however, Belgium and Netherlands have switched their source from Argentina to Russia probably because Argentina now is producing GE wheat. That is, since Belgium and Netherlands are part of the EU, they will not accept GE wheat and therefore will not import from Argentina. Apart from Belgium and Netherlands that have left the Argentina market, all the other trading partners such as Mexico, Nigeria, Brazil, Venezuela, and the rest of the world import GE wheat from Argentina. These countries are developing and emerging countries and have low production capacity and income to afford non-GE wheat. Before GE adoption, Egypt was importing non-GE wheat from Russia, after Argentina adopts the technology, Egypt has decreased its imports of non-GE wheat from Russia and now importing some amount of GE wheat from Argentina. Also, China, Indonesia, Algeria, Vietnam, and Turkey import large amount of wheat from Russia. GE wheat trade accounts for about 8% of the total trade in this scenario and total import from Argentina has increased from 7.97% to 8.08% due to adoption of GE technology.

Table 11: Trade Flows from Producing Countries to Importing Countries (Scenario 1)

Producing Countries	Consuming Countries	Type	Amount ($)
United States	United States	non	88,381
United States	ROW	non	298,490
Canada	Canada	non	86,325
Canada	China	non	98,557
Canada	Other Asia	non	14,119
Australia	Australia	non	21,576
Australia	Japan	non	17,712
Australia	ROW	non	139,223
Argentina	Argentina	GE	16,846
Argentina	Mexico	GE	20,333
Argentina	Nigeria	GE	11,311
Argentina	Brazil	GE	29,573
Argentina	Egypt	GE	17,784
Argentina	Venezuela	GE	3,390
Argentina	ROW	GE	16,175
Russia	Russia	non	112,196
Russia	Korea	non	10,195
Russia	China	non	238,095
Russia	Indonesia	non	25,245
Russia	Algeria	non	28,477
Russia	Belgium	non	12,737
Russia	Netherland	non	12,733
Russia	Vietnam	non	9,945
Russia	Egypt	non	36,417
Russia	Italy	non	12,735
Russia	Turkey	non	49,308

Scenario 1: Only Argentina produces GE wheat: Japan, Korea, Belgium, Netherlands, and Italy import non-GE wheat

Table 12 presents the trade flows from Scenario 2. In scenario 2, it is assumed that that Argentina and Australia are the only countries producing GE wheat but, Japan, Korea, Belgium, Netherland, and Italy import non-GE wheat. It can be observed when Australia produces GE wheat, Japan switches sources to Russia. Also, Korea, Belgium, Netherlands, and Italy still import from Russia. Interestingly, as Australia starts producing GE wheat, Vietnam has switches importing only from Russia and now imports about 33% of GE wheat from Australia and the remaining 67% of non-GE from Russia. Also, the rest of the world has stop importing from

Argentina and now imports from Australia. The shift in demand by the rest of the world might be due to differences in export price, transportation cost, and tariffs. Mexico, Nigeria, Brazil, Egypt, and Venezuela are still importing GE wheat from Argentina. Furthermore, as Australia joined Argentina in producing and exporting GE wheat, Egypt import of non-GE from Russia has decrease drastically by about 62% while the country's import of GE wheat from Argentina has increased by about 47%. Again, total GE trade from both Argentina and Australia account for about 20.74% of the total trade. Australia accounts for about for 61% of total GE trade while Argentina accounts for about 39% of the total GE trade.

Table 12: Trade Flows from Producing Countries to Importing Countries (Scenario 2)

Producing Countries	Consuming Countries	Type	Amount ($)
United States	United States	non	88,632
United States	ROW	non	297,784
Canada	Canada	non	86,479
Canada	China	non	98,125
Canada	Other Asia	non	14,120
Australia	Australia	GE	21,632
Australia	Vietnam	GE	3,164
Australia	ROW	GE	156,185
Argentina	Argentina	GE	16,865
Argentina	Mexico	GE	20,343
Argentina	Nigeria	GE	11,311
Argentina	Brazil	GE	29,623
Argentina	Egypt	GE	33,696
Argentina	Venezuela	GE	3,394
Russia	Russia	non	112,203
Russia	Japan	non	17,712
Russia	Korea	non	10,201
Russia	China	non	238,545
Russia	Indonesia	non	25,254
Russia	Algeria	non	28,478
Russia	Belgium	non	12,737
Russia	Netherland	non	12,733
Russia	Vietnam	non	6,786
Russia	Egypt	non	20,505
Russia	Italy	non	12,736
Russia	Turkey	non	49,310

Scenario 2: Only Argentina and Australia produce GE wheat: Japan, Korea, Belgium, Netherlands, and Italy import non-GE wheat

Under the scenario 3, Australia and Australia are the only countries producing GE-wheat and Korea, Belgium, Netherlands, and Italy will accept only non-GE wheat (see Table 13). Japan has recently stated that they will not accept GM wheat, but they will accept wheat from made from CRISPR or gene-editing. As a result, the assumption that Japan will not accept GE is relaxed and examine how this will affect trade flows. It can be observed that Japan, Korea, Belgium, Netherland, and Italy are still importing the same amount of non-GE wheat from Russia. Also, China, Indonesia, Algeria, Vietnam, Egypt, and Turkey are still importing non-GE wheat from Russia. Mexico, China, and Other Asia countries are still importing from Canada. More so, Vietnam, Nigeria, Brazil, Egypt, and rest of the world are still importing GE wheat from Argentina and Australia. Generally, the results from scenario 3 is quite similar to the results from scenario 2 suggesting that Japan decision to accept GE wheat or not does not really impact on the global wheat market. The results also suggest that Japan will likely import only non-GE wheat. This result is not surprising because Japan is wealthy and can afford high protein and quality wheat.

Table 13: Trade Flows from Producing Countries to Importing Countries (Scenario 3)

Producing Countries	Consuming Countries	Type	Amount ($)
United States	United States	non	88,632
United States	ROW	non	297,784
Canada	Canada	non	86,479
Canada	China	non	98,125
Canada	Other Asia	non	14,120
Australia	Australia	GE	21,632
Australia	Vietnam	GE	3,164
Australia	ROW	GE	156,185
Argentina	Argentina	GE	16,865
Argentina	Mexico	GE	20,343
Argentina	Nigeria	GE	11,311
Argentina	Brazil	GE	29,623
Argentina	Egypt	GE	33,696
Argentina	Venezuela	GE	3,394
Russia	Russia	non	112,203
Russia	Japan	non	17,712
Russia	Korea	non	10,201
Russia	China	non	238,545
Russia	Indonesia	non	25,254
Russia	Algeria	non	28,478
Russia	Belgium	non	12,737
Russia	Netherland	non	12,733
Russia	Vietnam	non	6,786
Russia	Egypt	non	20,505
Russia	Italy	non	12,736
Russia	Turkey	non	49,310

Scenario 3: Only Argentina and Australia produce GE wheat: Korea, Belgium, Netherlands, and Italy import non-GE wheat.

Table 14 presents the results from scenario 4. Under scenario 4, it is assumed that Argentina, Australia, and US are the only producers of GE wheat however, Korea, Belgium, Netherlands, and Italy import only non-GE wheat. Japan, Korea, Belgium, Netherlands, Italy, China, Indonesia, Algeria, Vietnam, Egypt, Italy, and Turkey import from Russia. Again, China and Other Asia import non-GE from Canada. The rest of the world import GE wheat from US and Australia this is equivalent to 66.24% of the total GE trade. US, Australia, Vietnam, Argentina, Mexico, Nigeria, Venezuela, account for the remaining 33.76% of GE trade. Total GE trade from Argentina, Australia, and the US in relation to total trade stands at 47.95%. While the US alone account for about 56.88% of the total GE trade, the country accounts for about 27.27% of the total trade. Russia accounts for about 38.04% of total trade while Argentina account for 8.04% of the total trade.

Table 14: Trade Flows from Producing Countries to Importing Countries (Scenario 4)

Producing Countries	Consuming Countries	Type	Amount ($)
United States	United States	GE	88,960
United States	ROW	GE	300,931
Canada	Canada	non	86,721
Canada	China	non	97,444
Canada	Other Asia	non	14,123
Australia	Australia	GE	21,704
Australia	Vietnam	GE	5,726
Australia	ROW	GE	153,143
Argentina	Argentina	GE	16,894
Argentina	Mexico	GE	20,358
Argentina	Nigeria	GE	11,311
Argentina	Brazil	GE	29,703
Argentina	Egypt	GE	33,281
Argentina	Venezuela	GE	3,401
Russia	Russia	non	112,213
Russia	Japan	non	17,712
Russia	Korea	non	10,209
Russia	China	non	239,253
Russia	Indonesia	non	25,268
Russia	Algeria	non	28,478
Russia	Belgium	non	12,738
Russia	Netherland	non	12,734
Russia	Vietnam	non	4,233
Russia	Egypt	non	20,920
Russia	Italy	non	12,737
Russia	Turkey	non	49,315

Scenario 4: Only Argentina, Australia, and US produce GE wheat: Korea, Belgium, Netherlands, and Italy import non-GE wheat.

