University of Alberta

Economics of genomic tools for crop improvement

by

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A thesis submitted to the Faculty of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of

Doctor of Philosophy
in
Agricultural and Resource Economics

Department of Resource Economics and Environmental Sociology

Spring 2014
Edmonton, Alberta

ABSTRACT

This thesis evaluates economic impact of adoption of crops developed by means of modern genomic tools. The economic impact of these improved crops is looked at from two different angles: the welfare implications from trading improved crops on the world market, and the benefits of adopting improved crops for domestic use in a small country. Hence, there are two essays in this thesis.

The first essay incorporates two subtopics that are interrelated and the analyses are presented in one paper. This first essay assesses economic selected welfare effects, for consumers and producers from international trade in potential drought-tolerant (DT) wheat developed by genetic modification (GM) versus marker-assisted selection (MAS) and conventional breeding. A non-spatial partial equilibrium trade model of world wheat trade is developed to assess economic welfare. Based on the assumptions employed in the model, the analysis shows that adoption of GM DT wheat generally increases trade economic welfare. The positive welfare changes from GM DT wheat adoption are driven by higher non-GM wheat prices. Adoption of MAS DT wheat on the other hand reduces trade economic welfare as measured by the sum of consumer and producer welfare. The negative welfare change in this case is driven by additional supplies of better performing MAS DT wheat in drought years.

The second essay estimates future economic returns from introduction of transgenic DT maize varieties on smallholder farms in Kenya under humanitarian license. Cost and benefit analysis with stochastic simulation of uncertain variables is employed to calculate Net Present Value of the future benefits of adopting transgenic DT maize at the farm and national level. The analysis shows that introduction of transgenic DT maize in Kenya produces positive private benefits for smallholder farmers and positive social benefit to society. Negative benefits to society occur only under very low adoption levels (i.e., equal or less than 10% of Kenya's total maize planting area), and if the yield advantage of the transgenic DT maize is conservatively low. Private benefits to the smallholder farmers are positive in all scenarios considered in this study.

ACKNOWLEDGEMENTS

Originally from a small town in Ukraine, I could not have possibly imagined ten-fifteen years ago that I will be graduating from one of the best agricultural economics departments in Canada with a PhD degree. Here I am completing this thesis, and there is a long list of people that are behind my success.

First and foremost, I would like to extend my deepest gratitude to my supervisor Prof. Jim Unterschultz, who was the best mentor, advisor, and colleague throughout my PhD program. Thank you for accepting me into your team, reading my course papers, projects, articles and thesis, and for giving me timely and very detailed feedback. Next, my thanks go to my supervisory committee: to Prof. Michele Veeman, who always encouraged me and provided sharp comments and input; to Prof. James Rude, for his constant advice on modelling and for being a great friend; to Prof. Scott Jeffrey for his big picture and "so what?" input to my research.

I also thank my external examiners: Prof. Dean Spaner (candidacy exam), for making me firmly believe that my research topic is very important and interesting; Prof. Richard Gray and Prof. Varghese Manaloor (final defense), for a critical look and advice. My thanks go to all academic members, staff and colleagues at the Resource Economics and Environmental Sociology Department (former Rural Economy), of the University of Alberta for making me feel like at home.

I am thankful to all the scientific and staff members of CIMMYT who hosted me in the Nairobi office during my research visit and provided with data and advice. My special thanks go to Marianne Bänziger, Bekele Shiferaw, Stephen Mugo, Hugo De Groote, Kai Sonder from CIMMYT, Sylvester Oikeh from AATF, and Vanessa Cook from Monsanto.

I would like to acknowledge and thank Genome Canada, Genome Prairie and Genome Alberta for their generous funding of my research.

I am also indebted to Prof. Dieter M. Hörmann, my supervisor at the Leibnitz University of Hanover (Germany). Thanks for believing in my abilities and leading me to a successful completion of my MSc degree that eventually led me to pursue a PhD degree.

Student years are the best years in the lives of many people. This journey of long hours of study, research, and stressful exams would have been way more difficult without love and support of my friends. In particular, I would like to thank Luda Dorosh and Tsega Temesgen for being there for me in good and bad times. I was fortunate to be encouraged and supported by my co-workers at “Lord’s shoes”. Thanks to my many friends from Ukraine and Russia, from Canada, China, Colombia, Egypt, Iran, Japan, Mexico, Lebanon, and Peru - I am sure you know who you are!

Finally, my thanks go to my family. I could not have become who I am without my dearest parents, who cherished and educated me, who taught me to be a fighter and to believe in myself. I am especially grateful to my best friend and husband Russell Weir, for his unconditional love and constant encouragement, for being proud of me, for cooking meals and doing chores while I was studying. This work is dedicated to him.

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ACRONYMS

AAFC	Agriculture and Agri-Food Canada
AATF	African Agricultural Technology Foundation
ACZ	Agroclimatic zone
Bt	*Bacillus thuringiensis*
CBA	Cost-benefit analysis
CGIAR	Consultative Group on International Agricultural Research
CFIA	Canadian Food Inspection Agency
CIMMYT	International Maize and Wheat Improvement Centre
CIS	Commonwealth of Independent States
CPI	Consumer Price Index
CWB	Canadian Wheat Board
DNA	Deoxyribonucleic acid
ERS	Economic Research Service of the United States Department of Agriculture
EU	European Union
FAO	Food and Agricultural Organization of the United Nations
FAS	Foreign Agricultural Service of the United States Department of Agriculture
FOB	Free On Board
FSANZ	Food Standards Australia New Zealand
GAIN	Global Agricultural Information Network, Foreign Agricultural Service of the United States Department of Agriculture
GAMS	General Algebraic Modeling System
GDD	growing degree days
GIS	Geographic Information System
GM	genetic modification
GTAP	Global Trade Analysis Project
HT	herbicide tolerance
IFPRI	International Food Policy Research Institute

IGC	International Grains Council
IPCC	Intergovernmental Panel on Climate Change
IP	intellectual property
IPRs	intellectual property rights
IR	insect resistance
ISAAA	International Service for the Acquisition of Agri-biotech Applications
KARI	Kenya Agricultural Research Institute
KNBS	Kenya National Bureau of Statistics
KSh	Kenyan Shilling
MAS	marker assisted selection
masl	meters above sea level
MMs	molecular markers
NARS	national agricultural research systems
NASS	National Agricultural Statistics Service of the United States Department of Agriculture
NBS	National Biosafety Committee
NOAA	National Oceanic and Atmospheric Administration of the United States Department of Commerce
NPV	Net Present Value
PDSI	Palmer Drought Severity Index
PBRs	plant breeder's rights
PNP	percent of normal precipitation
RATIN	Regional Agricultural Trade Intelligence Network of the Eastern Africa Grain Council
R&D	Research and Development
ROW	rest of the world
UN	United Nations
UPOV	International Union for the Protection of New Varieties of Plants
USAID	United States Agency for International Development
USDA	United States Department of Agriculture

WEMA	Water Efficient Maize for Africa
WTP	willingness to pay

CHAPTER 1. Introduction

> *"It is ... reasonable to examine the web of connections between genomics and agriculture and to enquire whether these connections could be strengthened in some way, perhaps by the addition of some vital 'missing link', so that the contribution from genomics can be made more effectively"*
> Reece and Haribabu, 2007 (p. 460)

1.1 Background

Humankind has strived to improve the quality of agricultural crops for thousands of years. In early history, people simply collected seeds for planting, choosing from the best and strongest plants and those with desirable characteristics. Later, conventional breeding techniques were developed to select varieties with particular traits of importance. In the last two decades of the 20th century the revolution of biological science, including rapid developments in genomics, gave new tools to plant breeders. Modern plant breeding has many advanced techniques to pursue development of new crop varieties with improved traits, such as higher yields, pest or disease resistance, resistance to abiotic stresses, and higher nutrition value. These may be especially important for ensuring food security of the world's growing population. In this research project, the economic welfare effects of two economically important modern complements to conventional plant breeding tools will be studied: genetic modification (GM), and marker assisted selection (MAS).

1.1.1 Conventional breeding in plants

The history of plant breeding has been traced back thousands of years to the beginning of domestication of wild plant species. Plant breeding involves deliberate generation of improved crop varieties, in which some desired characteristics (larger size, intensive color, shorter ripening time period, better taste, higher yield etc.) are present (McCouch, 2007). The economic importance of conventional plant breeding is that in the course of human history this enabled the transformation of wild plants with marginal usefulness into specialized crops in modern agriculture, which are widely cultivated and provide food for humankind (Manshardt, 2004).

Two important components of plant breeding are variation and selection (Murphy, 2007). Two individual plants are usually chosen by plant breeders for crossing. Since the genes of both individual plants will be present in the future generations, the best parent plants with the best characteristics of interest will be subjected to crossing. Choosing genetically close parents for crossing may restrict phenotypic variation in the progeny but facilitate expression of the specific desired traits. In contrast, choosing genetically different parents may produce larger variation and lead to an unexpected albeit positive outcome, since such crosses are usually the most productive (McCouch, 2007).

Overall, then, conventional plant breeding includes the following three steps: (a) establishing a population of parent plants with characteristics of interest, (b) selecting individual plants[1], in which these desired characteristics are expressed at higher levels, and (c) employing these selected plants for recombination to produce a new population to be used for subsequent improvement in future generations (Dreher et al., 2000). Along with biotechnology, conventional plant breeding is widely used. In fact, it is argued that genomics knowledge and technologies will measurably improve efficiency of conventional plant breeding, and not totally replace it (Reece and Haribabu, 2007).

[1] Selection is performed via field screening by plant breeders based on the visible differences in phenotypes of individual plants. Thus, here and thereafter under conventional breeding will be understood the process of traditional plant breeding, in which step two is performed via field screening.

1.1.2 Marker assisted selection in plants

Marker assisted selection is a breeding tool whereby molecular markers[2] (MMs) are used to identify gene(s) responsible for particular traits of interest in plants (or animals); conventional breeding is then applied to obtain varieties with the desired traits (see Ruane and Sonnino, 2007 for more details). Marker assisted selection is beneficial for plant breeding, since it increases the precision of breeding. For example, the desired trait can be selected from a single plant, or particular genes (not amenable to conventional plant breeding) can be maintained in the new generations without validation through additional tests (Koebner, 2004). In other words, MAS reduces the time and effort to achieve a particular variety improvement compared to conventional plant breeding. That, however, does not mean that MAS can replace conventional breeding. It complements conventional breeding and can be used as a tool.

MAS is used whenever there is a marker available for the trait of interest. Breeders can only select for so many traits at once and the number of markers that are available are increasing over time. When more markers become available they are used more and more. Right now probably every wheat breeder in Canada tests their lines for rust resistance markers, for example, because variety registration cannot be obtained without some level of rust resistance. They want to make sure they have some or all of the recognized markers for rust resistance before they go further with a line (Chris Barker, Genome Prairie, personal communication, April 29, 2010).

A high level of polymorphism[3] in plants is required for successful application of MAS tools in plant breeding. Potential benefits of MAS have been argued (Dreher et al., 2003; Morris et al., 2003). However, the uptake of the technology has only been widely observed in breeding maize (which has a highly polymorphic plant

[2] Molecular markers are segments of DNA on the chromosome that are associated with particular traits and situated near the genes of these particular traits (Ruane and Sonnino, 2007).

[3] Polymorphism is a presence of two or more different phenotypes in the same population of a species (Zaid et al., 2001).

genome) and rice (Koebner, 2004; McCouch, 2007). Less polymorphic crops (including wheat) involve higher costs to undertake MAS and appear to have lagged relative to maize. The discovery of appropriate MMs requires well-capitalized research institutes. However, this requirement may not be as major a constraint in the future with rapidly developing computer technologies and equipment that enable marker discovery and large-scale MAS application (Koebner, 2004). An important feature with the use of MAS is that by avoiding the use of transgenic methods, biosafety is less likely to be in question and the use of MAS is not controversial (Reece and Haribabu, 2007). The concern about the use of transgenic methods that may lead some buyers to avoid GM crops is not an issue with MAS tools. Marker assisted selection in crops is therefore becoming potentially more viable as an alternative to the use of GM as a way to improve crop varieties.

1.1.3 Genetic modification in plants

Genetic modification[4] or genetic engineering refers to the procedure of transgenesis that involves inserting/suppressing specific gene(s) in an organism via techniques of modern molecular biology (Zaid et al., 2001). The economic benefits of GM crops have been well documented (see section 2.2.1 for more details). Brookes and Barfoot (2006) assessed the overall impact of GM crops during the time period 1996-2005, including estimates of farm level benefits, and noted reduction of pesticide usage and reduction of adverse environmental impacts associated with these pesticides. In addition to their finding of substantial economic benefits at the farm level, they conclude that use of GM crops may have contributed to a 15% global reduction in pesticide use as well as a significant decrease in greenhouse gas emissions. However, there is consumer resistance to food with GM ingredients (Fernandez-Cornejo and Caswell, 2006). The levels of concern of scientists regarding the release of GM crops vary. Some scientists suggest that the environmental effects of GM crops are unpredictable, while other

[4] It is often noted that plant breeding per se involves genetic modification. However, in this thesis the term is used as it is commonly understood in society to refer to the use of transgenic methods, sometimes referred to as genetic engineering.

scientists believe that there is no risk associated with the release of GM crops (Kvakkestad et al., 2007). Thus, the issue of developing and consuming GM crops is still controversial.

1.2 Economic problem

There are a number of studies assessing economic impacts of existing GM crop varieties and proposed varieties which have not yet been commercialized. However, the impacts on the economic welfare of producers, consumers, and society from the development of new crop varieties by the use of conventional plant breeding and MAS tools relative to GM use, has not yet been studied.

GM technology is very controversial: there is resistance to GM food by some consumers, as well as trade restrictions on imports of GM food and feed by some countries. Although there have been numbers of studies on the economic benefits of GM herbicide-tolerant agricultural crops (employing both ex post and ex ante approaches), there is a considerable gap in the literature regarding the economic impact of developing crops tolerant to abiotic stress[5]. Very few studies on welfare implication assessments of GM drought-tolerant cereal crops have been published. However, with the potential for future climate change, crop traits such as drought (cold or saline) tolerance may be very important for modern agriculture.

To an even greater extent than in the developed world, developing countries are in need of better agricultural technologies to improve food security. Numbers of country-level case studies have assessed whether the adoption of different GM crops is beneficial for small scale producers and local economies. Many of these report the existence of economic benefits (see the literature review in sections 2.2.1 and 3.3.1). What is not known is the level of those benefits when technology transfer and local adaptation are performed through humanitarian licensing[6]. In reviewing the literature, no published studies that assess costs and benefits of transferring new improved crop varieties under humanitarian license were located.

[5] The typical sources of abiotic stress are drought, flood, strong winds, extreme temperatures, wildfires, and radiation.

[6] Humanitarian licensing is a part of IPR (Intellectual Property Rights) practice and is used for development purposes in order to provide access to certain technologies on a non-commercial basis (Louwaars et al., 2006).

The two essays of this dissertation are aimed at addressing the following questions: (a) whether different plant breeding tools in developing improved cereal crop varieties tolerant to abiotic stress (i.e. GM versus conventional breeding and MAS) would result in economic welfare gains compared to welfare gains of conventional wheat varieties; and (b) whether the transfer of improved cereal crop varieties under humanitarian license to low income countries is economically beneficial. It is hoped that this knowledge will contribute to a better understanding of the potential of these crop improvement tools, in terms of their cost effectiveness, feasibility and net benefits. The specific objectives and potential contribution of this study are discussed in the following sections.

1.3 Objectives and contribution of research

Given the ever improving technology and knowledge of plant breeding techniques, it is very likely that synergies of conventional breeding and biotechnology will persist into the future. However, with current agricultural practices, policies, economic and trade relations, and public perceptions, based on the economic problem specified earlier, the main objectives of the dissertation and its contribution to research are as follows.

Essay 1: Ex ante evaluation of the economic impact of genetic modification versus marker assisted selection (the case of drought tolerance in wheat)

The main objectives of this essay are:

1) To assess selected welfare effects, for consumers and producers of genetic modification versus marker-assisted selection and conventional breeding when these tools are used to develop an improved crop variety resistant to abiotic stress.
2) Based on a given specific case and given state of technology, to assess the relative merits or otherwise of the use of MAS techniques versus GM techniques to develop improved drought-tolerant wheat varieties.

The main contributions of this research are anticipated as:

1) This study is an empirical contribution to the existing economic literature on the little researched but very important case of drought tolerance in wheat.
2) This study addresses a considerable gap in the literature regarding the economic benefits of MAS tools in plant breeding.
3) This study is the first attempt to estimate welfare effects for an improved crop variety (a drought-tolerant wheat) developed by MAS tools in a trade-based model. These estimates will be compared with alternate situations in which the improved crop variety is developed by GM tools.
4) Most of the published works on the welfare implications of GM crops incorporate an outward shift of the supply curve to model improved

productivity of the GM crops. Few studies investigate the outcomes of an inward shift of the demand curve as a result of consumers' resistance to/non-acceptance of GM food. Consumer resistance to GM food is modeled in this paper. These give bases to compare estimates of economic welfare changes from new variety development that is based on MAS allied with conventional breeding.

Essay 2: Economic returns of transferring transgenic drought-tolerant maize technology to low income countries under humanitarian license (the case of Kenya)

The main objective of this essay is to assess benefits and costs of transferring transgenic maize varieties with improved drought tolerance under humanitarian license to low income countries.

Since most of technology transfer studies are case-based, this research is a contribution to the literature on case studies regarding adoption of improved agricultural crops in developing countries. In only a few studies, for a limited number of country cases, has the economic analysis of drought tolerance in crops been investigated. This research looks at the economic problem of introducing cereal crop varieties resistant to abiotic stress from a different perspective than specified earlier. This paper employs a developing economy setting, humanitarian licensing of biotechnology transferred to smallholders in this developing economy, and a closed economy assumption (the latter assumption is opposite to the world trade model setting of the first paper).

The two essays, considered together, provide a broader view of the same problem and should contribute to better understanding of the array of possible economic outcomes from adoption of crops resistant to abiotic stress across countries, levels of economic development and different modeling approaches.