In scenario 5, we assume that Argentina, Australia, US, Canada, and Russia are the only countries producing GE wheat, however, Korea, Belgium, Netherland, and Italy import only non-GE wheat. The results from scenario 5 are presented in Table 15. This result differs from the results in scenario 4. In the scenario 5, it can be observed that there has been a change in terms of the trade flows for Japan, Belgium, and Netherlands. Belgium and Netherland import non-GE wheat from Argentina while Korea and Italy maintained their trade with Russia. Japan imports non-GE wheat from Australia. Thus, apart from Japan, Korea, Belgium, Netherland, and Italy not accepting GE wheat, all the other countries import and consume GE wheat. When Argentina, Australia, US, Canada, and Russia produce GE wheat, Other Asia import GE wheat from Canada while Egypt import from Russia. In addition, GE trade accounts for about 95.39% of the total trade flows. Russia accounts for 37.95% of GE trade, followed by US (28.43%), Canada (13.94%), Australia (11.84%), and Argentina (7.15%)

Table 15: Trade Flows from Producing Countries to Importing Countries (Scenario 5)

Producing Region	Importing Countries	Type	Amount ($)
United States	United States	GE	89,766
United States	ROW	GE	298,659
Canada	Canada	GE	87,595
Canada	China	GE	97,965
Canada	Other Asia	GE	14,131
Australia	Australia	GE	21,882
Australia	Japan	non	17,711
Australia	ROW	GE	139,979
Argentina	Argentina	GE	16,969
Argentina	Mexico	GE	20,398
Argentina	Nigeria	GE	11,311
Argentina	Belgium	non	3,779
Argentina	Brazil	GE	29,910
Argentina	Netherland	non	12,736
Argentina	Venezuela	GE	3,418
Argentina	ROW	GE	15,696
Russia	Russia	GE	112,252
Russia	Korea	non	10,182
Russia	China	GE	238,828
Russia	Indonesia	GE	25,319
Russia	Algeria	GE	28,479
Russia	Belgium	non	8,956
Russia	Vietnam	GE	9,991
Russia	Egypt	GE	54,203
Russia	Italy	non	12,733
Russia	Turkey	GE	49,331

Scenario 5: Argentina, Australia, US, Canada, and Russia can produce GE wheat: Korea, Belgium, Netherlands, and Italy import non-GE wheat.

In Scenario 6, is assumed that there are no restrictions on production and imports. The results from scenario 6 is presented in Table 16. Even with trade liberalization, countries such as

Japan, Korea, Belgium, Netherland, and Italy are still importing non-GE wheat. These countries have already issued a statement indicating their unwillingness to consume GE food. Apart from these listed above, all the other countries import or will consume GE wheat when there are no barriers to trade.

Table 16: Trade Flows from Producing Countries to Importing Countries (Scenario 6)

Producing Region	Importing Countries	Type	Amount ($)
United States	United States	GE	89,766
United States	ROW	GE	298,659
Canada	Canada	GE	87,595
Canada	China	GE	97,965
Canada	Other Asia	GE	14,131
Australia	Australia	GE	21,882
Australia	Japan	non	17,711
Australia	ROW	GE	139,979
Argentina	Argentina	GE	16,969
Argentina	Mexico	GE	20,398
Argentina	Nigeria	GE	11,311
Argentina	Belgium	non	3,779
Argentina	Brazil	GE	29,910
Argentina	Netherland	non	12,736
Argentina	Venezuela	GE	3,418
Argentina	ROW	GE	15,696
Russia	Russia	GE	112,252
Russia	Korea	non	10,182
Russia	China	GE	238,828
Russia	Indonesia	GE	25,319
Russia	Algeria	GE	28,479
Russia	Belgium	non	8,956
Russia	Vietnam	GE	9,991
Russia	Egypt	GE	54,203
Russia	Italy	non	12,733
Russia	Turkey	GE	49,331

Scenario 6: no restrictions on production or imports

Table 17 shows imports of wheat by consuming countries under various scenarios. The level of imports does not change significantly under the different scenarios. When Argentina was the only producer of GE wheat in scenario 1, all consuming countries experience a positive change from the baseline except Canada, Netherlands, Korea, Indonesia, and Vietnam. Also, in scenario 2, when Australia joined Argentina in producing GE wheat all consuming countries experience a positive change from the baseline except the Netherlands. In scenario 5, when producing countries adopt the GE technology, all consuming countries experience a positive change from the baseline except for China, Japan, Belgium, Netherlands, Korea, and Italy. US experience largest change from the baseline followed by Australia and Canada.

Table 17: Total Consumption of Wheat by Consuming Countries from Producing Regions (% Change from Baseline)

Consuming Countries	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
US	0.380	0.665	0.665	1.037	1.953	1.953
Canada	-0.003	0.175	0.175	0.455	1.468	1.468
China	0.000	0.005	0.005	0.013	-3.039	0.042
Other Asia	0.000	0.010	0.010	0.025	0.081	0.081
Australia	0.344	0.602	0.602	0.939	1.768	1.768
Japan	0.002	0.001	0.001	0.003	-0.003	-0.003
Argentina	0.177	0.287	0.287	0.460	0.908	0.908
Mexico	0.077	0.126	0.126	0.201	0.397	0.397
Nigeria	0.001	0.001	0.001	0.002	0.004	0.004
Belgium	0.000	0.002	0.002	0.010	-0.016	-0.016
Brazil	0.276	0.448	0.448	0.718	1.418	1.418
Netherland	-0.036	-0.031	-0.031	-0.022	-0.013	-0.013
Venezuela	0.201	0.326	0.326	0.527	1.032	1.032
Russia	0.000	0.006	0.006	0.015	0.049	0.049
Korea	-0.001	0.051	0.051	0.132	-0.129	-0.129
Indonesia	-0.001	0.035	0.035	0.091	0.294	0.294
Algeria	0.000	0.000	0.000	0.001	0.004	0.004
Vietnam	-0.001	0.046	0.046	0.137	0.458	0.458
Egypt	0.001	0.001	0.001	0.001	0.004	0.004
Italy	0.000	0.005	0.005	0.013	-0.013	-0.013
Turkey	0.000	0.006	0.006	0.015	0.047	0.047
ROW	0.024	0.041	0.041	0.065	0.122	0.122

5.3. Results of Producer Welfare

Table 18 presents total producer welfare and the percentage change from the baseline under various scenarios. United States experiences a welfare gain when it started producing GE wheat. Similarly, Canada experience increase welfare of about 1.55% when it joined GE market. Argentina experienced a welfare gain of 5.54% in scenario 1 when they were the only country producing GE wheat however, in scenario 5 when all countries joined the GE market, Argentina's experienced a welfare gain decline to 1.51%. Also, in scenario 1 when Argentina was the only producer of GE wheat, Canada and Russia experienced a welfare gain while US and Australia experience a welfare loss. Australia experienced a welfare loss of about 0.89% in scenario 1 when Argentina was the only producer of GE wheat, however, when Australia joined Argentina in producing GE wheat, the country experiences a welfare gain of about 4.46% while Argentina recorded a gain of about 4.93%. It can also be observed that Argentina experienced a welfare gain in all scenarios and it's probably because it was the first country to commercialize GE wheat. While Russia experience a welfare loss in scenarios 2, 3 and 4, the country experiences a welfare gain in scenario 1, 5, and 6. In scenario 5, when all producing countries adopt GE technology, they all experience a welfare gain. Also, in scenario 6, where there are no restrictions on production and imports, all producing countries experienced a welfare gain.

Table 18: Results of Producer Welfare Under Each Scenario (% Change from Baseline)

Scenarios	United States	Canada	Australia	Argentina	Russia
Baseline	9,884,850	4,604,467	4,593,300	2,709,194	13,911,466
Scenario 1	9,795,844	4,604,966	4,552,215	2,859,319	13,912,841
Scenario 2	9,729,240	4,576,456	4,798,060	2,842,786	13,834,329
Scenario 3	9,729,240	4,576,456	4,798,060	2,842,786	13,834,329
Scenario 4	10,239,453	4,531,686	4,757,288	2,816,829	13,711,072
Scenario 5	10,023,731	4,675,829	4,657,468	2,750,002	14,108,061
Scenario 6	10,023,731	4,675,829	4,657,468	2,750,002	14,108,061
% Change from the Baseline					
Scenario 1	-0.900	0.011	-0.894	5.541	0.010
Scenario 2	-1.574	-0.608	4.458	4.931	-0.554
Scenario 3	-1.574	-0.608	4.458	4.931	-0.554
Scenario 4	3.587	-1.581	3.570	3.973	-1.440
Scenario 5	1.405	1.550	1.397	1.506	1.413
Scenario 6	1.405	1.550	1.397	1.506	1.413

5.4. Results of Consumer Welfare

Table 19 presents the results of total consumer welfare under the various scenarios. In scenario 1 when Argentina was the only producer of GE wheat, all consuming countries experience an increase in welfare except Canada, Korea, Indonesia, Netherland, and Vietnam. Also, in scenario 2, 3 and 4, apart from Netherlands that experienced a welfare loss, all the other consumers experienced a welfare gain. In scenario 5 when all producers adopt GE wheat technology all consumers experienced a welfare gain except Japan, Korea, Belgium, Netherlands and Italy. These are the countries that did not accept GE wheat. Similarly, in scenario 6, when there is no restriction on production or imports, all consumers experienced a welfare gain except Japan, Korea, Belgium, Netherlands, and Italy. It can generally be observed that all consumers benefit from GE wheat production or trade apart from the Japan, Korea, Belgium, Netherland, and Italy who have stated clearly that they will not accept GE wheat. The results suggest that GE wheat increase consumers' welfare.