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CHAPTER 2. Ex ante evaluation of the economic impact of genetic modification versus marker assisted selection (the case of drought tolerance in wheat)

2.1 Background and statement of the problem

Since the advent of the first generation of genetically modified (GM) crops, scientists have been able to improve traits of crops (e.g. pest and herbicide resistance) in a relatively shorter time than when using conventional breeding. However, GM issues debated up to now include: (a) are these crops safe for human consumption? (b) do they have adverse health impacts in the long term? (c) what impact do they have on biodiversity of ecosystems? This debate involves biotechnology companies, scientists, policy makers, NGOs and other stakeholders worldwide. As a result there are many scientific studies on the impacts of genetically modified organisms in different areas of research. Economists in particular looked at consumers' attitudes towards and acceptance of GM food by consumers (Bernard et al., 2005; Deodhar et al., 2008; Hu et al., 2004; Kaneko and Chern, 2003; Novoselova et al., 2005), GM risk perceptions (e.g., Kimenju and De Groote, 2008), costs and benefits of adopting GM crop varieties at a farm level (e.g., Alston et al., 2002; Bond et al., 2003), and welfare implications of adopting and/or trading GM crop varieties on the national and international levels (e.g., Berwald et al., 2006; Frisvold et al., 2003; Furtan et al., 2005; Mayer and Furtan, 1999). Most studies of welfare effects of adopting and trading GM crop varieties have reported substantial economic benefits from adoption of GM crops. An exception to this conclusion is Furtan et al. 2005, where producers lose economic surplus (or economic welfare)[7] (see section 2.2.2 for more details).

[7] Economic surplus (also known as economic welfare) refers to consumer surplus and producer surplus. Consumer surplus is the monetary gain to consumers that are able to buy units of product at a lower price than the maximum price they would be willing to pay for the last unit of that product consumed. Producer surplus is the monetary gain of producers that sell for a higher price than the lowest price they would be willing to sell successive units of their product (Just et al., 2004).

Ex ante welfare studies of GM crop adoption have focused mostly on biotic stress (e.g. pests, diseases, weeds) resistance and assume that the new GM technology is already introduced. Ex post studies have also been undertaken in which the welfare implications of the anticipated (or actual) adoption of a new variety are assessed. A base case in these studies has typically been the agricultural crop variety without any improvements in its resistance. However, it is not known how welfare outcomes of GM crop varieties would differ from the situation in which varietal improvements are obtained from marker assisted selection (MAS) plant breeding methods. Also, in the existing literature, few if any studies have been located that consider abiotic stress tolerance in crop varieties and the potential of this to produce welfare gains within those countries that adopt such varieties.

The identification of welfare impacts of agricultural crops that have improved tolerance to abiotic stress requires specification of a particular crop and trait. A specific agricultural crop, wheat, and a specific trait to be improved, drought tolerance, are chosen in this analysis.

There are some important reasons for drought tolerance in wheat to be investigated. First, wheat is one of the major staple crops worldwide, especially in regions with temperate climates. In 2008 wheat produced the second largest tonnage of cereal in the world (690 million tonnes) after maize (823 million tonnes) (FAO, 2011). Canada belongs to the ten largest wheat producing countries in terms of both value and quantity produced. Also, wheat is the largest cereal crop (by volume) produced domestically in Canada (Statistics Canada, 2012; FAO, 2011). Second, wheat is an important food in many developing countries where high percentages of daily calories intake come from consumption of wheat (Dubin and Brennan, 2009). Third, as a response to increasing demand for food, researchers are working on improvement of wheat varieties for desired traits such as cold tolerance (Båga et al., 2006), dough quality (Eagles et al., 2001), fusarium resistance, drought tolerance (Wilson et al., 2008; Wilson et al., 2003b), and rust resistance (CIMMYT, 2009). Among such traits, drought tolerance has important implications. Precipitation cannot be controlled and with predictions of continued climate change (IPCC, 2007), many agricultural areas may be at increased risk of receiving less or more varied amounts of precipitation. Production losses of agricultural crops due to drought are predicted to occur in different (especially rain-fed) areas of the world (Kostandini et al., 2009). Sparse rain conditions result not only in the loss of yield, but also in decreased uptake of nitrogen by the root system of plants, negatively affecting the nutritional value of the kernel (Tuberosa and Salvi, 2004). Thus, wheat (a strategic crop), and drought tolerance (a very important trait), are very appropriate and timely as focal issues of this case study.

Another reason to focus on drought tolerance in wheat is the direction of current research. In 2009 the company Monsanto announced its intention to develop drought-tolerant and fertilizer-efficient wheat varieties. This announcement by the company indicated that both biotechnology and marker-assisted selection would be used as tools to achieve these new varieties, within a ten- to fifteen-year time frame (Monsanto, 2012). Although genetically modified Roundup Ready® wheat, developed in North America by Monsanto, has not been commercialized[8], it is possible to speculate that this situation might change in the future.

An alternative tool of crop variety improvement, as compared to genetic modification, is marker assisted selection (MAS). The current rapid development of computer-based technologies for examining and comparing genomic information opens up more possibilities for the use of genomics in plant breeding, as processing information and performing different tasks becomes easier and cheaper. Thus, in recent years, MAS is becoming a popular tool that combines genomics knowledge and conventional plant breeding.

Improved varieties for some crops based on the use of molecular markers have been developed (Cao et al., 2003; Jena and Mackill, 2008; Neeraja et al., 2007),

[8] Monsanto stated a commitment to release Roundup-Ready ® wheat either on the whole North American continent, or not at all. In 2004 the Canadian Wheat Board (CWB) and others opposed the release of this wheat and the technology was shelved at that time (Berwald et al., 2006).

introduced, and are in commercial production. Examples are Arize® Dhani rice (India), and Angke and Conde cultivars of rice (Indonesia) which are resistant to bacterial leaf blight. However, the existing and potential economic benefits of applying MAS in developing these varieties have not been studied. The economic implications of MAS tools used for crop variety improvement deserve more attention.

Unlike the case of GM crops, the welfare effects of new varieties of crops developed by MAS tools have not been studied by economists, either for tolerance to herbicides/pesticides or for tolerance to abiotic stresses. It is not known whether or how welfare effects from development and adoption of improved crop varieties that have been developed by MAS would differ from those developed by GM. Comparison of the application of GM versus MAS tools, which are two major innovative techniques of crop improvement to date, is increasingly important. Efficient crop improvement techniques are especially needed due to fast-growing demand for food (IFPRI, 2008), falling land fertility, slowing yield growth and changing climate (Brown, 2004). The results of this study will help to provide information on those circumstances in which one or other of the two techniques may be more beneficial in terms of trade welfare.

2.2 Literature review

The objective of this literature review is:

- to investigate the types of studies that have addressed the welfare effects of the introduction of GM crops and the nature of benefits and costs that have been identified and/or are projected from this;
- to explore economic studies of GM wheat and the approaches these studies used;
- to investigate consumer acceptance of GM wheat products;
- to identify the status of application of MAS in wheat breeding and to locate studies on economics of MAS;
- to locate research on drought tolerance in wheat;
- to learn about the methods applied in various research studies as a means to identify methods that may suit this study.

2.2.1 Adoption of improved crops developed by GM tools

2.2.1.1 Ex post framework studies

Numbers of ex post studies on adoption of different GM crops in different countries concluded that these crops were beneficial to farmers. For example, Chinese farmers who adopted *Bt*[9] cotton saved 20-33% of their total variable costs while the yield output per hectare did not change (Pray et al., 2001). Based on a survey of farmers who adopted Roundup Ready® soybean in Argentina, total variable cost savings amounted to $21/ha (Qaim and Traxler, 2005). Qaim (2005) studied benefits of GM crops in developing countries and concluded that pesticide cost savings from adoption of *Bt* cotton amounted to 33-77% of pesticide expenditures on conventional cotton. Yorobe Jr. and Quicoy (2006) reported decreases of expenditures on insecticides by farmers growing *Bt* corn in the Philippines.

[9] *Bt* (*Bacillus thuringiensis*) is a soil bacterium. It is used in developing genetically engineered plants resistant to insects. *Bacillus thuringiensis* produces toxin causing death in pests that eat any part of the plant.

GM crop varieties with resistance to pests and diseases are not intended to increase yield, even though the distribution of yield may change due to decreased crop losses. In fact yields might even decrease, as during the early years of adoption when crop varieties that were used as recipients of pest and disease tolerance genes were not high-yielding varieties. In the United States, for example, the belief of higher potential yields from improved GM crop varieties was created by farmers (Fernandez-Cornejo and Caswell, 2006). However, some studies did report substantial yield advantages due to decreases in crop losses caused by pests and diseases (Qaim, 2005; Yorobe Jr. and Quicoy, 2006). Thirtle et al. (2003) conducted a survey of farmers who had adopted *Bt* cotton in South Africa in Makhathini Flats, one and two years after adoption. Although the adopting farmers did not report obtaining higher yields from *Bt* cotton (compared to conventional cotton) in the first season, in which there were favourable weather conditions, in the subsequent season with bad weather, the yield losses of the *Bt* cotton adopters were smaller than the yield losses of non-adopters.

Small-scale farmers benefited more than large scale farmers from adoption of GM crops in the regions of China, South Africa, and Argentina where studies were conducted (Gouse et al., 2004; Pray et al., 2001; Qaim and Traxler, 2005). Some of these studies also conclude that much of the benefits from adopting GM crop varieties went to farmers. As shown by Pray et al. (2001), 83-87% of the benefits from adoption of *Bt* cotton varieties went to farmers, while the rest went to biotechnology companies and seed producers. Gouse et al. (2004) concluded that 45-79% of the benefits from adoption of *Bt* cotton went to farmers, 20-52% went to biotechnology companies and 1-3% went to seed producers. There is evidence of positive environmental and health impacts from adoption of GM crops as a result of fewer applications of pesticides and herbicides (Pray et al., 2001; Qaim and Traxler, 2005), and conversion of farm practice from conventional to conservation tillage (Fernandez-Cornejo and Caswell, 2006). Most of these studies look at the producer side of the issue and consumer welfare is not considered.

There is consumer resistance to consuming food produced from GM plants (Huffman, 2003; Kaneko and Chern, 2003; Schmitz, 2004). Governments of some countries (e.g., EU, Japan, South Korea) have adopted policies that placed trade restrictions on GM food and crops (Sheldon, 2002). An incident in which imports of flaxseed from Canada were contaminated with a withdrawn GM variety (Triffid)[10] in September 2009 shows that there is a risk that GM seeds can unintentionally enter the crop distribution system. A similar incident took place in 2000 in the USA, when traces of Starlink™ corn[11], a variety intended for animal consumption only, were found in human food products (Schmitz, 2004; Schmitz et al., 2005). As a result of these types of problems, exporters as well as producers can bear costs of stricter trade regulations or lost markets.

2.2.1.2 Ex ante framework studies

Ex ante studies on potential adoption of different GM crops have usually investigated the expected economic impacts of crop varieties with some desired trait. Usually desired traits are either: (a) planned to be developed in the future, (b) currently at the development stage, or (c) developed already, but the crop variety has yet not been commercially released into the market.

Alston et al. (2002) assessed per acre farm-level benefits from adoption of rootworm resistant corn in the United States and aggregated these to the national level. The authors assumed the technology was available and adopted in all areas subject to chemical treatment against corn rootworm in 2000. Their results suggest the downstream benefits (to farmers) would have been $231 million, whereas upstream benefits (to seed companies and developers of technology) would have been $171 million that year. Bond et al. (2003) evaluated the potential

[10] FP967 flax ('Triffid') is a GM variety of flax tolerant to soil residues of triasulfuron and metsulfuron-methyl. It was developed in Canada and initially authorized for use both in Canada and the USA in 1990's. Yet, since the seed could not be exported to the European market, and at the request of the Canadian flax associations, the variety was de-registered in 2001 (GM Contamination Register, 2010).

[11] Starlink™ corn is a variety of *Bt* (*Bacillus thuringiensis*) corn which is resistant to insect pests.

profitability of adopting herbicide tolerant (HT) rice in California. To differentiate between producers these authors introduced three representative (low, medium, and high) cost scenarios of rice production budgets. These authors concluded that high-cost growers were most likely to benefit from adopting HT rice, whereas in the low and medium production cost scenarios, the benefits to growers would be small or insignificant.

Due to prohibitions on growing most GM crops in the countries of the EU, studies that have assessed GM food impacts in the EU have tended to apply ex ante frameworks to explore the potential economic benefits/costs if selected GM crops were to be grown commercially. Flannery et al. (2004) assessed costs and benefits of the hypothetical introduction of herbicide tolerant or disease resistant GM wheat, barley, sugar beet and potato crops in Ireland. All of the GM crops were predicted to economically outperform their conventional counterparts. However, the magnitude of anticipated benefits differed depending on the crop as well as on weed concentration and/or disease pressure. Potential annual welfare gains from introduction of several different GM crops (*Bt* maize, HT maize, HT sugar beet, HT oilseed rape) in the Czech Republic and Hungary were also estimated for the year 2005 by Demont et al. (2009). Under assumptions that the technologies were available in 2005 and the farmers could choose whether or not to adopt these, a total aggregate annual benefit of €82 million for both countries was estimated, of which €60 million (73%) would have gone to farmers and €22 million (27%) to the developer of technologies and seed companies. Dillen et al. (2009) built a partial equilibrium world trade model (based on EUWABSIM[12]) for HT sugar for the period of 1996-2014. The three aggregate markets of this model were: EU market (disaggregated further by countries to capture heterogeneity of sugar suppliers); the rest of the world (ROW) market for sugar beets; and the ROW market for sugar cane. The model was based on the following major assumptions: non-spatial (i.e. transportation costs are assumed to be constant); supply functions are non-linear with constant elasticities (NLCE) calibrated to real data of 1996-

[12] European Union Welfare effects of Agricultural Biotechnology SIMulation model

2006; and Intellectual Property Rights (IPRs) protect research and generate monopoly rents. The global benefits to society in this period are estimated to be €15.4 billion, of which 29% would accrue to EU farmers, 31% to the ROW producers and consumers, and 39% to seed companies. Except for Dillen et al. (2009) none of these ex ante studies address or assess the existence of consumer welfare changes that might result from the introduction of different GM crop technologies. This omission is a potential literature gap.

2.2.2 GM wheat

One issue relating to improved crops that has been the subject of economic study concerns the timing of approval and commercialization of herbicide tolerant (Roundup Ready®) GM wheat, developed by Monsanto, and optimal strategies to do this. Furtan et al. (2003) used real options theory to investigate a potential optimal time to license GM wheat in Canada. These authors concluded that Canadian producers will benefit from waiting to license this new technology, since without a reliable segregation system in place, wheat prices for both non-GM and GM wheat producers would be reduced. Furtan et al. (2005) argued that lack of information, resulting in consumer resistance to GM crops, would reduce producer welfare in a country where GM wheat was adopted. Based on the results of a wheat trade model with a differentiated product and a payoff matrix of possible approval outcomes, it was argued that an optimal strategy would be for the U.S. to approve GM wheat, but for Canada not to approve this. This result stems from there being no first-mover advantage to license GM wheat in the U.S. or in Canada. Due to a lack of an effective segregation system, all GM wheat in the producing country would be considered as GM. Non-GM importing markets would be closed to the exporting country which decided to license GM wheat.

In contrast, Huso and Wilson (2006) predicted changes in the prices of competing crop production technologies (GM versus conventional) in North Dakota, U.S. These authors argued that had Roundup Ready® GM wheat been introduced into that market, the prices of pesticides used on conventional wheat varieties would have decreased due to higher competition among herbicide producers for their sales to farmers using conventional wheat varieties. It is argued that this would result in increased economic surplus for growers of both GM and non-GM wheats. However, Huso and Wilson (2006) suggested that because of lower costs to use conventional technologies, the adoption rate overall of GM wheat varieties might not be as high as assumed in some studies. These authors estimated that the increase in economic surplus of conventional variety growers after introduction of GM wheat would be $13 to $20 million for North Dakota annually.

Other studies have estimated welfare implications of commercializing Roundup Ready® GM wheat. Johnson et al. (2005) developed a GM wheat trade model for the U.S., incorporating market segmentation (consumers that accept biotech wheat versus consumers that do not accept biotech wheat), cost savings for GM wheat producers, and segregation costs. This analysis of a hypothetical U.S. wheat market suggested that approval of GM wheat would lead to a relatively small annual loss of $27–28 million in total economic welfare. Berwald et al. (2006) extended this analysis by introducing vertical product differentiation (GM and non-GM wheat), into an aggregate world wheat trade model, incorporating levels of consumer aversion for GM crops between and within three regions: A, B, and C. Region A (Canada, the United States, and Argentina) is designated as the region of production of GM crops and the exporter of wheat; region B (the EU, Japan, and South Korea) is characterized as being where the majority of consumers prefer non-GM crops; and region C (Algeria, Brazil, China, Egypt, India, Iran, Morocco, and Russia) represents importers of wheat where the majority of consumers is assumed to be less averse to GM crops. This model predicted positive total economic surplus ranging from $2,158 to $3,596 million/year in each proposed scenario of GM wheat adoption. The scenarios were as follows: 1) both Canada and the U.S. adopt GM wheat; 2) only the U.S. adopts GM wheat; and 3) neither Canada nor the U.S. adopts GM wheat. In each of these three scenarios Argentina and region C adopt GM wheat, whereas region

B does not adopt this. The distribution of welfare gains varied by region and scenario.

A partial equilibrium world trade model for assessing welfare implications of Roundup Ready® wheat was also developed by Wilson et al. (2008). This is based on different assumptions on cost savings, yield gains, segregation costs, and markets accepting non-GM wheat than those used by Johnson et al. (2005) and Berwald et al. (2006). In the scenarios considered to be most likely by Wilson et al. (2008), an annual increase in producer and consumer total welfare of $301 and $252 million respectively was suggested, compared to the base case in 2003.

In the GM wheat trade models noted above, consumer welfare issues were addressed to a greater extent than in the noted ex ante welfare studies of other GM crops. However, all the studies on GM wheat consider only the case of Roundup Ready® wheat. Given the importance of drought-tolerant cereal crops and lack of analysis of this, welfare studies on Roundup Ready® wheat can provide a useful guide to methodology that can be considered for the present study (see section 2.3.1 for more details).

2.2.3 Consumer acceptance of GM wheat and GM wheat derived products

Issues discussed in the literature regarding consumers' acceptance of GM food products other than wheat are similar to the issues considered for wheat and wheat derived products (White and Veeman, 2007). However, there are some studies that specifically discuss or focus on GM wheat products. Wilson et al. (2003b) discuss the American Bakers Association's 2002 survey that concerns consumers' preferences regarding GM wheat and grain products. Among American respondents to this survey, three main groups were identified: 50% *loyalists*, who would buy products containing GM wheat anyway; 40% *potential switchers*, who would potentially switch to non-GM bakery products or would buy less; and 5% *market exit*, who had already stopped or would stop buying bakery products containing wheat. Another finding of this survey shows quite low familiarity of

American respondents (about 16%) with GM wheat. The acceptance of GM wheat tended to be higher among those respondents who are familiar with this.

White and Veeman (2007) summarized studies with a socio-economic focus on GM wheat. Most of these evaluate the producer side of the issue. Based on the existing literature (mainly Canadian) directed to consumers' perceptions about GM wheat products, the authors conclude that: (a) there is a considerable diversity and heterogeneity of consumers' attitudes regarding GM wheat; (b) the majority of consumers neither strongly oppose nor strongly favour GM wheat products, and some consumers are indifferent; (c) aversion to GM wheat components in food products is reduced if it is clear that there are some sound positive environmental or health benefits associated with consumption; (d) the type of information about GM food products that is available to consumers based on voluntary access impacts product choices; and (e) consumer willingness to pay varies considerably; overall an average discount of 50 Canadian cents per loaf of bread was estimated for bread with identified GM ingredients.

Earlier opinions of key Asian importers of the U.S. wheat regarding potential introduction of Roundup Ready® GM wheat on the market are summarized in Wilson et al. (2003b) based on Gillam (2002):

> "*Representatives for Chinese, Korean, and Japanese wheat buyers surveyed said they would not buy or use RRW. Eighty-two percent of buyers from Taiwan and 78% of buyers from South Asia said they would reject the wheat. If the country had regulatory approval of the trait, buyers from each country (with the exception of Japan) indicated they would accept some GM wheat with a tolerance. ...The majority of the responses indicated there was a future for biotechnology in wheat if there were some consumer benefit that could be marketed*" [p. 103].

The ten “at risk” importers of Canadian wheat that would not accept GM wheat are Algeria, Brazil, Iran, Italy, Japan, Malaysia, Morocco, South Korea, United Kingdom and Venezuela according to an earlier opinion of Canadian Wheat Board. These countries comprise a third of all Canadian wheat exports (Kuntz, 2001).

2.2.4 Current status of research on MAS tools

According to the reviewed literature, there are not as yet any studies assessing welfare implications or farm-level impacts from adoption of crop varieties developed by MAS. Hence, the present paper addresses a significant gap in the literature. Due to a lack of studies on the economics of MAS, literature on general trends in MAS will be overviewed. The objective of this literature overview is to investigate how MAS developed and whether there are valid reasons to conclude that this technique will be used widely in the future.

The majority of the articles on MAS techniques originate from the science literature (agronomy, plant breeding and genetics, molecular biology etc.) and report on discovery of molecular markers (MMs) for different crop traits and their validation. Bernardo (2008) argued that in the past 20 years, discovery of MMs in crop traits had become quite a routine process, as more and more molecular markers were identified and the cost of discovery of these decreased. At the same time, the use of MMs in variety selection process had been difficult. Relatively few articles have presented research on development of new crop varieties by applying MAS tools. This is due to the fact that most of the important agronomic traits of agricultural crops are complex (Reece and Haribabu, 2007). However, it is also argued that in recent years the uptake of MAS is no longer limited by the lack of valid markers, which was a limitation in past research (Koebner, 2004). Of most importance, there are tradeoffs between time and cost and these are important factors in the choice of conventional plant breeding (cheaper) versus use of MAS in plant breeding (faster) (Morris et al., 2003). However, it is understood that costs of MMs have declined over time.

2.2.5 Applying MAS tools in plant breeding of wheat

Even though the use of MAS in wheat has a 20-year history, the application of MAS has been slow so far (Koebner and Summers, 2007). Unlike maize, for example, wheat is an inbreeding[13] (self-pollinated) species, and new varieties of wheat are established as pure breeding lines (Koebner and Summers, 2003). This can make it difficult for plant breeders to protect their intellectual property innovations, since the seed collected from such pure lines can be used for planting in the following year. Seed volume sales are smaller and breeder margins are lower relative to crops such as maize (Koebner and Summers, 2003). For this reason private capital investments in wheat breeding programs (which historically have mostly been funded by public organizations) are not available to such an extent as for maize breeding programs. Reductions in the cost of MAS tool are expected to determine whether MAS in wheat is likely to be widely applied (Koebner, 2004; Koebner and Summers, 2007).

Koebner and Summers (2003) note that the only two examples of widespread application of MAS tools in wheat breeding up to 2003 had been selection for particular bread-making qualities and resistance to stem disease eyespot. A lack of suitable markers was seen as a limiting factor to more widespread application of MAS in wheat. More recent targets in MAS research are fusarium head blight resistance in winter wheat (by Monsanto), rust diseases, and resistance to a virus transmitted by aphids.

Although MAS tools are usually more expensive than traditional tools of conventional breeding, Brennan and Martin (2007) argued that markers enable some parts of the selection process to be conducted at a fraction of the cost of traditional phenotypic evaluation[14]. The resources saved in such a manner could

[13] Inbreeding species are the species that in the process of domestication became inbred (i.e. such species reproduce from parents which are genetically related to each other).

[14] Phenotypic evaluation is selection of the lines based on the direct measurements (or visual identification) of the desired traits in the field or laboratory.

be reinvested and consequently wheat breeding might exhibit higher gains from breeding and higher rates of return. Koebner and Summers (2007) argued that since economies of scale and discovery of more and better markers decrease per unit cost of MAS, its application in wheat breeding will grow.

2.2.6 Wheat drought tolerance research

Drought tolerance (DT) of different crops is being researched extensively (e.g., Gosal et al., 2009; Badu-Apraku and Yallou, 2009; Banziger et al., 2006; Sabaghpour et al., 2006; Tuinstra et al., 1996). Wheat has a very complex genome compared to other crops such as maize and rice. Therefore wheat genetic research has more technical barriers and is slower in general. Fleury et al. (2010) argues that recent advances of breeding for drought tolerance in wheat by means of both conventional breeding as well as modern molecular breeding techniques have been quite slow and that there is a need to rethink approaches to achieve better results. Gosal et al. (2009) summarize research on drought tolerance of different crops and state that transgenic varieties of DT wheat are still at the stage of lab experiments or confined field trials (such as described in Abebe et al., 2003; Pellegrineschi et al., 2004; Sivamani et al., 2000). Scientists are also continuing to discover more molecular markers associated with drought tolerance of wheat.

There are some examples of positive developments in the area of wheat drought-tolerant research (e.g., Bahieldin et al., 2005; BioSicherheit, 2008; Monsanto, 2012; TransGEN, 2011). Scientists from the Agricultural Genetic Engineering Research Institute (AGERI) in Cairo, Egypt, together with Monsanto, have been working on developing GM DT wheat and their selections had been in field trials for a couple of growing seasons by 2005 (Bahieldin et al., 2005; Thomson, 2004). The breeding programs of CGIAR’s (Consultative Group on International Agricultural Research) have made advances in developing drought tolerant crops, including durum wheat. At least to the earlier part of the last decade, these were being achieved by applying slower paced conventional breeding methods (CGIAR, 2003).

2.3 Methods and data

2.3.1 Base case simulation model of wheat trade

To estimate welfare effects from introducing drought-tolerant wheat developed by MAS/conventional breeding[15] or GM tools, a non-spatial partial equilibrium trade model of world wheat trade is developed. A trade model is chosen since wheat is extensively traded worldwide. For example, changes in the local wheat markets of major wheat exporting nations may have considerable implications in the world wheat market. Most of the reviewed literature on welfare implications of cereal crops employs trade models as a standard approach. A partial equilibrium approach to trade models is proposed since only one agricultural commodity, wheat, is of interest in this study. A non-spatial setting is proposed since distances between countries are not important in terms of their implications.

A particular wheat importing country has a number of demand equations, equal to the number of exporters, from which an importer buys wheat. The exporting countries in the proposed model include: United States, Canada, EU-27[16], Australia, Argentina, and Others (an aggregated exporter). Importing countries in the model are Egypt, EU-27, Brazil, Algeria, Japan, Indonesia, South Korea and the ROW (rest of the world). These countries are the largest commercial exporters and importers of wheat respectively.

Each exporting country is assumed to produce wheat just for export and does not import any wheat. Likewise, each importing country is assumed to import wheat and not to produce any wheat for export. The exception is the EU, which is seen as both an exporter and an importer of wheat. Each importing country has a

[15] MAS/conventional breeding is denoted thereafter as MAS or MAS breeding to shorten the expression. MAS/conventional breeding means that breeding is still conducted via traditional breeding (i.e. non-GM) methods, but using markers as a modern technology that facilitates the process of conventional breeding.

[16] The European Union comprises the following 27 Member States: Austria, Belgium, Bulgaria, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and the United Kingdom.

separate demand equation for wheat that comes from a specific exporting country. Thus, 48 equations in total (6 exporters by 8 importers) are required.

Table 2.1 Notations for base case wheat trade model

Subscript/ superscript	Description	Variable	Description
i	wheat exporting country	S_i	Quantity supplied by exporting country i, metric tonnes
j	wheat importing country	D_{ij}	Quantity demanded by importing country j from exporting country i, metric tonnes
k	wheat exporting country not equal to i (for notation purposes)	$P(S)_i$ $P(S)_k$	Free on Board (FOB) export price, $US per metric tonne
N	total number of exporting countries	F_{ij} F_{kj}	ocean freight rates from exporting country i (k) to importing country j, $US per metric tonne
M	total number of importing countries	P_i	Export supply price in exporting country i, $US per metric tonne (same as $P(S)_i$, used for notation purposes, see formula A.1c)
0	zero superscript, denotes baseline value obtained from the actual data	P_{ij}	Import demand price in importing country j from exporting country i, $US per metric tonne
		s_{ij} s_{kj}	value share of wheat in the importing country j from the exporter i (k)

Parameter	Description	Parameter	Description
a	intercept of the demand equation	η_{ij}	own-price elasticity of wheat demand in the importing country j from the exporter i (i.e., with respect to P_{ij})
b	slope coefficient of the demand equation	η_{kj}	cross-price elasticity of wheat demand in the importing country j (i.e., with respect to P_{kj})
c	intercept of the supply equation	ε	elasticity of wheat supply
d	slope coefficient of the supply equation	σ_j	elasticity of substitution between suppliers of wheat in the importing country j
		η_j	overall price elasticity of wheat demand in the importing country j

Following Rude et al. (2008), who employ partial equilibrium model to wheat trade, the base case trade model is specified by the set of equations A.1a to A.1d where:

- equation A.1a is demand for wheat from exporter *i* by importer *j* (see table 2.1 for detailed notations of the model);
- equation A.1b indicates the export supply of wheat from exporter *i*;
- equation A.1c is a relationship between export supply and import demand prices;
- equation A.1d is a market clearing condition whereby the sum of demands of wheat by *M* countries is equal to the supply of wheat from the exporter.

Supply[17] of each exporting country is assumed to be a function of own price, i.e. the price in that country only.

$$D_{ij} = a_{ij} + b_{ij}\left(P(S)_i + F_{ij}\right) + \sum_{k\neq i} b_{kj}\left(P(S)_k + F_{kj}\right), \forall i, j, k \quad \text{(A.1a)}$$

$$S_i = c_i + d_i P(S)_i \quad \text{(A.1b)}$$

$$P_i = P_{ij}, \text{ where } P(S)_i = P_i \text{ and } P_{ij} = P(S)_i + F_{ij} \quad \text{(A.1c)}$$

$$\sum_{j=1}^{M} D_{ij} \equiv S_i \quad \text{(A.1d)}$$

where $\sum_{k\neq i}$ indicates summation over all *k*, where *k*=1, 2,..., *i*-1, *i*+1,..., *N*.

To calibrate the set of equations A.1a to A.1d, the steps described below are performed. The intercepts a_{ij} are obtained by subtracting the sum of the product of slope coefficients and initial base prices in each demand equation from initial base quantities demanded:

$$a_{ij} = D_{ij}^0 - b_{ij}\left(P(S)_i^0 + F_{ij}\right) - \sum_{k\neq i} b_{kj}\left(P(S)_k^0 + F_{kj}\right), \forall i, j, k \quad \text{(A.2a)}$$

The intercepts c_i are obtained by subtracting the product of slope coefficients and initial base prices in each supply equation from initial base quantities supplied:

$$c_i = S_i^0 - d_i P(S)_i^0 \quad \text{(A.2b)}$$

The slope coefficients of demand and supply equations (b_{ij}, b_{kj} and d_i respectively) in equations A.1a and A.1b) are obtained by calibration from the equations of own-price demand elasticity (η_{ij}), cross-price demand elasticity (η_{kj}), and supply elasticity (ε_i):

$$\eta_{ij} = \frac{\partial D_{ij}^0}{\partial P_{ij}^0} \times \frac{P_{ij}^0}{D_{ij}^0} \quad \text{(A.3a)}$$

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[17] It should be noted that S_i in our model is essentially an excess supply of each wheat exporting country (i.e., the sum of the demands from all individual importing countries).

$$\eta_{kj} = \frac{\partial D_{ij}^0}{\partial P_{kj}^0} \times \frac{P_{kj}^0}{D_{ij}^0} \quad \text{(A.3b)}$$

$$\varepsilon_i = \frac{\partial S_i^0}{\partial P_i^0} \times \frac{P_i^0}{S_i^0} \quad \text{(A.3c)}$$

From equations A.3a to A.3c the expressions to calculate slope coefficients are obtained in the following way:

$$\frac{\partial D_{ij}^0}{\partial P_{ij}^0} = b_{ij} = \eta_{ij} \frac{D_{ij}^0}{P_{ij}^0} \quad \text{(A.4a)}$$

$$\frac{\partial D_{ij}^0}{\partial P_{kj}^0} = b_{kj} = \eta_{kj} \frac{D_{ij}^0}{P_{kj}^0} \quad \text{(A.4b)}$$

$$\frac{\partial S_i^0}{\partial P_i^0} = d_i = \varepsilon_i \frac{S_i^0}{P_i^0}. \quad \text{(A.4c)}$$

In order to differentiate wheat trade by country of origin, own-price and cross-price demand elasticities (η_{ij} and η_{kj}) are calibrated as described in Armington's (1969) mathematical appendix (equations 25 and 26):

$$\eta_{ij} = -[(1 - s_{ij})\sigma_j + s_{ij}\eta_j] \quad \text{(A.5a)}$$

$$\eta_{kj} = s_{kj}(\sigma_j - \eta_j) \quad \text{(A.5b)}$$

The detailed notations are as provided in table 2.1. The strength of the Armington's approach is that this allows estimating own and cross price elasticities of demand in each importing country with the minimum data of market shares of wheat in each importing country (s_{ij}, s_{kj}) elasticities of substitution (σ_j), and overall demand elasticities (η_j).

The base case model is calibrated to data on actual wheat trade in 2006/2007 and solved in Microsoft's Excel Premium Solver. Data on wheat traded in later years are available, however, due to a sharp spike of wheat prices in 2008-2009 as a consequence of economic crises, the use of these data could lead to biased results.

2.3.2 Data for the base case model

Wheat trade flows (i.e. export and import quantities in metric tonnes) and wheat yields (in tonnes per hectare) for 2006/07 (see tables A.1 and A.2 of appendix A) are compiled from the datasets of the Foreign Agricultural Service (FAS) of the

United States Department of Agriculture (USDA) (FAS, 2010) and the World Grain Statistics 2008 and 2009 of the International Grains Council (IGC) (IGC, 2011). Durum wheat quantities are subtracted from total wheat quantities and net wheat trade flows are used to calibrate the base case wheat trade model. Durum wheat possesses different characteristics as compared to common wheat. It is basically a different species, used mainly for pasta production, and is, therefore, excluded from the analysis.

Wheat export FOB prices are obtained from World Grain Statistics 2009 of the IGC (IGC, 2011). Annual averages are calculated for each exporting country/port for the year 2006/07 (see table A.1 of appendix A) for the following types of wheat:

1) Argentina: Trigo Pan wheat (Up River);
2) Australia: ASW (Australian Standard White) wheat (Eastern States);
3) Canada: CWRS (Canada Western Red Spring) wheat (St. Lawrence);
4) EU: France standard grade wheat (Rouen)
5) USA: HRW (Hard Red Winter) and DNS (Dark Northern Spring) wheat (Gulf) – a simple average price was calculated for these two types of wheat;
6) Other: the US wheat price was used.

Ocean freight rates for 2006/2007 (see table A.2 of appendix A) are obtained from World Grain Statistics 2008 and 2009 from the IGC (IGC, 2011).

Various elasticity estimates (see table A.3 of appendix A) are taken from Haley (1995). The nature of these is:

- Overall price elasticities of wheat demand in each importing country. Values for all importing countries except Algeria are available. For Algeria "Other North Africa" elasticity is used.
- Elasticities of substitution between suppliers of wheat in the importing country. Values for all importing countries except Algeria are available. For Algeria "Other North Africa" elasticity is used.

- Elasticities of supply. Values for all exporting countries except Other (which is the aggregate wheat exporter in the model) are available. The USA elasticity of supply estimate is used for the aggregate exporter.

Haley (1995), despite being a dated source, provides a good snapshot of elasticities of substitution across many wheat importing countries. Instead of obtaining these elasticities from different studies, the choice of a single study has the advantage of obtaining estimates from a source that employs the same methodology to estimate elasticities for a broad range of countries.

Calibrated intercepts and slopes for supply and demand equations for the base case trade model are presented in tables A.1 and A.2 of appendix A. Value shares of wheat in each importing country by country of origin are reported in table A.4 of appendix A. Calibrated own and cross-price elasticities of demand for each demand equation are presented in table A.5 of appendix A.

2.3.3 Adjustments for the base case model of wheat trade by introduction of drought-tolerant wheat developed by applying GM or MAS breeding tools

The adjustments to simulate this introduction are built in to the base case wheat trade model. The models of trade with MAS versus GM drought-tolerant wheat are differentiated from each other based on different assumptions and estimations of yield gains, adoption rates, costs associated with technology fees (GM wheat only), segregation costs (GM wheat only), wheat price differences, and consumer acceptance and demand. The following two sections describe these proposed assumptions.