Table 19: Results of Consumer Welfare Under Various Scenarios (% Change from Baseline)

Consuming Countries	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
United States	0.761	1.333	1.333	2.085	3.945	3.945
Canada	-0.006	0.350	0.350	0.912	2.957	2.957
Australia	0.689	1.207	1.207	1.887	3.568	3.568
Argentina	0.354	0.574	0.574	0.922	1.825	1.825
Russia	0.000	0.012	0.012	0.031	0.099	0.099
Mexico	0.155	0.251	0.251	0.403	0.797	0.797
Japan	0.004	0.002	0.002	0.006	-0.006	-0.006
Nigeria	0.002	0.003	0.003	0.004	0.008	0.008
Korea	-0.002	0.102	0.102	0.265	-0.259	-0.259
China	0.000	0.010	0.010	0.026	0.083	0.083
Indonesia	-0.001	0.070	0.070	0.182	0.589	0.589
Algeria	0.000	0.001	0.001	0.003	0.008	0.008
Belgium	0.000	0.010	0.010	0.026	-0.025	-0.025
Brazil	0.552	0.898	0.898	1.442	2.857	2.857
Other Asia	0.000	0.019	0.019	0.050	0.162	0.162
Netherlands	-0.071	-0.061	-0.061	-0.045	-0.026	-0.026
Vietnam	-0.002	0.109	0.109	0.284	0.919	0.919
Egypt	0.000	0.001	0.001	0.002	0.008	0.008
Italy	0.000	0.010	0.010	0.027	-0.026	-0.026
Turkey	0.000	0.011	0.011	0.029	0.094	0.094
Venezuela	0.402	0.653	0.653	1.048	2.075	2.075
ROW	0.047	0.083	0.083	0.130	0.244	0.244

5.5. Results of Total Welfare from Trade

Table 20 shows the total welfare for the system under the various scenarios. Total welfare increases in all the scenarios. Thus, total welfare continues to increase moving from scenario 1 through scenario 6. This result suggest that adoption of GE wheat technology is favorable to producers and consumers.

Table 20: Results of Total Welfare Under Various Scenarios

Scenarios	Total Welfare	% Change from the Baseline
Baseline	2,525,458,232	
Scenario 1	2,525,618,029	0.006
Scenario 2	2,525,890,055	0.011
Scenario 3	2,525,890,055	0.017
Scenario 4	2,526,487,811	0.024
Scenario 5	2,527,558,177	0.042
Scenario 6	2,527,558,177	0.083

5.6. Results of Sensitivity Analysis

Table 21 presents the results from the sensitivity analysis of US production elasticity and transportation cost. The rationale behind this analysis is to examine how changes in US production elasticity and transportation costs impact on the model. The results of the sensitivity analysis of US production elasticity did not change the trade flows. Also, 10% increase in transportation cost did not change flows. These results are presented in Table 21. In addition, it was observed that Sensitivity analysis of US elasticity negatively affected almost all-consuming countries except Japan and Algeria. Similarly, Sensitivity analysis due to 10% increase in transportation cost negatively affected most of the consuming countries except US, Canada, Japan, Argentina, and the Netherlands.

Table 21: Sensitivity Analysis of US Production Elasticity and Transportation Cost (Baseline)

Countries	Baseline	US Elasticity	% Change	Transport Cost	% Change
United States	88,047	87,912	-0.153	88,230	0.208
Canada	86,328	86,236	-0.107	86,470	0.164
China	336,653	336,583	-0.021	336,609	-0.013
Other Asia	14,119	14,113	-0.042	14,115	-0.028
Australia	21,502	21,406	-0.446	21,476	-0.121
Japan	17,711	17,711	0.000	17,711	0.000
Argentina	16,817	16,805	-0.071	16,833	0.095
Mexico	20,317	20,284	-0.162	20,299	-0.089
Nigeria	11,311	11,310	-0.009	11,310	-0.009
Belgium	12,737	12,734	-0.024	12,736	-0.008
Brazil	29,491	29,344	-0.498	29,421	-0.237
Netherland	12,737	12,736	-0.008	12,737	0.000
Venezuela	3,383	3,372	-0.325	3,379	-0.118
Russia	112,196	112,181	-0.013	112,192	-0.004
Korea	10,195	10,173	-0.216	10,181	-0.137
Indonesia	25,245	25,212	-0.131	25,226	-0.075
Algeria	28,477	28,477	0.000	28,477	0.000
Vietnam	9,945	9,922	-0.231	9,931	-0.141
Egypt	54,201	54,200	-0.002	54,200	-0.002
Italy	12,735	12,733	-0.016	12,734	-0.008
Turkey	49,308	49,300	-0.016	49,304	-0.008
ROW	453,781	453,530	-0.055	453,632	-0.033

5.7. Average Price Received by Producers

Table 22 shows the average price received for GE and non-GE wheat and the percentage change from the baseline. Overall, it was observed that average price received for GE wheat is relatively lower than non-GE wheat.

Table 22: Prices Received in Producing Regions for GE and non-GE.

	United States		% Change	Canada		% Change	Australia		% Change	Argentina		% Change	Russia		% Change
	non-GE	GE		non-GE	GE		non-GE	GE		non-GE	GE		non-GE	GE	
Baseline	200.86	0	0	216.37	0	0	240.71	0	0	221.97	0	0	289.89	0	0
1	200.09	0		215.6	0		239.94	0		0	219		281.1	0	
2	198.86	0		214.57	0		0	227		0	222		280.21	0	
3	198.86	0		214.57	0		0	226		0	222		280.15	0	
4	0	197	-1.83	212.96	0		0	225		0	220		278.61	0	
5	0	192	-4.39	0	208	-4.06	293.28	207	-16.14	230.86	174	-27.3	410.26	248	-16.99
6	0	192	-4.39	0	208	-4.06	293.28	207	-16.14	230.86	211	-4.99	410.26	248	-16.99

CHAPTER 6. SUMMARY AND CONCLUSIONS

6.1. Summary

Surfeit of studies exist in the literature to investigate how the adoption of biotechnology affect agricultural crops such as corn, soybeans, cotton, and barley etc. however, no studies have analyzed the trade implications of CRISPR/gene-edited wheat. The current study seeks to fill these gaps in the literature by analyzing the trade implications of adoption CRISPR/gene-edited wheat. The main objective of the study is to examine the trade implications of CRISPR/gene-edited wheat with emphasis on major producers and exporters of wheat such as Argentina, Australia, US, Canada, and Russia. The specific objectives of the study are to estimate producer welfare, consumer welfare, trade flows, and price levels etc.

The study employed a spatial partial equilibrium model to evaluate the trade impacts associated with adoption of GE under various scenarios. The choice of this model is justified because it enables us to evaluate the impact of CRISPR wheat on supply and demand, consumer and producer surpluses as well as world welfare. The study used a three-year average data from the period of 2015 to 2017. Overall, 5 producing countries and 22 consuming countries were used for the analysis. In all, six scenarios were developed for the analysis. Scenario 1 assumed that Argentina is the only country producing GE wheat, and that, Japan, Korea, Belgium, Netherlands, and Italy import only non-GE. In scenario 2, the study assumed that Argentina and Australia are the only countries producing GE wheat, but Japan, Korea, Belgium, Netherland, and Italy import only non-GE. In scenario 3, the study shocked the system from the demand side, assuming that Japan would accept GE wheat while maintaining that that Argentina and Australia are the only countries producing GE wheat and that, Korea, Belgium, Netherlands, and Italy import only non-GE. In scenario 4, the US produces GE wheat along with Argentina and

Australia, and that Korea, Belgium, Netherlands, and Italy import only non-GE. In addition, under scenario 5, Canada and Russia along with Argentina, Australia, and US producing GE wheat, but Korea, Belgium, Netherlands, and Italy import only non-GE. The last scenario assumed that there are no restrictions on production or imports of GE or non-GE wheat.

6.2. Findings

The following are the key findings from the study.

- When Argentina adopts GE wheat technology, all consuming countries experience a positive change in consumption from the baseline except Canada, Netherlands, Korea, Indonesia, and Vietnam.
- Also, when Argentina, Australia, US, Canada, and Russia adopt GE technology, all the countries in the study experienced a positive change in consumption from the baseline except China, Japan, Korea, Belgium, Netherlands, and Italy. The United States experienced the largest change from the baseline followed by Australia, and Canada. Similar results were observed when there are no restrictions on production and imports.
- The study finds that Mexico, Argentina, Nigeria, Brazil, Egypt, and Venezuela continue to consume GE wheat in all scenarios.
- Also, when there are no restrictions on production and imports, Japan, Korea, Belgium, Netherland, and Italy still import non-GE wheat.
- Argentina experience a welfare gain in all scenarios. In addition, when it adopts the GE technology, Canada and Russia experience a welfare gain while US and Australia experience a welfare loss.
- Both Argentina and Australia experience a welfare gain when they all adopt the GE wheat technology.

- In addition, when Argentina, Australia, US, Canada, and Russia all adopt GE wheat technology, they all experience a producer welfare gain. Canada experienced the largest producer welfare gain followed by Argentina, Russia, US, and Australia.
- When Argentina was the only producer of GE wheat, all consuming countries experience an increase in welfare except Canada, Korea, Indonesia, Netherlands, and Vietnam.
- More so, when Argentina, Australia, US, Canada, and Russia produce GE wheat, all consumers experienced a welfare gain except Japan, Korea, Belgium, Netherlands, and Italy.
- Similarly, when there are no restrictions on production and imports, all consumers experienced a welfare gain except for Japan, Korea, Belgium, Netherlands, and Italy.
- It was also observed that price of wheat for GE wheat are relatively cheaper than price of non-GE wheat.
- More so, total welfare from trade continues to increase due to GE wheat adoption.
- Sensitivity analysis of US production elasticity negatively affected almost all-consuming countries except Japan and Algeria. Similarly, sensitivity analysis in transportation cost negatively affected most of the consuming countries except US, Canada, Japan, Argentina, and the Netherlands.

6.3. Recommendations for Future Research

Due to limitations in getting data on wheat exports by classes especially for Australia, Argentina, and Russia, the study employed the aggregated wheat exports data for the analysis. The study suggests that those who are interested in a similar research can consider doing the analysis by using wheat exports by classes. Also, the current study essentially examined how the adoption of HB4 or CRISPR technology affect the global wheat trade patterns however, the study did not consider how the protein content in wheat affect the trade flows. The study also recommends future researchers to incorporates the protein content of wheat in their model.

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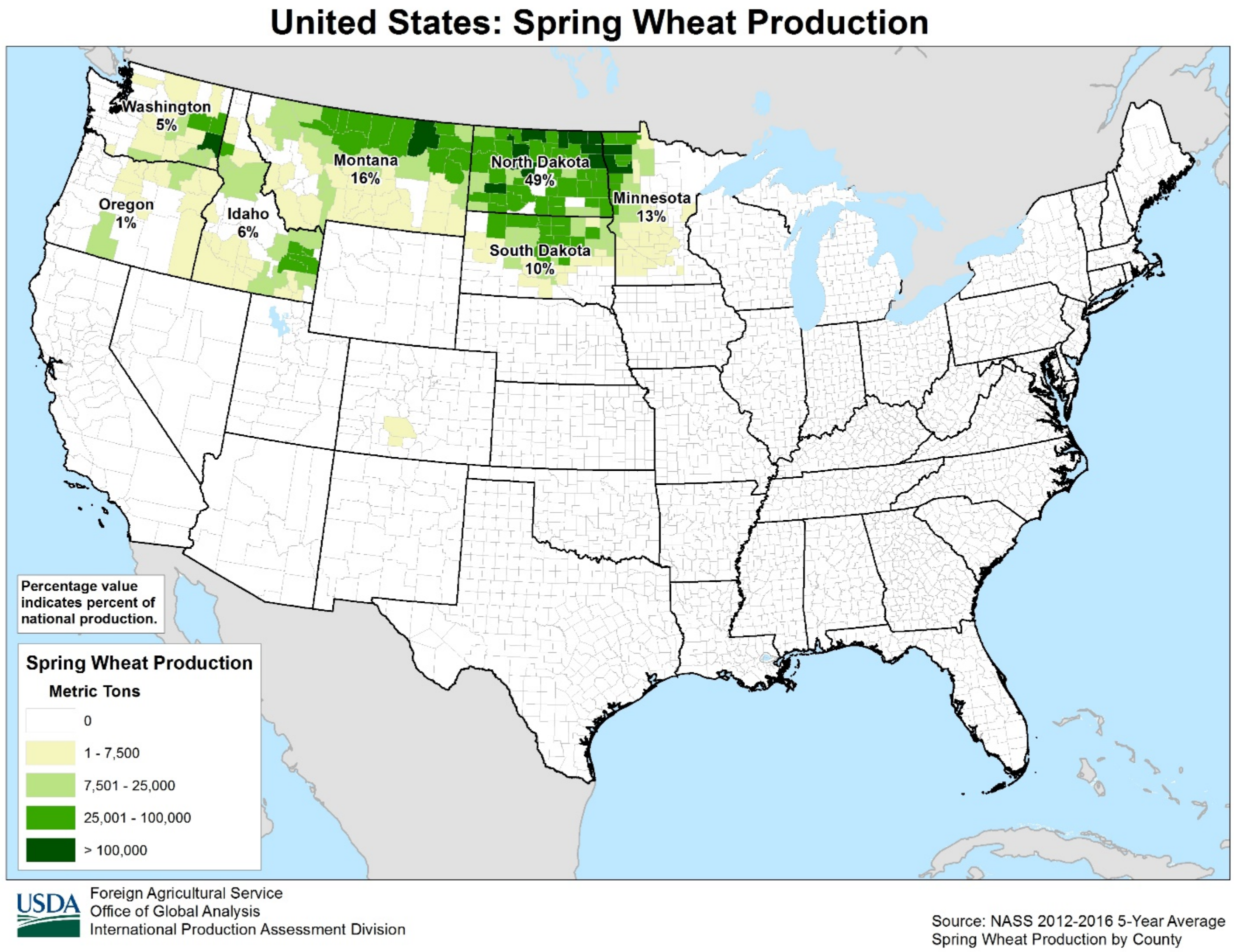
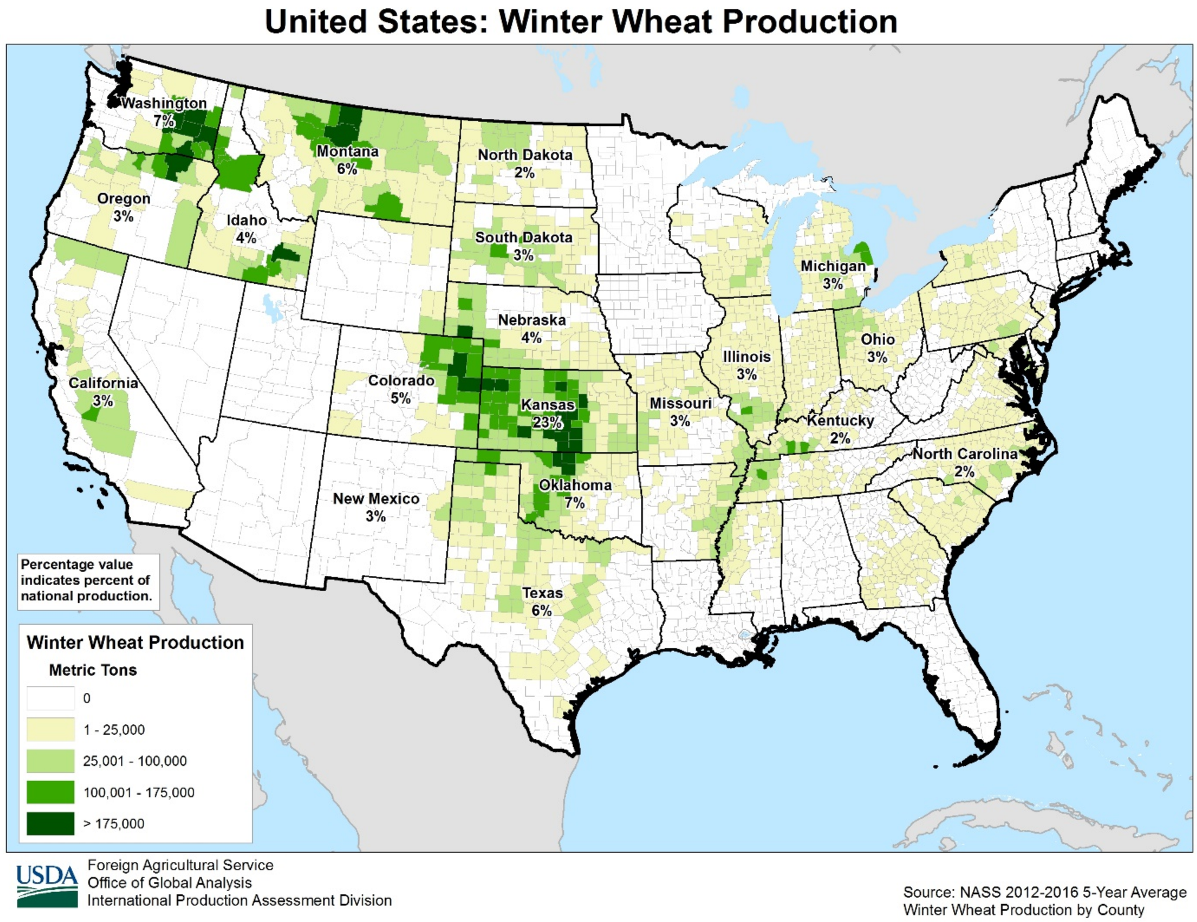
APPENDIX A: PRODUCTION REGION FOR US SPRING WHEAT