There are numbers of costs associated with developing improved crop varieties. These include laboratory and field costs associated with developing new variety,

variety registration costs and plant breeders' rights[18] (PBRs), regulatory approval costs for GM crops (i.e., biosafety compliance). However, all these costs are incurred before the variety is introduced on the market. These costs are viewed as sunk costs since it is not possible to capture them directly in a trade model. They are considered to be embedded in the technology fee (for GM DT wheat) and seed price premiums (for MAS DT wheat).

2.3.3.1 Adjustments of the supply equations for the GM DT wheat scenarios

In the case of MAS DT wheat scenarios, each exporting country is assumed to have one supply equation, whereas in the case of GM DT wheat scenarios each exporting country has two separate supply equations: one is for GM DT wheat and another one for non-GM (conventional) wheat. Supply equations of GM and conventional wheat are functions of slightly different variables since segregation cost, technology fee, and a parameter of consumer acceptance of GM wheat is introduced in the supply equation of GM DT wheat. The model should allow for having these two supply equations in each exporting country once GM DT wheat is introduced and only one supply equation otherwise. To achieve this, a framework similar to the one presented in Moschini et al. (2000) and Sobolevsky et al. (2005) with further modifications is applied.

To incorporate yield advantage of improved varieties, segregation costs, technology fees, differentiated prices for conventional and GM DT wheat, and land allocations between conventional and GM DT wheat, it is assumed that per hectare profit[19] of farmers in each exporting country for non-GM (conventional) and GM DT wheat (Π_i^n and Π_i^g) is written as:

$$\Pi_i^n = \frac{(1-\tau_i^n)G_i}{1+\epsilon}(P_i^n - \varphi_i)^{1+\epsilon} - \delta_i\omega_i - \kappa_i \qquad \text{(B.1a)}$$

$$\Pi_i^g = \frac{(1-\beta_i^g)G_i}{1+\epsilon}(P_i^g)^{1+\epsilon} - \delta_i\omega_i - \kappa_i - \mu_i \qquad \text{(B.1b)}$$

[18] Plant breeder's rights are a form of intellectual property rights (IPRs) that entitle plant breeders with a right to exclusively use, reproduce, and sell plant varieties that they develop, and allow their legal protection of this right (CFIA, 2010).

[19] Farmer's profit in this model is defined as total revenue minus direct cost of production (which includes seed, fertilizers and plant protection costs) (Agribenchmark, 2001).

where P_i^n and P_i^g are export prices for non-GM (conventional) and GM DT wheat respectively, and the other parameters and their assumed baseline values are provided in table 2.2.

By applying Hotelling's lemma[20] to the specification of profit functions (equations B.1a and B.1b), the yield functions for non-GM and GM DT wheat (y_i^n and y_i^g) are obtained:

$$y_i^n = (1 - \tau_i^n) G_i (P_i^n - \varphi_i)^\epsilon \quad \text{(B.2a)}$$

$$y_i^g = \left(1 - \beta_i^g\right) G_i (P_i^g)^\epsilon \quad \text{(B.2b)}$$

These functions are also used for calibration purposes with variables φ_i, τ_i^n and β_i^g set to zero at the time of calibration. Table 2.2 outlines the parameters and their baseline values. A more detailed explanation of possible scenarios that involve yield gain and/or yield loss decrease is given in section 2.3.3.2.1.

In Sobolevsky et al. (2005) the supply of land is modeled as a function of land rent $L = f(\overline{\Pi})$, where $\overline{\Pi} = max\{\Pi^n; \Pi^g\}$. In other words 100% of the total land available for cultivation of the crop (either to GM or non-GM) is assigned based on which crop gives larger profit per hectare. This is logical in the case of Roundup Ready® soybeans, which are researched in Sobolevsky et al. (2005). Herbicide resistant technology is cost-reducing by nature and may, therefore, be potentially adopted on any area. Drought tolerance is a technology that does not necessarily lead to a reduction in production costs. Rather it is a technology that enables mitigating risks related to crop loss due to unfavourable weather conditions. That is, in the regions which are not susceptible to drought or in the drought prone regions that experience drought periodically in a particular season, the advantages of planting DT crops may be nullified. As noted in Lybbert and Bell (2010), under conditions of extreme drought both DT and non-DT varieties fail. Thus, to model land allocation in this study, the following should be considered:

[20] Hotelling's lemma can be applied to an indirect profit function (i.e., a function of output and input prices). Output prices are denoted by *P*, and parameters *G* and *k* subsume all other input prices (other than seed price) See section 2.3.3.2 for more detail.

- in areas prone to extreme drought an incentive to adopt DT crop varieties may not exist, and the adoption levels may be quite low;
- in the areas with no or very infrequent drought, higher costs of DT varieties may not be justified and DT varieties may not be adopted.

The model could become overly complicated if weather variables with uncertain yield outcomes were to be incorporated. For simplification, it is assumed that of the total land available for wheat production in each exporting country (L_i), the fraction α_i is within the area where droughts are very infrequent. Farmers are not expected to adopt DT wheat on the area $\hat{L}_i = \alpha_i L_i$. It is also assumed that extreme drought did not take place in a reference years of 2006/2007, so that it was very likely that adoption of DT wheat would have occurred in the drought prone areas of wheat exporting countries in those years. Therefore, land allocation between non-GM and GM DT wheat (L_i^n and L_i^g) is modelled in the following way:

$$L_i^n = \hat{L}_i + \tilde{L}_i = \alpha_i \lambda_i (\Pi_i^n)^{\theta_i} + (1-\rho_i^g)(1-\alpha_i)\lambda_i(\Pi_i^n)^{\theta_i} \quad \text{(B.4a)}$$

$$L_i^g = \rho_i^g (1-\alpha_i)\lambda_i \left(\Pi_i^g\right)^{\theta_i} \quad \text{(B.4b)}$$

where $\hat{L}_i$ denotes land allocated to non-DT wheat only, and $\tilde{L}_i$ is the remainder of land to be planted with non-GM/non-DT wheat, the size of which depends on the adoption rate of GM DT wheat. This specification enables allocating the land to non-GM wheat only, when $\alpha_i = 1$, as well as combinations of non-GM and GM DT wheat, when $\alpha_i \in [0; 1]$. The reminder of land that can be allocated to GM DT wheat is determined by adoption rate of $\rho_i^g \in [0; 1]$.

Parameter θ_i (elasticity of land supply with respect to wheat profit per hectare) is calculated in the following way: $\theta_i = r_i \psi_i$, where $r = \frac{\Pi}{Py}$ is a farmer's share of unit revenue (determined in the course of calibration process), and ψ_i is the elasticity of land supply with respect to wheat price (Sobolevsky et al., 2005).

Supply of non-GM and GM DT wheat (S_i^n and S_i^g) by each exporting country is a product of land and yield, so that:

$$S_i^n = \hat{L}_i \hat{y}_i + \tilde{L}_i y_i^n \quad \text{(B.5a)}$$

$$S_i^g = L_i^g y_i^g \quad \text{(B.5b)}$$

Here $\hat{y}_i$ is the actual wheat yield obtained from the reference dataset. This yield will remain at the default level in the event of drought in the country, since the land area $\hat{L}_i$ is considered to be non-drought prone. Yield of non-GM (non-DT) wheat y_i^n may decrease as a result of drought, since land area $\tilde{L}_i$ may experience droughts.

2.3.3.2 Data used for adjustments of the supply equations for GM DT wheat scenarios

The baseline values for the supply equations of wheat trade model that allows for GM DT wheat are outlined in table 2.2. A more detailed discussion of key parameters (i.e., yield advantages and/or yield loss decreases, adoption rates, segregation costs, and technology fees) their definitions, sources of data in literature and justifications of baseline value choices is provided in the following sub-sections.

Seeding rate of wheat in Canada is set at the level of CWRS wheat in Manitoba. The average of 1.7 bushels per acre is converted to 114 kilograms per hectare (Government of Manitoba, 2011). For the United States the wheat seeding rate is set at 126 kilograms per hectare (AgriPro, 2011)[21]. For other countries average worldwide seeding rate of 100 kg per hectare is employed (John MacRobert, CIMMYT, personal communication, April 21, 2011).

Prices of conventional wheat seeds are obtained from various sources and converted to $US per kilogram where necessary: Argentina and EU (Dixon et al., 2010), Australia (Smith and Martin, 2008), USA (NASS, 2009). For Canada and Other (aggregate exporter) the seed price for the U.S. is used.

[21] Wheat seeding rate is calculated at 14,500 seeds per pound, 92% germination rate, 15% standard loss, and 1,200,000 plants per acre, and converted to kg/ha.

The elasticity of yield with respect to wheat price (0.03) is taken from Choi and Helmberger (1993) and applied to all wheat exporting countries in the model. The authors use U.S. data to estimate this elasticity. It is expected that wheat yields are quite inelastic to changes in wheat prices[22] in any wheat producing country, and therefore elasticity of yield with respect to price is assumed to be of equal magnitude across countries.

Table 2.2 Baseline values of parameters for the supply equations of the trade model adjusted for introduction of GM DT wheat

Parameter and description		Baseline values					
		ARG	AUS	CAN	EU	USA	Other
α	fraction of total wheat planting area, where farmer would not grow drought-tolerant wheat	-	-	0.5	-	0.4	-
ρ^g	adoption rate of GM DT wheat as a fraction of wheat planting area that is subject to droughts	-	-	0.7	-	0.6	-
β^g	yield loss of GM DT wheat in case of drought as a percent point of actual baseline wheat yield	-	-	0.05	-	0.05	-
τ^n	yield loss of non-GM wheat in case of drought as a percent point of actual baseline wheat yield	-	-	0.10	-	0.10	-
φ	segregation cost of non-GM wheat in $US per metric tonne	-	-	3	-	3	-
μ	technology fee of GM DT wheat in $US per hectare	-	-	15	-	15	-
δ	seeding rate of wheat in kilograms per hectare	100	100	114	100	126	100
ω	price of non-GM (conventional) wheat seed in $US per kilogram	0.27	0.24	0.33	0.52	0.33	0.33
ϵ	elasticity of yield w.r.t. wheat price	0.03	0.03	0.03	0.03	0.03	0.03
r	farmer's share of unit revenue	0.50	0.15	0.40	0.05	0.15	0.15
ψ	elasticity of land supply w.r.t. wheat price	0.6	0.8	0.8	0.6	0.8	0.6
κ	additive parameter subsuming other input prices	105.7	65.5	97.4	178.1	112.6	134.9
G	Multiplicative parameter subsuming other input prices	2.24	0.78	2.22	4.31	2.21	2.41
λ	scale parameter determined in the course of calibration ($\times 10^6$)	0.73	6.66	0.82	1.89	4.52	6.34

[22] Crop yield is assumed inelastic to changes in crop prices because prices do not directly impact yields. Yields are dependent on the weather, geographical zone, crop variety characteristics, and use of fertilizers and pesticides. However, increase in crop prices may induce crop growers to adopt higher yielding varieties.

Estimates of the elasticity of land supply with respect to wheat price for all countries in this study are not available in the literature[23]. The values of elasticity of land supply with respect to wheat prices are assumed to be equivalent to those with respect to soybean prices and estimates of these are adopted from Sobolevsky et al. (2005). The estimates for the elasticity of land supply with respect to wheat price for Australia and Canada are assumed to be 0.8 as in the case of USA. The estimate of the this elasticity for EU is assumed to be 0.6 as in Argentina, since expansion of arable land is quite limited and further increases in wheat area may be achieved only at the cost of decrease in planting areas of other crops. Farmers' shares of unit revenue (i.e. ratio of farmer's profit to revenue per hectare) are estimated based on calculations for a representative wheat farm in each wheat exporting country (Agribenchmark, 2011).

Following Sobolevsky et al. (2005), parameters G and k are multiplicative and additive parameters respectively that subsume all other input prices (i.e., other than seed prices). The values of these parameters are determined in the course of calibration. Parameter G ensures proper scaling in yield equations, and parameter k ensures that producer surplus calculated based on linear supply equations is equal to the producer surplus calculated based on profit equations. Scale parameter λ is determined in the course of model calibration and ensures proper scaling in supply equations.

2.3.3.2.1 Yield advantage (yield loss decrease)

GM wheat has not yet been grown commercially anywhere in the world. Data on yield gains from trials and studies on Roundup Ready® wheat (and other Roundup Ready® crops) are available. However, there has been research on developing drought-tolerant wheat (Bahieldin et al., 2005; BioSicherheit, 2008; Monsanto, 2012; TransGEN, 2011). It has been argued that, based on field trials in Australia,

[23] Estimates of the elasticity of land (acreage) supply with respect to wheat price are available in the literature only for winter wheat in eastern Canada and equal to 0.613 (Mielke and Weersink, 1990), 0.911 (von Massow and Weersink, 1993), 0.367 (Weersink, 2010). However, similar estimates for spring wheat in all wheat exporting countries considered in this study have not been located.

some drought-tolerant varieties of wheat show increases in yield by up to 20% under conditions of drought and do not decrease in yield under irrigation (BioSicherheit, 2008).

Applying different crop improvement tools (i.e. GM versus MAS) or even a single tool (e.g., GM) in developing drought tolerance in wheat may potentially lead to different outcomes of drought tolerance levels depending on the variety, agro-climatic zone, crop management practices. Therefore yield gain (or decrease in yield loss) of the improved varieties under the same drought levels may differ.

Tolerance to abiotic stress, including drought tolerance, is determined by multiple genes with complex interactions. If a variety that is optimized for yield under certain conditions is crossed with a variety that is naturally drought-tolerant, the offspring of such a cross may possess improved drought tolerance but may or may not have the same level of yield (in fact, yield may even decrease), which may not directly relate to the improvement in tolerance. If a single gene is inserted transgenically, a nonrelated yield loss may be avoided, but full improvement of drought tolerance may not be obtained[24] (Chris Barker, Genome Prairie, personal communication, April 29, 2010). That is, it is almost impossible to predict other characteristics a variety with improved drought tolerance may possess unless confirmed by trial data. Thus, under the current state of knowledge in genetics and breeding, a yield gain of DT crop varieties over conventional varieties cannot be guaranteed. However, the counterargument, for example, is that yield of hybrid maize in the U.S. has increased for the past 70 years, while there was also constant improvement in tolerance of maize to different abiotic stresses (CGIAR, 2003).

For the purpose of the analysis in this paper it is assumed that drought-tolerant wheat developed by GM exhibits (at least) no yield loss during the seasons with

[24] This is due to the fact that drought tolerance is not determined by only a single gene. Thus, inserting only one gene may not be effective in improving drought tolerance.

sufficient precipitation, that is, in “good years” GM DT wheat yields at least as much as conventional non-GM wheat. In other words, the possibility of yield penalty as a result of selection for abiotic stress is discarded. Beyond this basic assumption, and given the evidence provided above, two more possibilities of yield change associated with development of DT wheat varieties are proposed in this paper:

1) In the case of moderate drought, non-GM wheat varieties exhibit yield loss (τ_i^n) while GM DT wheat yield remains at the actual baseline yield level ($\hat{y}_i$), (i.e. $\beta_i^g = 0$).
2) In the case of moderate drought, non-GM wheat varieties exhibit yield loss (τ_i^n) while GM DT wheat varieties exhibit yield loss (β_i^g) less than the yield loss of non-GM wheat varieties (i.e. $\beta_i^g < \tau_i^n$).

Parameter β_i^g is a proportion by which mean yield of GM DT wheat would decrease compared to actual baseline mean yield. Parameter τ_i^n is a proportion by which mean yield of non-GM wheat would decrease compared to actual baseline mean yield. The difference between these two parameters $\tau_i^n - \beta_i^g$ constitutes yield gain of GM DT wheat over non-GM wheat. These parameters are exogenous in the model to allow for comparisons between different scenarios under the same levels of yield gains/losses. Due to the ex-ante character of the study and based on expert opinions, yield gain/loss is assumed. Sensitivity of the model outcomes to different levels of yield gains/losses is performed.

2.3.3.2.2 Adoption rates

Some studies on welfare effects from introduction of Roundup Ready® wheat have assumed adoption rates in producing regions (i.e. percentages of area planted to GM and non-GM wheat) (Berwald et al., 2006; Johnson et al., 2005). In other studies these are endogenous and estimated as part of the equilibrium solution (Furtan et al., 2005; Wilson et al., 2008). Some studies use the following levels of hypothetical adoption rates as a percentage of total wheat planting area for different GM wheat varieties (if these GM varieties were commercially available on the market):

- GM Roundup Ready® wheat – 75% in Argentina, Canada, and USA (Berwald et al., 2006);
- GM herbicide resistant wheat - 50% in Argentina (Smale et al., 2009);
- GM drought tolerant wheat – 15% in Bangladesh, 6% in India (Smale et al., 2009);
- GM wheat – 45% in Canada and USA, 30% in Australia and Latin American countries, 15% - in other countries (Anderson and Yao, 2003).

GM wheat is expected to sell at a price discount compared to conventional (non-GM) wheat, which is an important factor for potential adopters of GM DT wheat to consider. Generally factors that influence the decision to adopt GM DT wheat are expected to differ from those that may influence adoption of herbicide resistant GM wheat. In particular, all else equal, in each producing region the areas more susceptible to drought are expected to benefit more from the new technology and therefore be more likely to adopt this. Another characteristic of GM DT wheat variety that would favour its adoption is the expected absence of a yield penalty during the seasons with sufficient precipitation and soil moisture compared to the conventional wheat varieties that farmers currently grow.

As discussed earlier (see section 2.3.3.1), DT wheat varieties will not be adopted on a fraction α_i of the total wheat production land in each exporting country because in those areas droughts are very infrequent. In the scenarios for GM wheat, $\hat{L}_i = \alpha_i L_i$ denotes the area on which only conventional non-DT wheat is grown, while $(1 - \alpha_i)L_i$ is the area on which the adoption of DT wheat varieties is possible or desirable. Therefore, the adoption rate, ρ_i, as considered here is understood as a fraction of area $(1 - \alpha_i)L_i$. The adoption rate is incorporated into the model as an exogenous variable (except where stated otherwise). This enables comparison of welfare effects of introducing MAS and GM DT wheat where they could have the same adoption rates. Modelling adoption rate as an endogenous (choice) variable was considered. However, due to the static nature of the model the mathematical relationship between adoption rate and wheat prices is a "chicken and egg" problem. Adoption of a new wheat variety is a dynamic concept by nature, which depends, among other factors, on realised per hectare profit, which in turn depends on the wheat price. On the other hand, wheat price largely depends on the level of the variety adoption. Baseline values of adoption rates (ρ^g) are set at 70% (or 35% of the total wheat planting area) and 60% (or 36% of the total wheat planting area) for Canada and the USA respectively. These are varied for the sensitivity purposes.