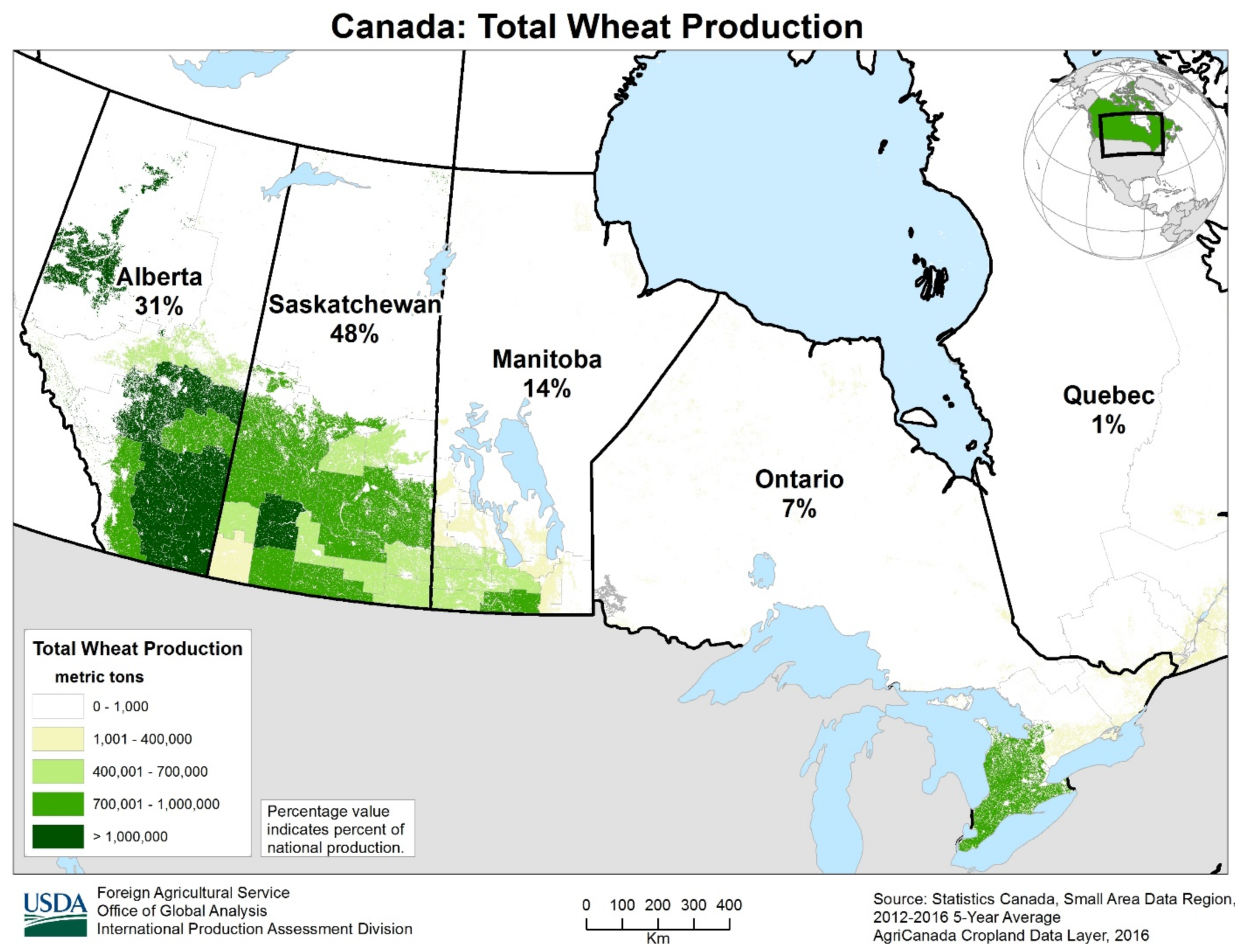
Source: USDA, 2019

APPENDIX B: PRODUCTION REGION FOR US WINTER WHEAT



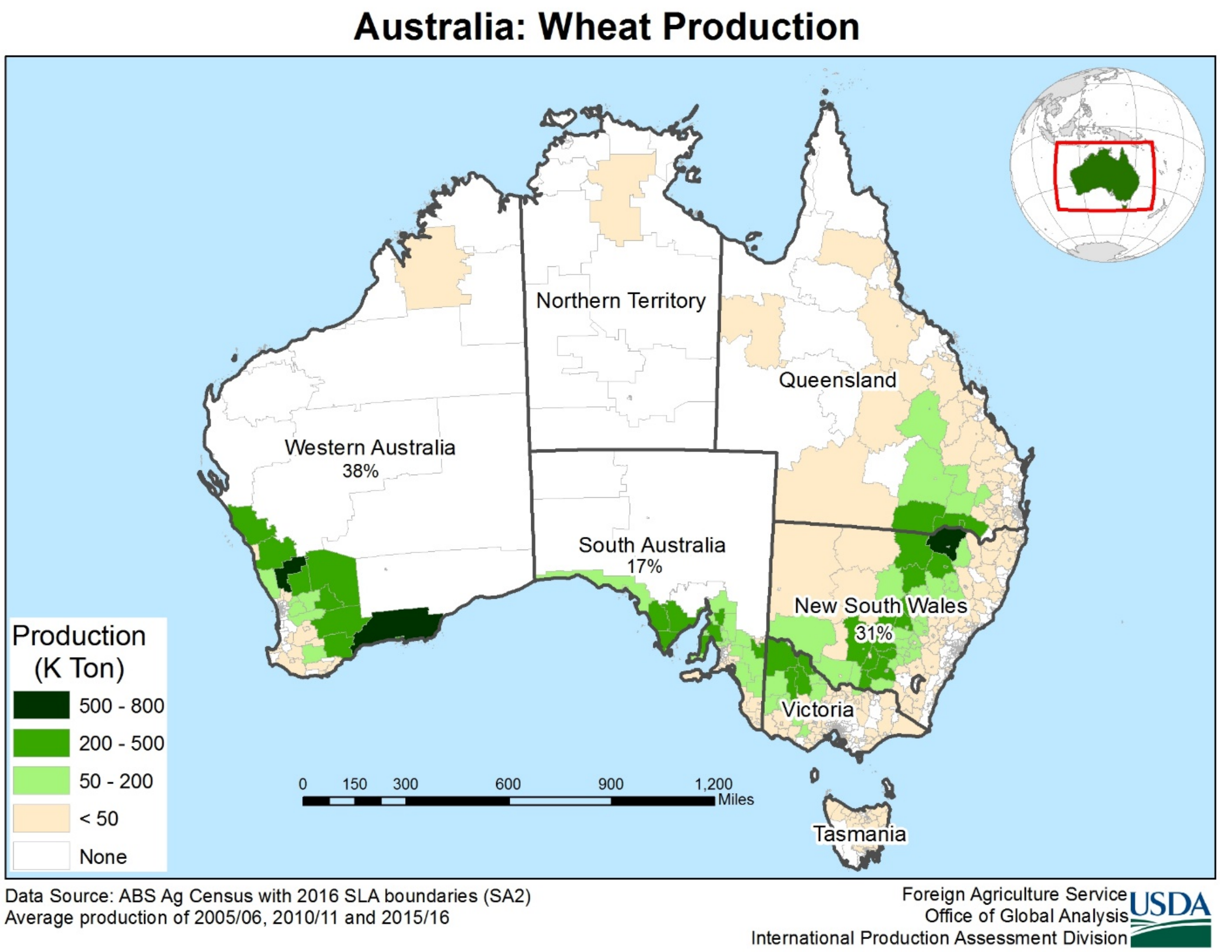
Source: USDA, FAS, 2017

APPENDIX C: PRODUCTION REGION FOR CANADA WHEAT



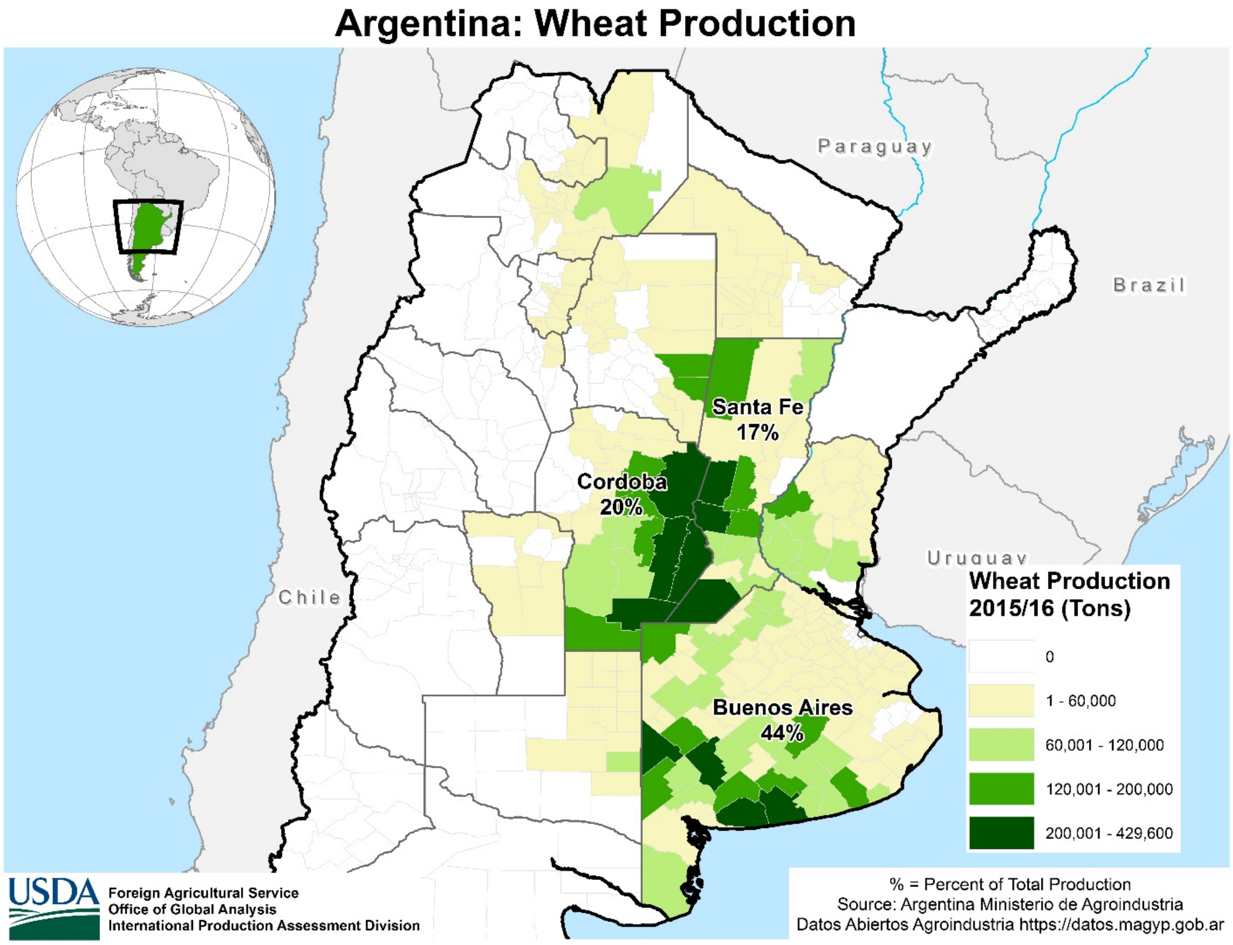
Source: USDA, FAS, 2017

APPENDIX D: PRODUCTION REGION FOR AUSTRALIA WHEAT



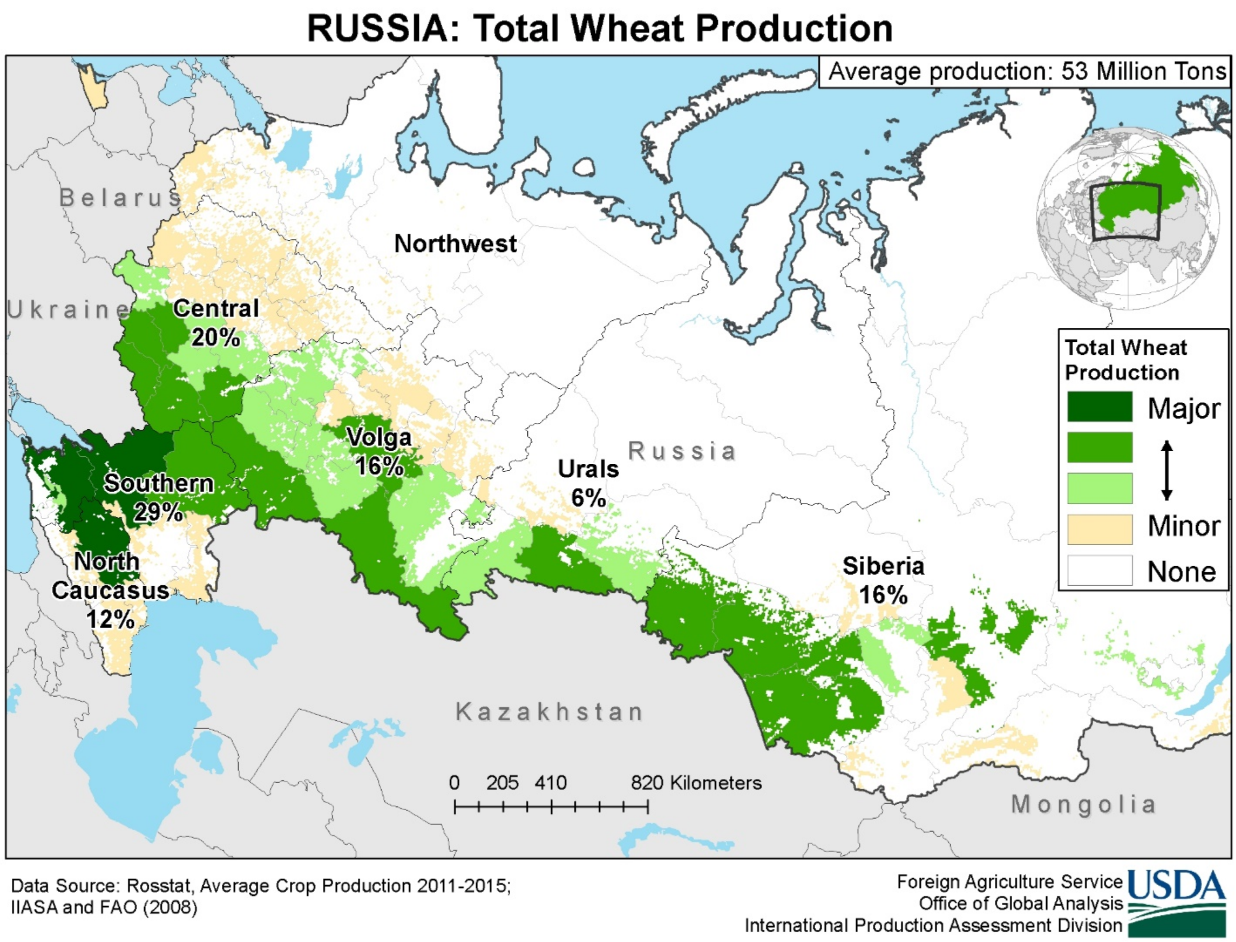
Source: USDA, FAS, 2017

APPENDIX E: PRODUCTION REGION FOR ARGENTINA WHEAT



Source: USDA, FAS, 2017

APPENDIX F: PRODUCTION REGION FOR RUSSIA WHEAT



Source: USDA, FAS, 2017

APPENDIX G: GAMS MODEL

```
****************************************************************************
*
*
* examines GM (or GE) wheat production and implications for wheat trade
*
****************************************************************************
*
OPTION LIMROW = 0;
OPTION LIMCOL = 0;
$OFFSYMLIST
$OFFSYMXREF
$OFFUELLIST
$OFFUELXREF
SETS
  wheat  /wht/
  type   /gm,non/
  countries /us, can, aust, arg, rus, mex, japan, nig, korea,
               chi, indo, alge, belg, bra, oasia, neth, viet, egypt, italy,
               turk, vene,row/
  cons(countries)   /us, can, aust, arg, rus, mex, japan, nig, korea, chi,
                      indo, alge, belg, bra, oasia, neth, viet, egypt, italy,
                      turk, vene, row/
  nogm(cons) /japan, korea, belg, neth, italy/
  nogm2(cons) /korea, belg, neth, italy/
```

```
*  prd(countries)
alias (countries,prd);
SETS
  canada(prd) /can/
  unitstat(prd) /us/
;
Table wprd(prd,wheat) production for each type of wheat in producing regions
        wht
us      55440
can     29929
aust    25198
arg     15900
rus     72855
mex     0
japan   0
nig     0
korea   0
chi     0
indo    0
alge    0
belg    0
bra     0
oasia   0
neth    0
viet    0
egypt   0
italy   0
turk    0
```

```
vene    0

row     0

;

Table pprice(prd,wheat)price received by farmers for each type of wheat in
producing regions

           wht

us      224.66

can     244.33

aust    220.67

arg     200.33

rus     187

mex     1

japan   1

nig     1

korea   1

chi     1

indo    1

alge    1

belg    1

bra     1

oasia   1

neth    1

viet    1

egypt   1

italy   1

turk    1

vene    1

row     1

;
```

```
Table trans(prd,cons)transportation costs between producing regions to
consuming countries
         mex      japan    nig      korea    chi      indo     alge
mex      0        0        0        0        0        0        0
japan    0        0        0        0        0        0        0
nig      0        0        0        0        0        0        0
korea    0        0        0        0        0        0        0
chi      0        0        0        0        0        0        0
indo     0        0        0        0        0        0        0
alge     0        0        0        0        0        0        0
us       74.34    44.72    21.78    17.05    43.44    51.59    21.78
can     124.75    37.28    44.69    35.35    36.57    46.48    44.69
aust     16.86    12.83    16.86    12.83    17.84    19.05    16.86
arg      27.67    51.6     24.8     43.39    37.28    46.91    26.52
rus      19.43    21.92    16.6     20.4     20.51    14.54    4.49

+        belg     bra      oasia    neth     viet     egypt    italy
belg     0        0        0        0        0        0        0
bra      0        0        0        0        0        0        0
oasia    0        0        0        0        0        0        0
neth     0        0        0        0        0        0        0
viet     0        0        0        0        0        0        0
egypt    0        0        0        0        0        0        0
italy    0        0        0        0        0        0        0
us       27.2     34.11    46.08    27.2     51.59    30.47    27.2
can      43.61    46.26    39.48    43.61    46.48    45.91    43.61
aust     26.77    16.86    19.05    26.77    19.05    17.38    25.63
arg      24.16    23.38    42.25    17.31    42.25    31.84    27.87
rus      8.36     15.97    16.6     8.54     20.51    14.54    3.3
```

```
+       turk    vene    us      can     aust    arg     rus     row

turk     0       0       0       0       0       0       0      0

vene     0       0       0       0       0       0       0      0

us      31.47   25.94   0.0     24.14   51.59   34.11   27.2    31.7

can     61.22   44.4    24.14   0       46.48   46.26   43.61   44.69

aust    23.92   24.42   51.59   46.48   0       16.86   16.86   16.86

arg     30.81   19.72   34.11   46.26   16.86   0       16.86   31.9

rus     6.37    14.64   27.2    43.61   19.86   16.86   0       15.28

row     0       0       0       0       0       0       0       0


;

Table tariffs(prd,cons) tariffs between producing regions to consuming

countries

         mex     japan   nig     korea   chi     indo    alge

mex      0       0       0       0       0       0       0

japan    0       0       0       0       0       0       0

nig      0       0       0       0       0       0       0

korea    0       0       0       0       0       0       0

chi      0       0       0       0       0       0       0

indo     0       0       0       0       0       0       0

alge     0       0       0       0       0       0       0

us      9.00    34.00   14.00   187.00  23.00   8.00    32.00

can     9.00    34.00   14.00   187.00  23.00   8.00    32.00

aust    9.00    34.00   14.00   187.00  23.00   8.00    32.00

arg     9.00    34.00   14.00   187.00  23.00   8.00    32.00

rus     9.00    34.00   14.00   187.00  23.00   8.00    32.00


+       belg    bra     oasia   neth    viet    egypt   italy
```

```
belg     0        0        0        0        0        0        0
bra      0        0        0        0        0        0        0
oasia    0        0        0        0        0        0        0
neth     0        0        0        0        0        0        0
viet     0        0        0        0        0        0        0
egypt    0        0        0        0        0        0        0
italy    0        0        0        0        0        0        0
us      13.80    15.00    10.00    13.80    17.60    15.00    13.80
can     13.80    15.00    10.00    13.80    17.60    15.00    13.80
aust    13.80    15.00    10.00    13.80    17.60    15.00    13.80
arg     13.80    15.00    10.00    13.80    17.60    15.00    13.80
rus     13.80    15.00    10.00    13.80    17.60    15.00    13.80

+       turk     vene     us       can      aust     arg      rus    row
turk     0        0        0        0        0        0        0      0
vene     0        0        0        0        0        0        0      0
us      40.20    13.50    0.00     20.40    5.20     10.90    9.50   0.00
can     40.20    13.50    3.10     0.00     5.20     10.90    9.50   0.00
aust    40.20    13.50    3.10     20.40    0.00     10.90    9.50   0.00
arg     40.20    13.50    3.10     20.40    1.10      0.00    9.50   0.00
rus     40.20    13.50    3.10     20.40    1.10     10.90    0.00   0.00
row     0        0        0        0        0        0        0       0
;
PARAMETERS
 supelas(prd,wheat) supply elasticities
 wprd(prd,wheat)   wheat production by country
 pprice(prd,wheat)      producer price of wheat by country
 a(cons)           intercept of demand equation by country
 b(cons)           price coefficient of demand equation by country
```

```
 d(prd,wheat)      intercept of supply equation by country
 e(prd,wheat)      price coefficient of supply equation by country
 trans(prd,cons)   transportation costs per MT from producer to consumer
 tariffs(prd,cons)    tarrifs between producing regions to consuming countries
 segfee            segregation fee
 techfee           technology fee on gm seed
 default(cons)     percentage of default on ccc loans
 severity(cons)    percent of ccc loan balanced defaulted
 gmsave(prd)       savings per MT for growing gm wheat
 percprot(wheat)
;
percprot(wheat) = 0.14;
*percprot('hrw') = 0.12;
*these data are from Dierson and Sherrick
PARAMETER
default(cons)
/
mex      0.04
japan    0.00
nig      0.05
korea    0.01
chi      0.00
indo     0.02
alge     0.05
belg     0.00
bra      0.04
oasia    0.04
neth     0.00
viet     0.04
```

```
egypt   0.054
italy   0.00
turk    0.042
vene    0.042
us      0.00
can     0.00
aust    0.00
arg     0.042
rus     0.00
row     0.042 /
;

PARAMETER
severity(cons)
/
mex     0.031
japan   0.00
nig     0.004
korea   0.002
chi     0.00
indo    0.105
alge    0.004
belg    0.00
bra     0.04
oasia   0.04
neth    0.00
viet    0.04
egypt   0.004
italy   0.00
```

```
turk    0.04
vene    0.04
us      0.00
can     0.00
aust    0.00
arg     0.04
rus     0.00
row     0.04              /;

 PARAMETER
*31811.4 savings without yield boost
*174962.7 savings with yield boost
 gmsave(prd)
/
us      11
can     11
aust    11
arg     11
rus     11
mex     0
japan   0
nig     0
korea   0
chi     0
indo    0
alge    0
belg    0
bra     0
oasia   0
```

```
neth    0
viet    0
egypt   0
italy   0
turk    0
vene    0
row     0
           /;
* gmsave(prd) = 174962.7;
* gmsave('wter') =0;
* gmsave(unitstat) =0;
techfee = 2.057 ;
segfee  = 2.33  ;

* trans(prd,cons)=trans(prd,cons)*7142.86;
*DATA should be in 1000s MT protein and $per 1000MT
 PARAMETER
 wcons(cons)  countries      cons
   /          mex            7400
              japan          6400
              nig            4097
              korea          4318
              chi          121667
              indo           8950
              alge          10317
              belg           4615
              bra           11733
              oasia          5135
              neth           4615
```

```
            viet          3725
            egypt        19633
            italy         4615
            turk         17800
            vene          1237
            aust          7545
            us           31174
            can          27722
            arg           5700
            rus          40666
            row         166548
 /;

PARAMETER
 tot
 totc
 totp;
totc=SUM(cons,wcons(cons));
totp=SUM((prd,wheat),wprd(prd,wheat));
tot=totp-totc;

DISPLAY totc, totp, tot;
*wprd('wter','hrw') = wprd('wter','hrw') *0.896754085174837;
*wprd(unitstat,'wht')=wprd(unitstat,'wht')*1.08596887343365;
*wprd(canada,'wht')=wprd(canada,'wht')*1.2288954324623;
*wprd(prd,wheat) = wprd(prd,wheat)/totp*totc;
wcons(cons) = wcons(cons)*totp/totc;
totp=SUM((prd,wheat),wprd(prd,wheat));
totc=SUM(cons,wcons(cons));
```

```
DISPLAY totc,totp,wprd;


PARAMETER demelas(cons)
/         mex    -0.11
          japan  -0.006
          nig    -0.001
          korea  -0.11
          chi    -0.016
          indo   -0.11
          alge   -0.001
          belg   -0.012
          bra    -0.3
          oasia  -0.02
          neth   -0.012
          viet   -0.11
          egypt  -0.001
          italy  -0.012
          turk   -0.02
          vene   -0.291
          aust   -0.5
          us     -0.5
          can    -0.5
          arg    -0.3
          rus    -0.012
          row    -0.02