The adoption rate is modelled as an endogenous variable only in the scenarios with GM DT wheat, in order to determine the lowest possible adoption of GM DT wheat at which the prices of GM and non-GM wheat in each GM DT wheat exporting country would be equal. This procedure enables the model to obtain the lowest possible adoption rates of GM DT wheat in Canada and the USA for the GM DT market to exist. If exporting countries had even lower levels of adoption, this would cause GM DT wheat prices to rise above non-GM wheat prices, and none of the importing countries would buy GM wheat. Based on these lowest levels of adoption, the baseline adoption levels are chosen for the benchmark scenario and are kept constant in scenario analysis. A more detailed discussion about the values of these baseline adoption levels is provided in the results sections 2.4.2.1 and 2.4.3.1.

Drought-susceptible wheat planting areas in each wheat exporting country are determined as a basis to assess areas that may be planted to DT wheat. The remainder of the wheat planting area is assumed not to require wheat varieties to be drought-tolerant. Values of α_i (i.e., the fraction of land with conventional non-DT wheat varieties only) for Canada and USA are determined to be 50% and 40% of total wheat planting areas, respectively. The areas where a long-term Palmer

Drought Severity Index (PDSI)[25] is in the range of -1.00 (moderate drought) to -4.00 (extreme drought) and less are assumed to be drought prone areas where drought-tolerant wheat varieties would be preferred. PDSIs are obtained for Canada (AAFC, 2011b) and USA (NOAA, 2011) and overlapped with wheat production area maps for Canada and USA respectively (USDA, 2011) to determine drought prone areas.

PDSIs are not available for Argentina and Australia. A proxy measure for determining drought prone areas in Argentina and Australia is based on the percent of normal precipitation (PNP) and temperature anomaly in the region (NOAA, 2011), calculated as outlined below.

Most wheat in Argentina (about 93%) is produced in the provinces of Buenos Aires, Cordova, Santa Fe, and Entre Rios (USDA, 2011). The drought prone areas are therefore assumed to be those parts of Buenos Aires and Cordova, where the PNP ranges from 75% to as low as 25% at any specific month of the year. The remainder of the area, where there are no apparent anomalies of temperature and precipitation (as shown by values of α_i) is estimated to be 50 % of the total wheat production area.

In Australia, 94% of wheat production comes from the south-western part of Western Australia, the south part of South Australia, and Victoria and New South Wales states (USDA, 2011). Among the named states, only large parts of Western Australia's PNP indicate normal ranges. Historically, major droughts have occurred and continue to happen throughout New South Wales, South Australia, Victoria and Queensland. It is established that the area with frequent drought covers about 60% of total wheat production area and α_i for Australia is therefore 40%.

[25] Palmer Drought Severity Index is an index of meteorological drought developed in 1965 in the USA by Wayne Palmer. The index calculation is based on soil moisture and temperature. Negative numbers denote drought condition (Dai, 2011).

2.3.3.2.3 Segregation cost

Segregation is defined as maintaining separation of marketing channels for GM and non-GM wheat at all stages from seed acquisition and production, transportation, and processing to delivery of the final product[26]. Identity preservation (IP) is another broader term which refers to traceability requirements imposed by some countries with stricter GM content tolerance levels (Moss et al., 2008). There is literature on segregation costs for different existing GM crops (Bullock and Desquilbet, 2002; Moschini et al., 2005; Moss et al., 2008), as well as for hypothetically introduced GM wheat (Huygen et al., 2003; Taylor et al., 2003; Wilson and Dahl, 2005; Wilson and Dahl, 2006; Wilson et al., 2005; Wilson et al., 2003a). This literature provides a basis to choose assumed values of the segregation cost parameter in modeling GM DT wheat trade in this study. For example, in the Roundup Ready® wheat trade model of Wilson et al. (2005) the authors use different levels of segregation costs depending on the tolerance to GM content importing countries. These costs range from $3 to $6 per metric tonne if the tolerance level ranges from <5% to <0.9% respectively. In Taylor et al. (2003) a $2.23 per metric tonne segregation cost is applied to non-GM wheat imported from USA and/or Canada by EU, Japan, and South Korea.

Contamination tolerance levels applied to imported food products with GM content in different countries usually range from <5% to <0.9%. These tolerance levels and related labelling requirements (as applied to only registered GM crops) are summarized in table 2.3.

There is some concern in the literature whether segregation would be operational and effective, or totally infeasible. The primary threat is the complete loss of major export markets if segregation proved unsuccessful. There are also uncertainties about costs necessary for segregation and whether segregation would

[26] The major institutions where segregation would be necessary are: seed industry (purity of non-GM seed), farm production (during planting, growing, harvesting, storage and grain delivery), transport, local and/or export elevators, processing plants.

be required for GM wheat products, non-GM wheat products, or both (Taylor et al., 2003).

Table 2.3 Restrictions on importing approved GM products

Country	Labelling	Tolerance
Algeria	-	Planting, importation and distribution is illegal
Brazil	All food and feed products over tolerance level	1%
Egypt	-	Policy is at the stage of development
EU	All food, oils and animal feed over tolerance level	0.9%
Indonesia	Food derived from biotechnology must be labelled. Plans to extend to GM feeds.	5% on three major ingredients
Japan	All food for human consumption over tolerance level	5% on three major ingredients
South Korea	All products with GM as major input except those where novel DNA or protein removed	3% on five major ingredients

Source: AAFC (2011a); GAIN (2009); Gruère and Rao (2009); Wilson et al. (2005).

Ideally segregation should be performed at different stages of crop production (table 2.4) and recognise various risks of contamination (table 2.5). Table 2.4 also describes options of those who would incur costs of segregation.

Based on the literature review at the beginning of this section, the assumed baseline value of segregation cost is set at $3 per metric tonne in Canada and the USA, which is assumed to be incurred by non-GM wheat producers (Sobolevsky et al., 2005; Taylor et al., 2003). As a result of segregated markets for GM and non-GM wheat, GM DT wheat producers may obtain better yields under drought conditions, but they receive a lower price for their product. GM DT wheat is expected to be a weakly inferior good (see section 2.3.3.5) and consumers would not buy it if its price is equal to or higher than the price of non-GM wheat. It follows that non-GM wheat producers receive relatively higher prices for their wheat. If no well-functioning segregation system was to be in place, both GM DT wheat and non-GM wheat would receive the same price. This might create an incentive for non-GM wheat producers to segregate their wheat to enjoy higher wheat prices. Following this logic, model segregation costs are incurred by non-GM producers. Sensitivity analyses are performed to assess sensitivity to different levels of segregation costs.

Table 2.4 Stages of GM wheat segregation: Possible options regarding incidence of segregation costs in Canada

Stages	Options
On-farm segregation	1. Both GM and non-GM farmers cover own on-farm segregation costs
	2. Levy on GM wheat seed sales to cover monitoring and segregation costs of non-GM wheat. This could be at point of sale (i.e., based on seed purchased) or end-point (i.e., based on tonnage produced or sold). Levy fund would cover non-GM farmers' on farm segregation costs.
	3. Government assists GM and non-GM farmers to pay for the implementation of certification programs.
Post-farm segregation and monitoring costs (e.g., sampling and testing of wheat deliveries and shipments, special handling requirements and fees)	1. Technology developer pays all post-farm segregation and monitoring costs directly
	2. Costs are shared among all producers, by levy, with the exception of farmers selling into the domestic feed market
	3. Levy fund covers segregation and monitoring costs for non-GM wheat shipments.
Contamination costs	1. Technology developer pays the costs of contamination directly.
	2. Costs are shared among all producers, by levy, with the exception of farmers selling into the domestic feed market
	3. Levy fund serves as insurance fund to cover costs of contamination.

Source: CWB (2003)

Table 2.5 Identity preservation and causes of potential contamination (through accidental mixing)

Possible causes of mixing	Level of vertical supply chain at which this type of mixing may occur	Methods used to preserve identity and prevent this type of mixing	Additional costs of segregation and IP
Cross-pollination (maize)[a]	• Seed production • Farm production	• Plant all-male border rows • Increase spatial and temporal isolation of non-GM seed fields	• Costs of reduced land used for actual grain production • Costs of giving an incentive to others not to grow GM crops near non-GM zones
Equipment not clean	• Seed production (bagging equipment) • Farm production (planter, combine and on-farm storage, truck or elevator) • Handling system (elevator grain paths) • Processing system (machinery)	• Clean equipment • Dedicate equipment to GMOs or non-GMOs	• Costs of capacity under-use • Costs of managing new grain flows • Costs of moving grain further • Costs of reduced blending ability
Mixing of a GM lot thought to be non-GM with a non-GM lot	All levels	• Tests on GMO content • Contracts	• Testing costs • Contracting costs • Indirect costs of waiting for test results

[a] It should be noted that wheat is a self-pollinated crop, and, therefore, there is less chance that conventional wheat would be cross-pollinated by GM DT wheat.

Source: Bullock and Desquilbet (2002).

2.3.3.2.4 Technology fee

The technology fee refers to an annual payment by GM wheat producers to a biotechnology company for the rights to use the technology (i.e. GM drought-tolerant wheat seeds) that season. Existing literature provides estimates and actual costs for technology fees charged for GM soybean, canola and maize seeds (e.g.,Taylor et al., 2003). Some studies provide estimates of technology fees that apply to Roundup Ready® wheat, based on modeling results and discussions with Monsanto staff (Furtan et al., 2005; Kuntz, 2001; Wilson et al., 2005; Wilson et al., 2008). It was not possible to locate research that would provide estimates on the magnitude of technology fee for GM DT wheat. Based on the Roundup Ready® wheat literature the technology fee of $15 per hectare (in each exporting country that will be adopting GM DT wheat) is assumed, and is subject to sensitivity analyses.

2.3.3.3 Adjustments of the supply equations for MAS DT wheat scenarios

A crop variety developed by applying MAS tools does not impose any potential biosafety risks (Reece and Haribabu, 2007). Therefore, DT wheat developed by MAS is assumed to be equivalent in terms of its nutritional value to conventional wheat varieties. MAS DT wheat scenarios require only one supply equation for each exporting country, since this wheat does not require segregation and is accepted on the importing markets as equivalent to conventional wheat. Importers pay the same price for both conventional wheat and DT wheat developed by MAS tools. To differentiate costs of production of these wheat varieties compared to non-DT wheat, per hectare profits are expressed as in the case of GM DT scenarios:

$$\Pi_i^n = \frac{(1-\tau_i^n)G_i}{1+\epsilon}(\tilde{P}_i)^{1+\epsilon} - \delta_i\omega_i^n - \kappa_i \quad \text{(C.1a)}$$

$$\Pi_i^m = \frac{(1-\beta_i^m)G_i}{1+\epsilon}(\tilde{P}_i)^{1+\epsilon} - \delta_i\omega_i^m - \kappa_i \quad \text{(C.1b)}$$

where subscript *n* in this case denotes non-DT (conventional) wheat and subscript *m* indicates MAS DT wheat, $\tilde{P}_i$ is a price that is the same for non-DT wheat and improved (i.e., MAS) wheat. The other assumed parameters are provided in table 2.6 or described previously.

Yield equations are calibrated in the following manner:

$$y_i^n = (1-\tau_i^n)G_i(\tilde{P}_i)^{\epsilon} \quad \text{(C.2a)}$$

$$y_i^m = (1-\beta_i^m)G_i(\tilde{P}_i)^{\epsilon} \quad \text{(C.2b)}$$

As in the GM DT wheat scenarios, these equations are also used for calibration purposes with τ_i^n and β_i^m set to zero.

Land allocated between non-DT and MAS DT wheat varieties (L_i^n and L_i^m) is defined similarly as in the GM DT wheat scenarios:

$$L_i^n = \hat{L}_i + \tilde{L}_i = \alpha_i\lambda_i(\Pi_i^n)^{\theta_i} + (1-\rho_i^m)(1-\alpha_i)\lambda_i(\Pi_i^n)^{\theta_i} \quad \text{(C.4a)}$$

$$L_i^m = \rho_i^m(1-\alpha_i)\lambda_i(\Pi_i^m)^{\theta_i} \quad \text{(C.4b)}$$

The supply equation of each exporting country is the sum of production of non-DT wheat and MAS DT wheat:

$$S_i = \hat{L}_i \hat{y}_i + \tilde{L}_i y_i^n + L_i^m y_i^m \tag{C.5}$$

2.3.3.4 Data used for adjustments of the supply equations for MAS DT wheat scenarios

Some of the baseline values for the supply equations of the wheat trade model with MAS wheat replicate the baseline values of GM DT wheat trade model (see table 2.2), i.e., these do not generally change depending on what kind of wheat variety is planted. These are the fraction of land where DT wheat is not adopted (α), seeding rate of wheat (δ), elasticity of yield with respect to wheat price (ϵ), parameters subsuming all other input prices (κ and *G*), farmer's share of unit revenue (r), elasticity of land supply with respect to wheat price (ψ), and scaling parameter (λ). Technology fee (μ) and segregation cost (φ) do not apply in the case of MAS DT wheat. Key parameters (i.e. yield advantage/loss and adoption rates) as well as seed price of MAS DT wheat are outlined in table 2.6.

Table 2.6 Baseline values of parameters for the supply equations of the trade model adjusted for introduction of MAS DT wheat

Parameter	Description	Baseline values					
		ARG	AUS	CAN	EU	USA	Other
ρ^m	adoption rate of MAS DT wheat as a fraction of wheat planting area that is subject to droughts	-	-	0.7	-	0.6	-
β^m	yield loss of MAS DT wheat in case of drought as a percent point of actual baseline wheat yield	-	-	0.05	-	0.05	-
τ^n	yield loss of non-DT wheat in case of drought as a percent point of actual baseline wheat yield	-	-	0.10	-	0.10	-
ω^m	price of MAS DT seed as a percent point increase from conventional wheat seed price	-	-	0.3	-	0.3	-

Baseline values of yield advantage/loss and adoption rates are set at the same levels as in GM DT wheat trade model, to be able to compare outcomes. However, these values will change in scenario analyses. It is initially assumed that MAS DT wheat is only available in Canada and the USA.

No literature or information on seed prices of wheat or other crops improved via MAS tools was located. Studies on the development cost of MAS in maize (Dreher et al., 2003; Morris et al., 2003) and wheat (Kuchel et al., 2005) look at the laboratory stage of a variety development. Laboratory and field costs are high fixed costs that occur long before the variety is on the market and the pricing decision is made. The best available reference point in terms of seed pricing for wheat varieties developed by MAS is the difference between biotech and non-biotech seed prices for corn and soybean in the USA, available from Agricultural Statistics, NASS, USDA, various years. The seed prices of biotech corn and soybean varieties exceed non-biotech varieties by 50-80% per unit of seed quantity. The technology fee that is collected by a biotech company is included in the seed price. A conservative 30% increase in the seed price for MAS DT wheat relative to non-DT wheat is used in the base model. Sensitivity analysis is applied to changes in MAS DT wheat seed prices.

2.3.3.5 Adjustments of the demand equations for GM DT wheat scenarios

Only scenarios with GM DT wheat require adjustments to the demand equations. In the model it is proposed that demand for MAS DT wheat does not differ from wheat demand in the base case wheat trade model. Also, the premise is that all markets accept MAS DT wheat, since this is considered equivalent to conventional varieties in terms of biosafety and consumer acceptance. Therefore, the behaviour of consumers will not change compared to the base case trade model. The differences in the trade models for DT wheat developed by MAS tools are only incorporated into the supply side.

Numbers of studies have used a vertical differentiation model adapted from Mussa and Rosen (1978) as a standard framework to characterise demand for GM versus non-GM products (e.g., Berwald et al., 2006; Fulton and Giannakas, 2004; Moschini et al., 2005; Sobolevsky et al., 2005). Following these examples, a vertical differentiation concept is used to differentiate consumer acceptance and non-acceptance of GM DT wheat.

A variation of Mussa and Rosen's (1978) concept of vertical differentiation is employed in Sobolevsky et al. (2005). Individual consumer utility from wheat consumption, assuming quasi-linear preferences can be presented, following Sobolevsky et al. (2005) as:

$$U(y, q^n, q^g) = y + u(q^n + \theta q^g) \quad \text{(D.1)}$$

where y is a composite (*numéraire*) good, q^n is a non-GM food product, q^g is the GM food product and θ is a parameter that characterises heterogeneity of consumers in terms of their preferences of non-GM versus GM food. With quasi-linear preferences, prices determine the quantity of $(q^n + \theta q^g)$ consumed, and then the remaining income determines the quantity of y consumed. There is no income effect on $(q^n + \theta q^g)$. It is further assumed that the income of each individual consumer is high enough for the interior solution to hold. Since GM food is assumed to be a weakly inferior substitute for non-GM food, it follows that $\theta \in [0,1]$.

It should be noted that a quasi-linear utility function with underlying quasi-homothetic preferences allows exact aggregation of individual demands (Sobolevsky et al., 2005). This is the case because an indirect utility function associated with quasi-homothetic preferences can take Gorman Polar form. Gorman Polar form includes an element of individual specific preferences and an element of preferences common for all individuals. When individual demands are aggregated under these assumptions, the aggregate demand becomes independent of income (for more details see Mas-Colell et al., 1995). Thus, two important implications that stem from quasi-linear utility specification are:

- Exact aggregation of individual demands;
- Aggregate demand is independent of income. This implies that Marshallian demand curves can be used to measure consumer surplus in all wheat importing countries as the income effect on the demand function is zero.

Given the assumptions embedded in the specifications of consumer preferences, outlined above, either GM or non-GM wheat will be chosen by an individual consumer. In the case that $p^g \geq \theta p^n$ (where p^g and p^n are the prices of GM and non-GM wheat respectively) only non-GM wheat will be consumed, whereas if $p^g < \theta p^n$, only GM wheat will be bought. Therefore, the individual demand function for these two cases can be derived from the optimality conditions of the utility equation:

$$q^n = d(p^n),\ q^g = 0,\ \text{for}\ \theta \leq \frac{p^g}{p^n} \tag{D.2a}$$

$$q^g = \frac{1}{\theta} d\left(\frac{p^g}{\theta}\right),\ q^n = 0,\ \text{for}\ \theta > \frac{p^g}{p^n} \tag{D.2b}$$

where $d(.)$ is an individual demand function satisfying $d^{-1}(.) = u'(.)$. Further, the aggregate market demand functions for non-GM and GM wheat ($D^n(.)$ and $D^g(.)$ respectively) can be obtained as follows:

$$D^n(p^n, p^g) = \int_0^{p^g/p^n} d(p^n)\mathrm{d}\,F(\theta) \tag{D.3a}$$

$$D^g(p^n, p^g) = \int_{p^g/p^n}^{1} \frac{1}{\theta} d\left(\frac{p^g}{\theta}\right) \mathrm{d}F(\theta) \tag{D.3b}$$

where $F(\theta)$ is a distribution function of the types of consumers.

To calibrate these demand equations to the linear demand equations in the base case model, the linear specification based on Sobolevsky et al. (2005) is used. Weak inferiority of GM DT wheat is reflected by the following specification of the domain of demand functions:

1) When $P_{ij}^n > P_{ij}^g$

$$\begin{cases} D_{ij}^n = a_{ij}^n - b_{ij}^n P_{ij}^n + \sum_{k \neq i} b_{kj}^n P_{kj}^n + m_{ij} P_{ij}^g \\ D_{ij}^g = a_{ij}^g - b_{ij}^g P_{ij}^g + \sum_{k \neq i} b_{kj}^g P_{kj}^g + m_{ij} P_{ij}^n \end{cases} \tag{D.4a}$$

2) When $P_{ij}^n = P_{ij}^g = P_{ij}$

$$\begin{cases} D_{ij}^{n} \in \begin{bmatrix} a_{ij}^{n} - (b_{ij}^{n} - m_{ij})P_{ij} + \sum_{k \neq i} b_{kj}^{n} P_{kj}, \\ (a_{ij}^{n} + a_{ij}^{g}) - (b_{ij}^{n} + b_{ij}^{g} - 2m_{ij})P_{ij} + \sum_{k \neq i}(b_{kj}^{n} + b_{kj}^{g})P_{kj} \end{bmatrix} \\ D_{ij}^{g} \in \left[0, a_{ij}^{g} - (b_{ij}^{g} - m_{ij})P_{ij} + \sum_{k \neq i} b_{kj}^{g} P_{kj}\right] \end{cases} \quad \text{(D.4b)}$$

3) When $P_{ij}^{n} < P_{ij}^{g}$

$$\begin{cases} D_{ij}^{n} = (a_{ij}^{n} + a_{ij}^{g}) - (b_{ij}^{n} + b_{ij}^{g} - 2m_{ij})P_{ij}^{n} + \sum_{k \neq i}(b_{kj}^{n} + b_{kj}^{g})\, P_{kj}^{n} \\ D_{ij}^{g} = 0 \end{cases} \quad \text{(D.4c)}$$

All parameters are positive. Parameter m_{ij} is a cross-price coefficient between non-GM and GM-wheat within the same importing country, P_{ij} is an own price of wheat and P_{kj} is a cross-price of wheat (i.e., when demand equation describes wheat flow from country *i* to country *j*, cross-price is a price of wheat in the other exporting country *k*, when *k≠i*). For each wheat demand equation (from a specific exporting country *i* to a specific importing country *j*) 15 parameters need to be calibrated: $a_{ij}^{n}, a_{ij}^{g}, b_{ij}^{n}, b_{ij}^{g}, m_{ij}$, five parameters for non-GM cross-price effects b_{kj}^{n} (since there are six exporting countries in total), and five parameters for GM cross price-effects b_{kj}^{g}. In other words, each of the 48 demand equations from the base case model needs to be split into two demand equations that would represent demand for non-GM and GM wheat in each importing country respectively.

To solve for 15 parameters, 15 equations need to be set up. First of all, the demand equation of the base case model is used in the calibration process since this reflects a pre-innovation state of the world (when GM wheat was not yet introduced):

$$D_{ij}^{0} = (a_{ij}^{n} + a_{ij}^{g}) - (b_{ij}^{n} + b_{ij}^{g} - 2m_{ij})P_{ij}^{0} + \sum_{k \neq i}(b_{kj}^{n} + b_{kj}^{g})\, P_{kj}^{0} \quad \text{(D.5a)}$$

Here initial base quantities (D_{ij}^{0}) and prices (P_{ij}^{0}) are used. This state of the world is also described by equation D.4c, where the price of GM wheat is assumed to be much higher than the price of non-GM wheat and consequently the demand for GM wheat is zero. From equations D.5a and A.1a it also follows that:

$$a_{ij}^{n} + a_{ij}^{g} = a_{ij} \quad \text{(D.5b)}$$

$$-(b_{ij}^{n} + b_{ij}^{g} - 2m_{ij}) = b_{ij} \quad \text{(D.5c)}$$

$$b_{kj}^{n} + b_{kj}^{g} = b_{kj}, \forall k \quad \text{(D.5d)}$$

where a_{ij}, b_{ij}, and b_{kj} are parameters of the base case model demand equations that are already known.

Assuming GM DT wheat was introduced in the reference year (2006/2007), but non-GM and GM DT wheat prices were equal[27], some fraction of consumers (γ_j) would be indifferent between non-GM and GM DT wheat when $P_{ij}^{n} = P_{ij}^{g} = P_{ij}$, such that:

$$\frac{a_{ij}^{g} - \left(b_{ij}^{g} - m_{ij}\right)P_{ij}^{0} + \sum_{k \neq i} b_{kj}^{g} P_{kj}^{0}}{\left(a_{ij}^{n} + a_{ij}^{g}\right) - \left(b_{ij}^{n} + b_{ij}^{g} - 2m_{ij}\right)P_{ij}^{0} + \sum_{k \neq i}\left(b_{kj}^{n} + b_{kj}^{g}\right)P_{kj}^{0}} = \gamma_j \quad \text{(D.5e)}$$

At the price level $P_{ij}^{n} = P_{ij}^{g} = P_{ij}$ own-price and cross-price demand elasticities of non-GM wheat are respectively:

$$\eta_{ij} = -b_{ij}^{n} \frac{P_{ij}^{0}}{a_{ij}^{n} - \left(b_{ij}^{n} - m_{ij}\right)P_{ij}^{0} + \sum_{k \neq i} b_{kj}^{n} P_{kj}^{0}} \quad \text{(D.5f)}$$

$$\eta_{kj} = b_{kj}^{n} \frac{P_{kj}^{0}}{a_{ij}^{n} - \left(b_{ij}^{n} - m_{ij}\right)P_{ij}^{0} + \sum_{k \neq i} b_{kj}^{n} P_{kj}^{0}} \quad \text{(D.5g)}$$

where η_{ij} and η_{kj} are own-price and cross-price demand elasticities of demand.

2.3.3.6 Data used for adjustments of the demand equations for GM DT wheat scenarios

To calibrate demand equations for GM DT and non-GM wheat in each importing country by country of origin, baseline demand quantities (D^0), prices (P^0), calibrated intercepts and slope coefficients, calibrated own and cross-price demand elasticities are used. However, the fraction of consumers that would be indifferent between buying GM or non-GM wheat products if prices were equal (γ) is an important parameter to be specified. Sobolevsky et al. (2005), whose model is used in this paper with modifications, specifies this fraction of

[27] Some studies describe that at the early stages of adoption the proper segregation system is either not available (Sobolevsky et al., 2005) or even if some segregation is available, it is not possible to effectively segregate GM and non-GM crops to achieve tolerance levels of importing countries (Furtan et al., 2003), creating a "market for lemons" (Akerlof, 1970). In other words, since GM and non-GM wheat is not visually distinguishable by a consumer, the market would value both types of wheat at the same, lower, price.

consumers to be γ = 0.5. This is quite a high value, but may be justified for the soybean market, since a high proportion of soybeans is produced for livestock feeding using soybean meal. Moschini et al. (2005) set the value of this parameter to γ = 0.25 suggesting this applied to GM food in general.

Wheat use differs substantially across countries. In 2006/2007 wheat feed use in Africa, Asia, and South America was as low as 1.5 – 2.5 % of total wheat use; in North, Central America and Commonwealth of Independent States (CIS) countries this was larger but still moderate at 18 – 28 %, while in Europe this was as high as 55 %. Globally, average wheat feed use constituted 16% of total wheat demand (IGC, 2011). It can be concluded that wheat is mainly used for food, except in Europe, where GM food import restrictions are already in place. In this paper it is assumed that EU does not import GM DT wheat.

Consequently, the value for the fraction of consumers assumed to be indifferent between buying non-GM or GM wheat at the same price is set at γ = 0.4. This value is more conservative than the value in Sobolevsky et al. (2005), where soybean is used mainly for feed, and less conservative than in Moschini et al (2005), where only the food product market is considered.

2.3.4 Equilibrium conditions and welfare calculation

2.3.4.1 Equilibrium conditions for GM DT wheat scenarios

By modifying the set of equilibrium equations A.1 of the base case model, equilibrium of the world market of wheat with the presence of GM DT wheat production can be described by the equations E.1 to E.5. Equations E.1a are demand equations for non-GM and GM DT wheat respectively from exporter *i* (or *k*) by importer *j*. This specification of the demand equations applies only to those importing countries that accept GM DT wheat, corresponds to the set of equations D.4a, and is only valid when $P_{ij}^{n} \geq P_{ij}^{g}, \forall i, j$.

$$\begin{cases} D_{ij}^{n} = a_{ij}^{n} - b_{ij}^{n} P_{ij}^{n} + \sum_{k \neq i} b_{kj}^{n} P_{kj}^{n} + m_{ij} P_{ij}^{g}, \forall i, j, k \\ D_{ij}^{g} = a_{ij}^{g} - b_{ij}^{g} P_{ij}^{g} + \sum_{k \neq i} b_{kj}^{g} P_{kj}^{g} + m_{ij} P_{ij}^{n}, \forall i, j, k \end{cases} \quad \text{(E.1a)}$$

The set of the demand equations E.1b is used instead of E.1a for the importing countries that do not accept GM DT wheat. In this case the demand for non-GM wheat takes the form of the pre-innovation state and corresponds to the equations D.4c, whereas the demand for GM DT wheat is set to zero.

$$\begin{cases} D_{ij}^{n} = \left(a_{ij}^{n} + a_{ij}^{g}\right) - \left(b_{ij}^{n} + b_{ij}^{g} - 2m_{ij}\right)P_{ij}^{n} + \sum_{k \neq i}(b_{kj}^{n} + b_{kj}^{g})P_{kj}^{n} \\ D_{ij}^{g} = 0 \end{cases} \quad \text{(E.1b)}$$

Export supply of non-GM and GM DT wheat is described by equations E.2. In those exporting countries that do not produce GM DT wheat, supply in E.2b is restricted to zero and only one price equation, E.3a, is used.

$$S_{i}^{n} = L_{i}^{n} y_{i}^{n} \quad \text{(E.2a)}$$

$$S_{i}^{g} = L_{i}^{g} y_{i}^{g} \quad \text{(E.2b)}$$

The relationship between export supply and import demand prices (P_i and P_{ij}), even though not explicitly shown in the demand and supply equations, is as follows:

$$P_{i(k)}^{n} = P_{i(k)j}^{n}, \text{ where } P_{i(k)}^{n} = P(S)_{i(k)}^{n} \text{ and } P_{i(k)j}^{n} = P(S)_{i(k)}^{n} + F_{i(k)j} \quad \text{(E.3a)}$$

$$P_{i(k)}^{g} = P_{i(k)j}^{g}, \text{ where } P_{i(k)}^{g} = P(S)_{i(k)}^{g} \text{ and } P_{i(k)j}^{g} = P(S)_{i(k)}^{g} + F_{i(k)j} \quad \text{(E.3b)}$$

Finally, market clearing conditions are specified by the set of equations E.4. The notations used for equations E.1 to E.4 are as described previously.

$$\sum_{j=1}^{M} D_{ij}^{n} \equiv S_{i}^{n} \quad \text{(E.4a)}$$

$$\sum_{j=1}^{M} D_{ij}^{g} \equiv S_{i}^{g} \quad \text{(E.4b)}$$

2.3.4.2 Equilibrium conditions for MAS DT wheat scenarios

Since demand for MAS DT wheat is not vertically differentiated, the demand equation for wheat from exporter i by importer j, price relationships, and market clearing conditions are specified as in equations A.1 of the base case model. Supply from each exporting country i is specified as C.5. The set of equations F.1 is supplemented by appropriate notations, as specified previously.

$$D_{ij}^{m} = a_{ij}^{m} + b_{ij}^{m} P_{ij}^{m} + \sum_{k \neq i} b_{kj}^{m} P_{kj}^{m}, \forall i, j, k \quad \text{(F.1a)}$$

$$S_i^m = L_i^n y_i^n + L_i^m y_i^m \quad \text{(F.1b)}$$

$P_{i(k)}^m = P_{i(k)j}^m$, where $P_{i(k)}^m = P(S)_{i(k)}^m$ and $P_{i(k)j}^m = P(S)_{i(k)}^m + F_{i(k)j}$ (F.1c)

$$\sum_{j=1}^{M} D_{ij}^m \equiv S_i^m \quad \text{(F.1d)}$$

2.3.4.3 Welfare calculations

The calculation of consumer surplus (CS) and producer surplus (PS) follows a standard procedure (Jehle and Reny, 2001; Mas-Colell et al., 1995). Consumer surplus, calculated for each demand curve, is the area under the inverse demand curve and above equilibrium market price line[28]. The inverse demand curve takes the following form:

$$P_{ij} = \frac{-(a_{ij}+\sum_{k\neq i} b_{kj}P_{kj})}{b_{ij}} + \frac{1}{b_{ij}}D_{ij} \quad \text{(G.1a)}$$

where $\frac{-(a_{ij}+\sum_{k\neq j} b_{kj}P_{kj})}{b_{ij}} = A_{ij}$ to simplify notation. When solving the model, new equilibrium prices are found simultaneously and automatically included into the term A_{ij}. This way all cross price effects are captured in the intercept of an inverse demand curve.

Based on formula G.1a consumer surplus is calculated:

$$CS_{ij} = \frac{1}{2}(A_{ij} - P_{ij})D_{ij} \quad \text{(G.1b)}$$

In the scenarios for GM DT wheat, consumer surplus is calculated under import demand equation lines and above wheat price lines for non-GM and GM wheat coming from all exporting countries, following equation G.1b. These are summed up to obtain total consumer surplus for a particular importing country. In the scenarios for MAS DT wheat each importing country has only one demand equation for wheat shipped from a specific exporting country. It should be reminded that each importing country has as many demand equations as the number of countries this importing country trades with. For example, Algeria has four separate demand equations for wheat from Argentina, EU, USA, and Other

[28] The income effect on the demand function is zero (see section 2.3.3.5). Only when this is true does consumer surplus equal the area under the demand function and above the equilibrium price line. The majority of wheat importing nations exhibit medium or high per capita levels and relatively small consumption levels of wheat, suggesting that during the period of one year income effects of the modeled price changes are unlikely to be appreciable.

(aggregate exporter). Once Algeria starts importing GM DT wheat from the USA, the total number of demand equations increases to five (i.e., now having two demand equations for non-GM and GM DT wheat from the USA). Wheat imported to Algeria from the USA is considered a different product from wheat imported to Algeria from the EU. It is assumed there are no domestic producers of wheat in Algeria. This assumption holds for all other importing countries. Thus, consumer surplus in all importing countries denotes surplus from consuming only imported wheat.

Producer surplus is producer revenue minus variable costs. This is usually represented as the area above the inverse supply curve and below equilibrium market price line. However, in this model, profit functions of producers are calibrated. Thus, the producer surplus in each exporting country is calculated as follows:

$$PS_i = \Pi_i L_i \qquad \text{(G.2a)}$$

Producer surplus from a liner supply equation had to be calculated first to make sure that both calculation approaches produce the same result. In the base case model, where no GM and MAD DT wheat was introduced yet, producer surplus was calculated in the following way[29]:

$$PS_i = \frac{1}{2} P_i (S_i + c_i) \qquad \text{(G.2b)}$$

Since producer surplus is calculated based on supply equations that describe only export supply (see section 2.3.1), revenues from wheat sales to domestic consumers in wheat exporting countries are not included into the calculation of producer surplus. Revenues from sales to domestic consumers are implicitly being held constant.

[29] From the inverse supply equation $P_i = -\frac{c_i}{d_i} + \frac{1}{d_i} S_i$ producer surplus is measured as a difference between the area obtained by multiplying P_i by S_i and the area under supply curve and above quantity axis. This produces an area under price line and above inverse supply curve that corresponds to PS. Inverse supply curve intersects quantity axis at point c_i. Therefore, $PS_i = P_i S_i - \frac{1}{2} P_i (S_i - c_i) = P_i S_i - \frac{1}{2} P_i S_i + \frac{1}{2} P_i c_i = \frac{1}{2} P_i S_i + \frac{1}{2} P_i c_i = \frac{1}{2} P_i (S_i + c_i)$.

In the course of calibration producer surplus calculated from the profit function was adjusted to be equal to producer surplus calculated from the linear supply function by introducing parameter k (see section 2.3.3.2 for more detail).

In the scenarios for GM DT wheat, to obtain total producer surplus for a particular exporting country equation G.2a is adjusted as:

$$PS_i = \Pi_i^n L_i^n + \Pi_i^g L_i^g \qquad \text{(G.2c)}$$

Each exporting country has only one export supply equation (or profit function) that is used to calculate producer surplus in that country. When GM DT wheat is introduced, each exporting county has two export supply equations for non-GM and GM DT wheat (or two profit functions respectively). Producer surplus from both of these equations is summed up to obtain total producer surplus for a particular exporting country. For example, the USA has one wheat export supply equation in scenarios with MAS DT wheat, and two export supply equations in scenarios with GM DT wheat. It is assumed there are no domestic consumers of the USA wheat. This assumption holds true for all other exporting countries.

The assumption of no domestic producers in wheat importing countries and no domestic consumers in wheat exporting countries is a limitation of this study. For example, in the USA a considerable share of wheat is produced for domestic market. In this case exclusion of the U.S. domestic consumers from calculation of total consumer surplus may lead to underestimation of total consumer surplus. This limitation is noted. Here and thereafter in this thesis consumer surplus is related only to import demand consumer surplus, and producer surplus is related only to export supply producer surplus. Overall welfare is, therefore, denoted in this study as "trade welfare" and not "total welfare", as it does not include welfare of domestic consumers in wheat exporting countries and welfare of domestic producers in wheat importing countries.