 /;
```

```
TABLE supelas(prd,wheat)

         wht
us      0.21
can     0.31
aust    0.31
arg     0.31
rus     0.31
mex     0
japan   0
nig     0
korea   0
chi     0
indo    0
alge    0
belg    0
bra     0
oasia   0
neth    0
viet    0
egypt   0
italy   0
turk    0
vene    0
row     0
;
```

```
PARAMETER cprice(cons)
/       mex     235
        japan   485
        nig     211.45
        korea   254.25
        chi     325
        indo    309
        alge    207.89
        belg    243
        bra     196.2
        oasia   209.5
        neth    237.2
        viet    209.5
        egypt   218.4
        italy   235.5
        turk    358
        vene    240.35
        aust    231.33
        us      211.3
        can     255
        arg     261
        rus     205
        row     140.31
/;
*cprice(cons)=cprice(cons)/0.135;
b(cons) = demelas(cons)*wcons(cons)/cprice(cons);
a(cons) = wcons(cons) - b(cons)*cprice(cons);
LOOP((prd,wheat)$wprd(prd,wheat),
 e(prd,wheat) = supelas(prd,wheat)*wprd(prd,wheat)/pprice(prd,wheat);
```

```
 d(prd,wheat) = wprd(prd,wheat) - e(prd,wheat)*pprice(prd,wheat);
);
DISPLAY a,b,d,e;
DISPLAY cprice;
VARIABLES
 supply(prd,cons,wheat,type)  wheat production by producer  wheat and type
 demand(cons,prd,wheat,type) wheat consumption by consumer wheat and type
 totsup(prd,wheat)    total wheat supply by producer
 totcons(cons)        total wheat consumption by consumer
 totwel
;
POSITIVE VARIABLES
 supply,demand,totsup,totcons;
EQUATIONS
 produce(prd,wheat)
 eat(cons)
 objective
 balance(prd,cons,wheat,type)
 bal1
* uplim(prd)
;
*uplim(prd)..SUM(cons,supply(prd,cons,'wht','gm')) =L=
*              SUM((cons,type),supply(prd,cons,'wht',type))*0.3;
produce(prd,wheat).. SUM((type,cons),supply(prd,cons,wheat,type))
=E=totsup(prd,wheat);
eat(cons).. SUM((type,wheat,prd),demand(cons,prd,wheat,type))
=E=totcons(cons);
balance(prd,cons,wheat,type)$(e(prd,wheat))..
      supply(prd,cons,wheat,type) =E= demand(cons,prd,wheat,type);
```

```
bal1.. SUM((prd,cons,wheat,type),supply(prd,cons,wheat,type))
                  =E=
              SUM((cons,prd,wheat,type),demand(cons,prd,wheat,type));
objective..   SUM(cons$b(cons),POWER(totcons(cons),2)/(2*b(cons))
                   -a(cons)*totcons(cons)/b(cons))
             - SUM((prd,wheat)$e(prd,wheat),
                  POWER(totsup(prd,wheat)-d(prd,wheat),2)/2/e(prd,wheat)
               )
           -SUM((prd,wheat,type,cons)$e(prd,wheat),
              (totsup(prd,wheat)-d(prd,wheat))/e(prd,wheat)*
             supply(prd,cons,wheat,type)*default(cons)*severity(cons)
             )
             -
SUM((prd,cons,wheat,type),supply(prd,cons,wheat,type)*(trans(prd,cons)+(tarif
fs(prd,cons)/100)*pprice(prd,wheat)))
             +SUM((prd,cons),supply(prd,cons,'wht','gm')*gmsave(prd))
             -SUM((prd,wheat)$(ORD(prd) LE 5), segfee*
                   SUM(nogm,supply(prd,nogm,wheat,'non'))
              )
              =E=totwel;
;
MODEL gm1 /ALL/;
*supply.fx(canada,cons,wheat,'gm') = 0;
*supply.fx(prd,cons,'hrw','gm') = 0;
LOOP((prd,wheat)$(e(prd,wheat) EQ 0),
 supply.fx(prd,cons,wheat,type) = 0;
);
PARAMETER gmon   set equal to 0 to turn GM wheat off set to one to turn GM
wheat on;
```

```
gmon = 1;
IF( (gmon EQ 0),
supply.fx(prd,cons,wheat,'gm') = 0;
segfee = 0;
);
LOOP(prd$(gmsave(prd) EQ 0),
supply.fx(prd,cons,wheat,'gm') = 0;
);
PARAMETERS
 cppd(cons)
 pprd(prd,wheat)   actual price received
 pwelf(prd,wheat)
 cwelf(cons)
 sumwelf
 welfdiff
 gmyes(prd)
 ;
PARAMETERS
 pricerec(prd,cons,wheat,type)   price received by producers
 gmus
 gmcan
 gmhere(prd)
;
ALIAS (wheat,w1), (prd,p1)  ;
PARAMETERS
 impldiff(prd,cons)
 totprod(prd,wheat)
 testprice(unitstat)
 lostwelf(unitstat)   welfare losses due to default on ccc loans
```

```
 proddiff(prd,wheat)   change from baseline in wheat production
 tconsw   total consumer welfare
;
SET
 scenario /baseline,gm1,gm2,gm3,gm4,gm5,gm6/;
;
FILE out /gmwheat_5.txt/;
*solve here
*baseline NO GE
LOOP(scenario,
  IF((ORD(scenario) EQ 1),
    supply.fx(prd,cons,wheat,'gm') = 0;
    segfee = 0;
  );
  IF((ORD(scenario) EQ 2),
     display "Scenario 1. only argentina produces GE, Importers: non-GE JAP,
KOR, BEL, ITL, NTH";
     supply.up('arg',cons,wheat,type) = inf;
     segfee = 0;
     LOOP(cons$nogm(cons),
       demand.fx(cons,prd,wheat,'gm') = 0;
     );
  );

    IF ((ORD(scenario) EQ 3),
      display  "Scenario 2. only Argentina and Australia produce GE Importers
non-GE JAP, KOR, BEL, ITL, NTH";
      supply.up('arg',cons,wheat,type) = inf;
      supply.up('aust',cons,wheat,type) = inf;
```

```
      LOOP(cons$nogm(cons),
        demand.fx(cons,prd,wheat,'gm') = 0;
      );
     segfee = 0;
     );
  IF((ORD(scenario) EQ 4),
  display "Scenario 3. Only ARG and AUS produce GE, Importers non-GE  KOR,
BEL, ITL, NTH";
     supply.up('arg',cons,wheat,type) = inf;
     supply.up('aust',cons,wheat,type) = inf;
     LOOP(cons$nogm2(cons),
       demand.fx(cons,prd,wheat,'gm') = 0;
      );
     segfee = 0;
     );
  IF((ORD(scenario) EQ 5),
  display "Scenario 4. Only ARG and AUS, US produce GE, Importers non-GE KOR,
BEL, ITL, NTH";
     supply.up('arg',cons,wheat,type) = inf;
     supply.up('aust',cons,wheat,type) = inf;
     supply.up('us',cons,wheat,type) = inf;
     LOOP(cons$nogm2(cons),
     demand.fx(cons,prd,wheat,'gm') = 0;
     );
     LOOP((prd,nogm2),
      supply.up('us',nogm2,wheat,'non') = inf;
     );
    );
```

```
  IF((ORD(scenario) EQ 6),
     display "Scenario 5. Only ARG, AUS, US, CAN, RUS produce GE, Importers