Trade welfare (TW) is calculated as follows:

$$TW = \sum_{i=1}^{N} \sum_{j=1}^{M} CS_{ij} + \sum_{i=1}^{N} PS_i \tag{G.3}$$

Trade welfare is then maximized subject to the set of equilibrium constraints of equations E.1 to E.4 for the GM DT wheat scenarios and equations F.1 for the MAS DT wheat scenarios. All welfare results are reported as the change in PS and CS, and as the change in trade welfare (ΔTW), which is the difference between trade welfare of a baseline scenario and trade welfare from the specific scenario.

Profit of the improved variety developer is usually included into the calculation of total welfare. In the case of MAS DT wheat the revenue of seed breeder could be approximated by multiplying area seeded to MAS DT wheat (in ha) by seeding rate of wheat (in kg/ha) and by price premium of MAS DT wheat seed in $/kg (above the price of conventional wheat seed). In the case of GM DT wheat the revenue of biotechnology company could be approximated by multiplying area seeded to GM DT wheat (in ha) by technology fee (in $/ha). However, information on the costs to develop these MAS or GM DT wheat varieties is not available, and calculation of profits become challenging. Therefore, I excluded profits of seed breeders or biotechnology companies from the calculation of welfare. This can be considered a limitation of this study.

2.4 Results and discussion

2.4.1 Scenario descriptions

The summary of all scenarios for GM DT wheat and MAS DT wheat model is presented in table 2.7. Details and results for each are described in the following sections, as is sensitivity to key parameters.

Table 2.7 Description of the various DT wheat scenarios

Scenario sets	**Explanation**
Base case / Benchmark 0	Actual 2006/2007 wheat trade flows. *Exporters:* Argentina, Australia, Canada, EU, USA, Other *Importers:* Algeria, Brazil, Egypt, EU, Indonesia, Japan, South Korea, ROW
Benchmark 1	Base case + 10% mean yield loss of conventional wheat in Canada and USA due to drought
Benchmark 2	Base case + 10% mean yield loss of conventional wheat in Canada, USA, Argentina, and EU, and 20% mean yield loss of conventional wheat in Australia due to drought
GM DT wheat	
Scenario G0	GM wheat is adopted in Canada and USA There is no drought occurring GM DT wheat varieties have the same levels of yield as conventional wheat varieties EU, Japan and South Korea do not import GM wheat from Canada and USA
Scenario G1[a]	GM wheat is adopted in Canada and USA There is 10% mean yield loss of conventional wheat in Canada and USA due to drought EU, Japan and South Korea do not import GM wheat from Canada and USA
Scenario G2[a]	GM wheat is adopted in Canada and USA There is 10% mean yield loss of conventional wheat in Canada, USA, Argentina, and 20% mean yield loss of conventional wheat in Australia due to drought EU, Japan and South Korea do not import GM wheat from Canada and USA
Scenario G3[a]	GM wheat is adopted in Canada and USA There is 10% mean yield loss of conventional wheat in Canada and USA due to drought All importing countries accept GM DT wheat, assuming segregation system is well functioning
MAS DT wheat	
Scenario M0	MAS DT wheat is adopted in Canada and USA There is no drought occurring MAS DT wheat varieties have the same level of yield as conventional wheat varieties
Scenario M1[a]	MAS wheat is adopted in Canada and USA There is 10% mean yield loss of conventional wheat in Canada and USA due to drought
[a] – Mean yield loss of GM or MAS wheat due to drought in Canada and the USA in the respective scenarios is assumed to be 5% as outlined in tables 2.2 and 2.6.	

Benchmark scenarios are necessary to compare the outcomes of various scenarios and the sensitivities of different parameters relative to the common baseline outcome. The welfare effects (producer and consumer surplus) are then calculated for each scenario in terms of a change (e.g., $\Delta PS, \Delta CS$) from the common benchmark scenarios to assess whether the surplus increases (positive sign of the change) or diminishes (negative sign of the change).

The base case model, calibrated to actual 2006/2007 wheat trade data (see tables A.1 and A.2 of appendix A), serves as the benchmark (denoted benchmark 0) for the G0 and M0 scenarios (here and thereafter see table 2.7 for scenario definitions). These scenarios are just one step away from the base case. It is assumed that either GM or MAS DT wheat, respectively, is introduced both in Canada and the USA. However, there is no drought that would lead to wheat yield losses occurring in any of the countries in the model. In practice, drought tolerant varieties may perform better than conventional varieties even when there is no drought. However, it is conservatively assumed that the mean yield of GM or MAS DT wheat varieties is equal to the mean yield of conventional wheat varieties when there is no drought.

The base case model (i.e., benchmark 0) cannot serve as a benchmark for the rest of the scenarios, since the aim of this paper is to model performance of drought-tolerant wheat varieties under conditions of drought. Therefore, it is necessary to calculate welfare effects of the base case model assuming that some fraction of wheat yields was lost due to drought. In scenarios G1-G3 and M1 this yield loss is partially or totally avoided on those wheat planting areas where DT wheat is adopted. The benchmark 1 for G1, G3 and M1 scenarios is therefore a base case model into which a 10% mean yield loss is introduced in Canada and USA. This benchmark reflects the situation assumed when drought occurs only in the country-adopters of GM DT wheat[30]. The benchmark 2 for G2 scenario is a base case model in which a 10% mean yield loss is introduced in Canada, USA, and Argentina, and a 20% mean yield loss is introduced in Australia. This benchmark reflects the situation when drought occurs not only in the country-adopters of GM DT wheat, but also in other major exporting countries that do not have GM DT wheat technology available. Yield loss of 10% or 20% is introduced by setting $\tau = 0.1$ or $\tau = 0.2$ for the respective countries.

Scenario G1 is chosen to reflect the resistance of some countries to purchases of GM food. In particular, EU, Japan, and South Korea have strict policies in place to limit/exclude GM food imports, and are modelled elsewhere (e.g., Berwald et al., 2006) as countries that would not import GM wheat. Canada and the USA are modeled as country-adopters of GM DT wheat technology, since there is a high chance that this technology would be available first in the USA. Canada is very close to the USA geographically, and could also adopt this technology. Scenario G1 is an outer bound of what could happen if GM DT wheat is adopted. This is not a very realistic scenario as it only shows how the markets react when they are perfectly segregated along the shares of production allocated to GM and non-GM wheat. Without perfect segregation welfare gains from introducing GM DT wheat in Canada and USA may be reduced or nullified (i.e. “market for lemons”, see section 2.3.3.6). Without a perfect segregation system EU, Japanese and S. Korean wheat markets could be lost for Canada and the USA.

For the scenario M1, same country-adopters of MAS DT wheat varieties are chosen to enable comparison of GM DT and MAS DT wheat adoption and welfare implications.

[30] Only Canada and the USA are modelled as countries that adopt GM or MAS DT wheat. This does not preclude that Australia or any other major wheat producer and/or exporter will not adopt this wheat. Canada and the USA were selected based on the higher probability of introducing GM wheat in the USA by Monsanto. Canada has a common with the USA border and a very interrelated market.

Scenario G2 is a slight modification of Scenario G1. Scenario G2 assesses how occurrence of droughts in the countries that do not adopt GM DT wheat varieties influences welfare distributions. The only differences between the G1 and G2 scenarios is that in G2, Argentina and Australia are assumed to experience mean wheat yield losses of 10% and 20% respectively as a result of drought, but GM DT wheat is not available in these two countries.

Scenario G3 is similar to G1. However, it is hypothetically assumed that all of the importing countries (including the EU, Japan, and South Korea) are importing GM DT wheat. This scenario assesses outcomes for the world wheat market if there were no strict regulations against the importation of GM wheat, but all importing countries had demand for both non-GM and GM DT wheat.

2.4.2 Scenarios of GM DT and MAS DT wheat under absence of drought

2.4.2.1 Results of scenario G0

The equilibrium export prices of benchmark 0 are the prices from the calibrated base case model (see table A.1 of appendix A, and table 2.8). The welfare implications of G0 are differences of consumer and producer surplus from benchmark 0 (here and thereafter see table 2.7 for scenario definitions).

In scenario G0, Canada and the USA are considered to have adopted GM DT wheat in the reference year, 2006/2007. It is assumed that no drought occurs in the reference year, and the GM DT wheat varieties do not perform better than conventional wheat varieties. It is also assumed that the EU, Japan, and South Korea do not import GM wheat from Canada and the USA. This hypothetical scenario shows what happens when a new costly technology (GM DT wheat) does not perform differently from a conventional technology (non-GM wheat) while there is demand for this new technology (i.e., in all importing countries except EU, Japan, and South Korea). The G0 scenario was first solved with a constraint that forced GM DT wheat prices to be equal to non-GM wheat prices. At the same time adoption rates of GM DT wheat in Canada and USA were made endogenous, keeping all other variables at their baseline values. The solution of price levels and adoption rates is presented in table 2.8. As discussed in the section 2.3.3.2.2, this enables the model to obtain the lowest possible adoption rates of GM DT wheat in Canada and the USA for the GM DT market to exist. Based on the lowest possible levels of adoption, the baseline adoption levels are chosen for the benchmark scenario and are kept constant in all scenario analyses. Table 2.2 of section 2.3.3.2 contains the rest of the baseline parameter values that are used in the model.

Table 2.8 Equilibrium solution: the lowest GM DT wheat adoption rates when non-GM and GM DT wheat prices are held equal, scenario G0

	Argentina	**Australia**	**Canada**	**EU**	**USA**	**Other**
Price, non-GM wheat, $US/tonne (benchmark 0)	188.00	232.00	234.00	206.00	219.00	219.00
Price, non-GM wheat, $US/tonne	190.66	236.40	241.79	209.93	225.41	223.14
Price, GM DT wheat, $US/tonne	-	-	241.79	-	225.41	-
Adoption of GM DT wheat, % of drought-prone wheat planting area	-	-	0.63	-	0.51	-

Based on the lowest possible adoption rates of GM DT wheat in Canada (63%) and the USA (51%) from table 2.8, assumptions about adoption rates are developed. In scenario G0, it is assumed that GM DT wheat was introduced in Canada and the USA in 70% (or 35% of total wheat planting area) and 60% (or 36% of total wheat planting area) of drought prone wheat planting areas respectively in 2006/2007 (the reference year). It is also assumed that GM DT wheat varieties have the same mean yield as conventional wheat varieties under conditions of no drought in Canada and the USA in the reference year. The results of scenario G0 are presented in table 2.9.

Introduction of GM DT wheat leads to an increase in export prices of conventional wheat varieties and a decrease in export prices of GM DT wheat varieties (compared to the benchmark 0). This occurs because of the assumption that all importing countries except the EU, Japan, and South Korea demand GM wheat[31]. Consequently, some of the area that was planted to conventional wheat is designated to GM DT wheat, reducing the area planted to conventional wheat and driving up prices of conventional wheat. As a result, total exported wheat grain is reallocated between markets of non-GM and GM DT wheat. Segregation costs for conventional wheat also contribute to higher prices of conventional wheat compared to GM DT wheat. The change in producer surplus in all wheat exporting countries is positive and total producer welfare gain is $US 1,825 million (or 11% higher) compared to the benchmark 0.

Table 2.9 Results for scenario G0: welfare change from benchmark 0

Country	Export price		Benchmark 0		Scenario G0	
	Non-GM	**GM**	**Total PS**	**Total CS**	**Δ PS**	**Δ CS**
	in $US/tonne		in 1,000 $US		in 1,000 $US (%Δ)	
Argentina	199.40		1,575,950		179,337 (11)	
Australia	250.73		1,446,621		239,953 (17)	
Canada	264.29	231.90	2,631,868		306,389 (12)	
EU	222.81		1,794,097	263,940	201,602 (11)	46,162 (17)
USA	247.13	207.62	3,673,523		271,857 (7)	
Other	237.40		4,752,749		625,836(13)	
Algeria				727,136		-25,256 (-3)
Brazil				2,013,984		346 (0)
Egypt				448,388		19,761 (4)
Indonesia				369,555		2,390 (1)
Japan				1,211,288		69,560 (6)
S. Korea				507,823		10,246 (2)
ROW				3,652,104		40,766 (1)
TOTAL			**15,874,807**	**9,194,217**	**1,824,974 (11)**	**163,973 (2)**

Note: PS – producer surplus, CS – consumer surplus
Changes in CS and PS are denoted in absolute values and % changes from benchmark 0

Increase of total producer welfare as result of introducing weakly inferior GM DT wheat that does not perform better than non-GM wheat seems counter intuitive at first. Figure B.1 in appendix B conceptually illustrates changes in producer surplus in different exporting countries. In the exporting countries that do not adopt GM DT wheat, increase in non-GM prices leads to increase in quantity of

[31] Demand for GM DT wheat is driven by its lower prices compared to conventional wheat. If a fraction of consumers in each importing country is indifferent between buying GM or non-GM wheat when the prices are the same, then when GM prices are lower, more will be demanded.

non-GM wheat supplied relative to benchmark 0. Naturally, increased price and quantity supplied leads to increases in producer surplus in these countries.

Exporting countries that adopt GM DT wheat have two types of producers: those who adopt GM DT wheat, and those who do not adopt this. Producers that do not adopt GM DT wheat benefit from higher non-GM wheat prices in the same way as countries non-adopters of GM DT wheat do. Producers, who adopted GM DT wheat, lose producer surplus. GM DT wheat prices are lower relative to benchmark 0 prices. Adoption is induced by expected yield advantage that was not realized as a result of the absence of drought. Overall, producer surplus decrease of GM DT wheat producers is lower relative to the producer surplus increase of non-GM wheat producers.

When looking at the changes in consumer surplus, Algeria loses about $US -25 million when GM DT wheat is introduced in Canada and the USA. Algeria imports wheat from Canada, the USA, and EU. However, the import share from the EU is significantly larger. This means that Algeria imports predominantly non-GM wheat at a relatively higher price relative to benchmark 0. Figure B.2 in appendix B illustrates changes in cumulative[32] consumer surplus under scenario G0 in Algeria. All other importing countries gain with consumer surplus varying from as low as $US 0.3 million in Indonesia to a high of about $US 70 million in Japan. This is a somewhat counterintuitive result. Figure B.3 in appendix B illustrates changes in consumer surplus in scenario G0 in Japan, EU, and South Korea. These countries import only non-GM wheat, price of which has increased relative to benchmark 0. This result may be caused by cross-price effects dominating own price effects. At the same time, total wheat export supply quantities in G0 increase relative to benchmark 0 as a response to higher non-GM wheat prices. Therefore, there is additional quantity of wheat in the system that has to be consumed by some or all importing countries. Consumer surplus

[32] Cumulative or net consumer surplus depicted on figure B.2 is a summation of consumer surpluses of all demand curves for Algeria.

changes in these countries would be best represented by an illustration in figure B.3 of appendix B. It should be noted, that changes in consumer surplus are very small in magnitude relative to benchmark 0 (see table 2.9). Consumer surplus effects in Brazil, Egypt, Indonesia, and ROW are also positive. However, these countries demand both non-GM wheat and GM DT wheat, and have two demand equations that describe trade flows from Canada and the USA. Net effect of consumer surplus changes in these countries is very small (see table 2.9).

Scenario G0 suggests that even when a yield advantage of DT wheat is not present (in the absence of drought), the vertically differentiated market for wheat (GM versus non-GM) creates welfare gains. Sensitivity analysis is not provided for this scenario as the results are very similar to those of the G1-G3 scenarios.

2.4.2.2 Results of scenario M0

Similarly to G0, in scenario M0 Canada and the USA are considered to have adopted MAS DT wheat in reference year, 2006/2007. To make this scenario comparable with G0, it is assumed that MAS DT wheat was introduced in Canada and the USA in 70% (or 35% of total wheat planting area) and 60% (or 36% of total wheat planting area) of drought prone wheat planting areas respectively. There is no drought occurring in the reference year, and MAS DT wheat varieties do not perform better than conventional wheat varieties. It means that MAS DT wheat varieties have the same mean yield as conventional wheat varieties under conditions of no drought. Table 2.6 of section 2.3.3.4 contains the rest of the baseline parameter values that are used in the model. The welfare implications of M0 are differences of consumer and producer surplus from benchmark 0. Results of scenario M0 are presented in table 2.10.

Introduction of MAS DT wheat leads to a very slight, less than a dollar, increase in export prices of wheat compared to benchmark 0. This occurs because the seed cost of MAS DT wheat varieties is higher compared to the seed cost of conventional wheat. The change in producer surplus in all wheat exporting countries that are not adopters of MAS DT wheat is positive, however, quite low in magnitude. The producers in these countries benefit from the slightly increased wheat prices, but they only grow conventional wheat with a lower seed cost. Because of slightly increased prices of wheat, the area planted to wheat increases slightly, and so does wheat supply. Figure B.4 of appendix B illustrates changes in producer surplus in countries that are non-adopters of MAS DT wheat.

Table 2.10 Results for scenario M0: welfare change from benchmark 0

Country	**Export price**	**Benchmark 0**		**Scenario M0**	
		Total PS	**Total CS**	**Δ PS**	**Δ CS**
	in $US/tonne	in 1,000 $US		in 1,000 $US (%Δ)	
Argentina	188.17	1,575,950		2,659 (0.2)	
Australia	232.28	1,446,621		3,580 (0.2)	
Canada	234.49	2,631,868		-20,102 (-0.8)	
EU	206.25	1,794,097	263,940	3,029 (0.2)	43 (0.02)
USA	219.40	3,673,523		-35,643 (-1.0)	
Other	219.28	4,752,749		9,471 (0.2)	
Algeria			727,136		-342 (-0.05)
Brazil			2,013,984		19 (0.00)
Egypt			448,388		-49 (-0.01)
Indonesia			369,555		95 (0.03)
Japan			1,211,288		-90 (-0.01)
S. Korea			507,823		-305 (-0.06)
ROW			3,652,104		-767 (-0.02)
TOTAL		**15,874,807**	**9,194,217**	**-37,006 (-0.2)**	**-1,397 (-0.02)**

Note: PS – producer surplus, CS – consumer surplus
Changes in CS and PS are denoted in absolute values and % changes from benchmark 0

The change in producer surplus in Canada and the USA is negative and outweighs the positive producer surplus change in the other exporting countries. This occurs because the magnitude of the price increase does not outweigh the effect of decrease of both non-MAS and MAS DT wheat supply quantities in these two countries (see figure B.5 of appendix B). Canada and the USA lose surplus because the slight increase in wheat prices does not outweigh increases in their seed cost for MAS DT wheat. The total producer surplus change in all exporting countries, therefore, becomes negative and is equal to $US -37 million.