non-GE KOR, BEL, ITL, NTH";
     supply.up(prd,cons,wheat,'non') = inf;
     supply.up(prd,cons,wheat,'gm') = inf;
     segfee = 0
     LOOP(cons$nogm2(cons),
       demand.fx(cons,prd,wheat,'gm') = 0;
      );
     );

   IF((ORD(scenario) EQ 7),
     display "Scenario 6. no restrictions on production or imports ";
     supply.up(prd,cons,wheat,'non') = inf;
     supply.up(prd,cons,wheat,'gm') = inf;
     demand.up(cons,prd,wheat,type) = inf;
     segfee = 0;
     );



  LOOP(prd$(gmsave(prd) EQ 0),
   supply.fx(prd,cons,wheat,'gm') = 0;
  );
*supply.fx(unitstat,nogm,wheat,type) = 0;
*supply.fx(prd,cons,'wht','gm') = 0;
LOOP((prd,wheat)$(e(prd,wheat) EQ 0),
  supply.fx(prd,cons,wheat,type) = 0;
);
```

```
*LOOP(prd$(ORD(prd) LE 3),
* supply.fx(prd,'iran',wheat,type)=0;
* supply.fx('nd','iraq',wheat,type)=0;
*);
*supply.fx('nd','us','wht','gm')=0; supply.fx('nd','us','wht','non')=0;
*supply.fx('os','us','wht','gm')=0; supply.fx('os','us','wht','non')=0;
*supply.fx('wter','us','hrw','gm')=0; supply.fx('wter','us','hrw','non')=0;
LOOP(cons$nogm(cons),
 demand.fx(cons,prd,wheat,'gm') = 0;
);
SOLVE gm1 MAXIMIZING totwel using nlp;
LOOP(cons$b(cons),
 cppd(cons) = -eat.m(cons)/1000;
 cwelf(cons) = -totcons.l(cons)**2/b(cons)/2;
);
tconsw = sum(cons,cwelf(cons));
LOOP((prd,wheat)$e(prd,wheat),
 pprd(prd,wheat) = produce.m(prd,wheat);
);
*pprd(prd,wheat) = pprd(prd,wheat)/1000*percprot(wheat);
pprd(prd,wheat) = pprd(prd,wheat);

gmyes(prd) = SUM(cons,supply.l(prd,cons,'wht','gm'));

LOOP((prd,wheat)$(e(prd,wheat) AND totsup.l(prd,wheat)),
 pwelf(prd,wheat) = (totsup.l(prd,wheat)-
d(prd,wheat))/e(prd,wheat)*totsup.l(prd,wheat)
            -0.5*POWER((totsup.l(prd,wheat)-d(prd,wheat)),2)/e(prd,wheat)
 ;
```

```
);
sumwelf = SUM(cons,cwelf(cons)) +
SUM((prd,wheat)$e(prd,wheat),pwelf(prd,wheat));
welfdiff = sumwelf-totwel.l;

 LOOP((prd,cons,wheat)$supply.l(prd,cons,wheat,'non'),
  impldiff(prd,cons) = produce.m(prd,wheat)+ eat.m(cons);
 );
proddiff(prd,wheat) = wprd(prd,wheat)-totsup.l(prd,wheat);
DISPLAY cppd,pprd,pwelf,cwelf, sumwelf, totwel.l, welfdiff, gmsave, proddiff;

LOOP(unitstat,
 lostwelf(unitstat) = SUM((type,cons,wheat)$e(unitstat,wheat),
               (totsup.l(unitstat,wheat)-
d(unitstat,wheat))/e(unitstat,wheat)*

supply.l(unitstat,cons,wheat,type)*default(cons)*severity(cons)
              )   ;
);
DISPLAY lostwelf;
gmus=0;
gmcan=0;
LOOP((unitstat,cons)$supply.l(unitstat,cons,'wht','gm'),
  gmus = gmus + supply.l(unitstat,cons,'wht','gm');
);
LOOP((canada,cons)$supply.l(canada,cons,'wht','gm'),
  gmcan = gmcan + supply.l(canada,cons,'wht','gm');
);
```

```
LOOP(canada,
 IF ((gmcan GT 0),
gmhere(canada) = 1;
 );
);
LOOP(unitstat,
 IF ((gmus GT 0),
  gmhere(unitstat) = 1;
 );
);
DISPLAY gmhere, gmus,gmcan;

LOOP((prd,cons,wheat,type)$supply.l(prd,cons,wheat,type),
pricerec(prd,cons,wheat,type) = -eat.m(cons)-trans(prd,cons);
IF((nogm(cons) AND gmhere(prd)),
pricerec(prd,cons,wheat,type) = pricerec(prd,cons,wheat,type) -segfee;
 );
);
*pricerec(prd,cons,wheat,type)=pricerec(prd,cons,wheat,type)/1000*percprot(wh
eat);
pricerec(prd,cons,wheat,type)=pricerec(prd,cons,wheat,type);
DISPLAY pricerec;

LOOP(unitstat$e(unitstat,'wht'),
 testprice(unitstat) = (totsup.l(unitstat,'wht')-
d(unitstat,'wht'))/e(unitstat,'wht');
);
*testprice(unitstat) = testprice(unitstat) / 1000 * .14;
testprice(unitstat) = testprice(unitstat);
```

```
*totprod(prd,wheat) =
SUM((cons,type),supply.l(prd,cons,wheat,type)/percprot(wheat));
totprod(prd,wheat) = SUM((cons,type),supply.l(prd,cons,wheat,type));

DISPLAY testprice, totprod;

put out;
put "output from wheat5.prn. GE wheat vs non-GE wheat scenarios";
put /;
put /;
PUT scenario.tl /;
put /;
IF((ORD(scenario) EQ 1),
  put "Baseline";
);
IF((ORD(scenario) EQ 2),
  put "Scenario 1. only ARG produces GE, Importers non-GE: JAP, KOR, BEL,
ITL, NTH";
);
IF((ORD(scenario) EQ 3),
  put "Scenario 2. only ARG and AUS produce GE, Importers non-GE: JAP, KOR,
BEL, ITL, NTH";
);
IF((ORD(scenario) EQ 4),
  put "Scenario 3. Only ARG and AUS produce GE, Importers non-GE: KOR, BEL,
ITL, NTH";
);
IF((ORD(scenario) EQ 5),
```

```
  put "Scenario 4. Only ARG, AUS, and US produce GE, Importers non-GE: KOR,
BEL, ITL, NTH";
);
IF((ORD(scenario) EQ 6),
  put "Scenario 5. ALL (ARG, AUS, US, CAN, RUS) produce GE, Importers non-GE:
KOR, BEL, ITL, NTH";
);
IF((ORD(scenario) EQ 7),
  put "Scenario 6. no restrictions on production or imports";
);
PUT /;
put "Trade flows from producing countries to importing countries"
put /;
supply.l(prd,cons,wheat,type)=supply.l(prd,cons,wheat,type)/percprot(wheat);
loop((prd,cons,wheat,type)$supply.l(prd,cons,wheat,type),
put prd.tl,cons.tl,wheat.tl,type.tl,supply.l(prd,cons,wheat,type);
put /;
);
put /;
PUT "total welfare" , totwel.l:20:2 /;
put /;
PUT "consumer welfare" /;
LOOP(cons,
 PUT cons.tl, cwelf(cons):20:2;
 PUT /;
);
put /;
PUT "total consumer welfare",tconsw:24:2 /;
put /;
```

```
PUT "producer welfare" /;
LOOP((prd,wheat)$(pwelf(prd,wheat)),
 put prd.tl,wheat.tl,pwelf(prd,wheat):20:2;
 put /;
);
put /;
PUT "prices received" /;
LOOP((prd,cons,wheat,type)$supply.l(prd,cons,wheat,type),
 put prd.tl,cons.tl,wheat.tl,type.tl,pricerec(prd,cons,wheat,type);
 put /;
);
put /;
PUT "production totals by region and wheat" /;
LOOP((prd,wheat)$totprod(prd,wheat),
 put prd.tl, wheat.tl, totprod(prd,wheat):20:4 /;
);
put /;
PUT "GM production and consumption" /;
LOOP((prd,cons)$supply.l(prd,cons,'wht','gm'),
 PUT prd.tl, cons.tl, supply.l(prd,cons,'wht','gm') /;
);
 put /;
DISPLAY totsup.l;
);
```