Consumer surplus change is negative in almost all countries, except the EU, Brazil, and Indonesia. The magnitude of the impact is very small, being only under $US 100,000 (or under 0.03%) in the EU, Brazil, Egypt, Indonesia and Japan, and under $US 1 million (or under 0.06%) in Algeria, South Korea, and the ROW (see table 2.10). Figure B.6 of appendix B illustrates decrease in consumer surplus in Algeria, Egypt, S. Korea, Japan, and ROW. Changes in consumer surplus that are shown in figure B.3 of appendix B for scenario G0 also reflect the nature of changes in consumer surplus in scenario M0 for the case of Brazil, EU, and Indonesia. The total consumer surplus change is $US -1.4 (or -0.02%) million compared to benchmark 0.

Scenario M0 suggests that even when yield advantage of MAS DT wheat is not present (in the absence of drought), the trade welfare change is negative compared to benchmark 0. Sensitivity analysis is not conducted for this scenario as the results are very similar to those of the M1 scenario.

2.4.3 Scenarios of GM DT and MAS DT wheat with yield losses of conventional wheat due to drought in Canada and the USA

2.4.3.1 Results of scenario G1

The solutions for equilibrium export prices in benchmark 1 are presented in table 2.11. The welfare implications of G1 are seen in the differences of consumer and producer surplus from benchmark 1 (here and thereafter see table 2.7 for scenario definitions).

In scenario G1, Canada and the USA are considered to have adopted GM DT wheat in reference year, 2006/2007. Droughts in Canada and the USA are assumed to occur in the reference year, and to cause 10% mean yield loss of conventional wheat but only 5% mean yield loss of GM DT wheat. It is also assumed that the EU, Japan, and South Korea do not import GM wheat from Canada or the USA. As in scenario G0, the G1 scenario was initially solved with a constraint that forced GM DT wheat prices to be equal to non-GM wheat prices. The adoption rates of GM DT wheat in Canada and the USA were made endogenous. The solution of price levels relative to benchmark 1 and adoption rates is presented in table 2.11.

Table 2.11 Equilibrium solution: the lowest GM DT wheat adoption rates when non-GM and GM DT wheat prices are held equal, scenario G1

	Argentina	**Australia**	**Canada**	**EU**	**USA**	**Other**
Price, non-GM wheat, $US/tonne (benchmark 1)	195.66	245.57	253.67	217.33	238.29	231.53
Price, non-GM wheat, $US/tonne	195.25	243.94	253.68	216.72	236.86	230.65
Price, GM DT wheat, $US/tonne	-	-	253.68	-	236.86	-
Adoption of GM DT wheat, % of drought-prone wheat planting area	-	-	0.56	-	0.49	-

Based on the lowest possible adoption rates of GM DT wheat in Canada (56%) and the USA (49%) from table 2.11, assumptions about adoption rates are developed. In scenario G1, it is assumed that GM DT wheat was introduced in Canada and the USA on 70% (or 35% of the total wheat planting area) and 60% (or 36% of the total wheat planting area) of drought prone wheat planting areas respectively in the reference year. Results of scenario G1 are presented in table 2.12.

Similarly to scenario G0, introduction of GM DT wheat when there is drought in Canada and the USA leads to changes in wheat prices. Export prices of conventional wheat varieties are higher and export prices of GM DT wheat are lower compared to benchmark 1. The reason for this price change is the existence of segregated markets for GM and non-GM wheat as in the case of scenario G0. However, in scenario G1, higher yield losses for conventional wheat, relative to GM DT wheat, also drive up the prices of conventional wheat. This is why, in scenario G1, the gap between the price of conventional wheat and GM DT wheat is larger than in scenario G0.

Table 2.12 Results for scenario G1: welfare change from benchmark 1

Country	Export price		Benchmark 1		Scenario G1	
	Non-GM	GM	Total PS	Total CS	Δ PS	Δ CS
	in $US/tonne		in 1,000 $US		in 1,000 $US (%Δ)	
Argentina	207.13		1,696,022		183,534 (11)	
Australia	263.38		1,607,238		243,942 (15)	
Canada	286.08	237.69	2,533,381		288,596 (11)	
EU	234.06		1,929,907	265,351	201,373 (10)	46,069 (12)
USA	264.53	214.80	3,569,651		204,454 (6)	
Other	249.90		5,178,154		629,920 (12)	
Algeria				711,925		-24,777 (-3)
Brazil				2,013,770		1,264 (0)
Egypt				446,564		21,498 (5)
Indonesia				373,927		6,961 (2)
Japan				1,203,800		73,590 (6)
S. Korea				493,882		10,676 (2)
ROW				3,617,246		76,672 (2)
TOTAL			**16,514,353**	**9,126,465**	**1,751,819 (11)**	**211,952 (2)**

Note: PS – producer surplus, CS – consumer surplus
Changes in CS and PS are denoted in absolute values and % changes from benchmark 1

The change in producer surplus in all wheat exporting countries is positive and total producer welfare gain is $US 1,752 million (or 11% higher) compared to benchmark 1. Producer surplus changes in scenario G1 are graphically illustrated in Figure B.7 of appendix B). Consumer surplus distribution is similar in magnitude to scenario G0 and very small. Algeria loses about $US 25 million (or 3%) from introduction of GM DT wheat in Canada and the USA. All other importing countries gain with consumer surplus varying from as low as $US 1 million in Brazil to a high about $US 77 million in the ROW. Figures B.2 and B.3 of appendix B of consumer changes in scenario G0 can graphically illustrate consumer changes in scenario G1.

Several conclusions can be drawn based on this scenario. The major conclusion is that adoption of GM DT wheat is welfare increasing and is driven mainly by higher non-GM wheat prices. This arises because some countries reject GM DT wheat imports and demand only non-GM wheat. This drives up prices of non-GM wheat. At the same time, drought causes more losses of non-GM wheat and this also drives up non-GM wheat prices. The existence of the two segregated markets, one for GM DT and the other for non-GM wheat causes wheat price difference on these two markets. As a result producer surplus in exporting countries increases and overweighs the consumer surplus decrease. It is understood that GM and non-GM wheat prices cannot grow apart infinitely. If non-GM wheat price were too high and GM price were too low, adoption of GM DT wheat would contract unless there were significant yield losses of non-GM wheat. In the case of our model, adoption rates are fixed.

Another feature is that cross-price effects and country of origin of wheat do matter. Some studies that utilize trade models take into account only own price effects and aggregate quantities of commodities that flow into the country. This study shows that even when own prices increase (e.g., South Korea), consumer welfare may still go up compared to the benchmark welfare. While this may look counter theoretical, two potential reasons of this have to be noted:

- In the case GM DT wheat model land supply of wheat is a function of wheat price. When price increases (for non-GM wheat for example), the total area planted to wheat increases relative to benchmark. As a result total quantity of wheat supplied by all exporting countries increases relative to benchmark. This wheat has to be redistributed among importing countries, even if the price of non-GM wheat is higher, while relative demand shares for non-GM and GM wheat remain constant in the model.
- The magnitude of total producer surplus change is higher than the magnitude of total consumer surplus change. Even if the cross-price effects did not dominate own price effects in some cases, the trade welfare result would not change by a large amount. Small changes of consumer surplus from benchmark may be considered insignificant in statistical terms.

Dominating cross-price effects occur because the importing country pays slightly different prices for wheat originating from different exporting countries. Moreover, in countries that accept both GM and non-GM wheat, there are price differences for these two types of wheat that can impact consumer welfare either positively or negatively. Thus, depending on whether an importing country accepts GM wheat or not, which exporting countries provide most of their import volumes, and on the price levels and cross-price effects, consumer welfare may be positive or negative.

2.4.3.2 Results of scenario M1

The benchmark for scenario M1 for MAS DT wheat is the same as for scenario G1 for GM DT wheat, which is a base case model with introduced 10% mean wheat yield loss in Canada and the USA. To calculate results, the baseline values of the various parameters from table 2.6 are used. Model results are presented in the table 2.13.

Table 2.13 Results for scenario M1: welfare change from benchmark 1

Country	**Export price**	**Benchmark 1**		**Scenario M1**	
		Total PS	**Total CS**	**Δ PS**	**Δ CS**
	in $US/tonne	in 1,000 $US		in 1,000 $US (%Δ)	
Argentina	193.71	1,696,022		-30,787 (-1.8)	
Australia	241.38	1,607,238		-41,048 (-2.6)	
Canada	248.75	2,533,381		-33,364 (-1.3)	
EU	214.45	1,929,907	265,351	-34,550 (-1.8)	-363 (-0.1)
USA	233.36	3,569,651		-55,845 (-1.6)	
Other	228.35	5,178,154		-108,477 (-2.1)	
Algeria			711,925		3,843 (0.5)
Brazil			2,013,770		99 (0.0)
Egypt			446,564		310 (0.1)
Indonesia			373,927		-1,165 (-0.3)
Japan			1,203,800		1,966 (0.2)
S. Korea			493,882		3,529 (0.7)
ROW			3,617,246		7,909 (0.2)
TOTAL		**16,514,353**	**9,126,465**	**-304,070 (-1.8)**	**16,128 (0.2)**
Note: PS – producer surplus, CS – consumer surplus Changes in CS and PS are denoted in absolute values and % changes from benchmark 1					

In scenario M1, MAS DT wheat is introduced in Canada and the USA in the reference year under conditions of drought in these two countries, and MAS DT wheat varieties lose 5% of mean yield compared to conventional wheat varieties that lose 10% of mean yield. This leads to a slight decrease in export prices (table 2.13) compared to price levels in benchmark 1 (table 2.11). This is expected, since lower yield loss of MAS DT wheat results in higher wheat mean yield worldwide and therefore lower equilibrium price. This leads to a negative change in producer surplus in all exporting countries. Figures B.8 and B.9 of appendix B illustrate graphically changes in producer surplus in countries that did not adopt MAS DT wheat, and in the countries that did adopt this (i.e., Canada and the USA) respectively.

All wheat importing countries except the EU and Indonesia have a positive change in consumer surplus due to the decrease in wheat prices. In Indonesia and the EU country cases only it seems to be that cross-price effects overall are stronger than the own price effects. This leads to a slight decrease in consumer surplus, which is less than $US 1 million (or -0.1% change from benchmark) in the EU and slightly more than $US 1 million (or -0.3% change from benchmark) in Indonesia. Figures B.10 and B.11 of appendix B illustrate graphically changes in consumer surplus in wheat exporting countries for scenario M1.

Total loss of total producer surplus in M1 is equal to $US -304 million and total gain of consumer surplus is $US 16 million. Therefore, trade welfare change from benchmark 1 is equal to $US -288 million.

Adoption of MAS DT wheat in the drought prone areas of the countries that are major exporters of wheat may lead to a decrease in trade welfare. Individually producers that adopted MAS DT wheat may feel that they are better off as their yields are higher than they would have been with conventional wheat only. However, in aggregate the increase in production reduced wheat prices relative to the benchmark scenario with drought. As a result producer surplus in exporting countries decreases and outweighs increases in consumer surplus. This arises because drought tolerance in MAS wheat is essentially a technological advancement that allows producing more wheat (i.e., losing less wheat yield if drought occurs) at a lower price. The distribution of welfare benefits between producers and consumers usually depends on the elasticities of the demand and supply, and the nature of the supply shift caused by introduction of a technological advancement. In this particular case, demand for wheat is price inelastic and negative price effect outweighs positive quantity effect.

The outcome of scenario M1 is different from that of scenario G1. In the case of GM DT wheat scenario, the price premium paid on non-GM wheat allows wheat exporters to benefit even when drought occurs. This happens because certain importing countries reject better performing but cheaper GM DT wheat in favor of more expensive conventional wheat. In the case of MAS DT wheat scenario, there is only one price for both conventional wheat and MAS DT wheat. Therefore, if some portion of wheat planted area is sown to MAS DT wheat, it will produce better yield in a drought year compared to conventional wheat. However, it will be sold at the same price as conventional wheat, which will be lower than the benchmark price due to higher level of wheat supply.

2.4.4 Scenario of GM DT wheat with yield losses of conventional wheat due to drought in Argentina, Australia, Canada and the USA

The solution for equilibrium export prices in benchmark 2 are presented in table 2.14. The welfare implications of G2 are seen in the differences of consumer and producer surplus from benchmark 2 (here and thereafter see table 2.7 for scenario definitions).

In scenario G2, Canada and the USA are considered to have adopted GM DT wheat in reference year, 2006/2007. Droughts in Canada and the USA are assumed to occur in the reference year, and to cause 10% mean yield loss of conventional wheat but only 5% mean yield loss of GM DT wheat. Argentina and Australia experience mean wheat yield losses of 10% and 20% respectively as a result of drought, but GM DT wheat is not available in these two countries. The EU, Japan, and South Korea do not import GM DT wheat from Canada and the USA.

As in G1, the model was solved first with adoption rates kept endogenous. Prices of GM DT wheat in Canada and the USA were held equal to non-GM wheat prices in the respective countries. The solution of price levels relative to benchmark 2 and adoption rates is presented in table 2.14.

Table 2.14 Equilibrium solution: the lowest GM DT wheat adoption rates when non-GM and GM DT wheat prices are held equal, scenario G2

	Argentina	**Australia**	**Canada**	**EU**	**USA**	**Other**
Price, non-GM wheat, $US/tonne (benchmark 2)	212.91	271.44	264.24	226.73	248.68	241.97
Price, non-GM wheat, $US/tonne	210.28	267.25	258.89	222.97	241.92	237.60
Price, GM DT wheat, $US/tonne	-	-	258.89	-	241.92	-
Adoption of GM DT wheat, % of drought-prone wheat planting area	-	-	0.52	-	0.46	-

The adoption rates of minimum 0.52 and 0.46 in Canada and the USA respectively are necessary for GM DT market to exist, holding all other variables at their baseline values. These minimum adoption rates are a bit lower than adoption rates of 0.56 and 0.49 in Canada and the USA respectively in scenario G1. The equilibrium prices are higher compared to the scenario G1 (see table 2.11). This occurs because in benchmark 2 world wheat yield losses due to drought are higher compared to benchmark 1. However, for benchmark 2, adoption levels of 0.7 (or 35% of total wheat planting area) and 0.6 (or 36% of total wheat planting area) in Canada and the USA respectively are still used as baseline values. Model results are presented in table 2.15.

Introduction of GM DT wheat leads to an increase in export prices of conventional wheat varieties and a decrease in export prices of GM DT wheat varieties (compared to benchmark 2). This is the same outcome as in scenario G1. In scenario G2, the prices of non-GM wheat in exporting countries are even higher than in scenario G1, since scenario G2 assumes higher yield losses of conventional wheat due to drought.

The change in producer surplus in all wheat exporting countries is positive and total producer welfare gain is $US 1,827 million (or 11% higher) compared to benchmark 2. Consumer surplus effects are similar to those from scenario G1 in magnitude and in the direction of change. Total producer surplus in the model is positive and higher compared to G1, and total consumer surplus is positive and lower compared to G1. Trade welfare change is higher in scenario G2, even though mean wheat yield loss due to drought is higher in this scenario. Conceptual graphical representation of consumer and producer welfare changes is similar to scenario G0 (see Figures B.2, B.3) and scenario G1 (see Figure B.7).

Table 2.15 Results for scenario G2: welfare change from benchmark 2

Country	**Export price**		**Benchmark 2**		**Scenario G2**	
	Non-GM	**GM**	**Total PS**	**Total CS**	**Δ PS**	**Δ CS**
	in $US/tonne		in 1,000 $US		in 1,000 $US (%Δ)	
Argentina	226.43		1,641,571		194,164 (12)	
Australia	293.22		1,277,359		221,511 (17)	
Canada	302.11	237.69	2,722,254		296,005 (11)	
EU	245.82		2,042,907	263,658	230,464 (11)	46,891 (18)
USA	277.55	214.80	3,821,593		158,366 (4)	
Other	262.99		5,535,075		726,344 (13)	
Algeria				702,473		-27,512 (-4)
Brazil				1,956,032		-1,171 (0)
Egypt				446,149		22,702 (5)
Indonesia				368,779		344 (0)
Japan				1,211,486		75,299 (6)
S. Korea				480,900		8,301 (2)
ROW				3,612,625		74,503 (2)
TOTAL			**17,040,759**	**9,042,103**	**1,826,853 (11)**	**199,356 (2)**

Note: PS – producer surplus, CS – consumer surplus
Changes in CS and PS are denoted in absolute values and % changes from benchmark 2

The main conclusion of scenario G2 is that when droughts occur in multiple wheat exporting countries producer welfare in these countries is higher compared to when drought occurs only in a few wheat exporting countries. More severe droughts in multiple wheat exporting countries cause world prices of conventional wheat to rise and the producer welfare increase outweighs consumer surplus decrease.

2.4.5 Scenario of GM DT wheat with the assumption that all importing countries of the model accept GM DT wheat

This scenario is denoted as G3 and is built on the same assumptions as scenario G1 except one: it is assumed that all importing countries accept GM DT wheat provided there is an effective segregation system in place. Canada and the USA are still considered to have adopted GM DT wheat in the reference year, 2006/2007. Droughts in Canada and the USA are assumed to occur in the reference year, and to cause 10% mean yield loss of conventional wheat but only 5% mean yield loss of GM DT wheat. The welfare implications of G3 are seen in the differences of consumer and producer surplus from benchmark 1 (here and thereafter see table 2.7 for scenario definitions).

As in scenarios G0 to G2, the G3 scenario was initially solved with a constraint that forced GM DT wheat prices to be equal to non-GM wheat prices. The adoption rates of GM DT wheat in Canada and USA were made endogenous. The solution of price levels relative to benchmark 1 and adoption rates is presented in table 2.16.

Table 2.16 Equilibrium solution: the lowest GM DT wheat adoption rates when non-GM and GM DT wheat prices are held equal, scenario G3

	Argentina	**Australia**	**Canada**	**EU**	**USA**	**Other**
Price, non-GM wheat, $US/tonne (benchmark 1)	195.66	245.57	253.67	217.33	238.29	231.53
Price, non-GM wheat, $US/tonne	192.24	238.99	245.38	212.28	229.72	225.74
Price, GM DT wheat, $US/tonne	-	-	245.38	-	229.72	-
Adoption of GM DT wheat, % of drought-prone wheat planting area	-	-	0.75	-	0.65	-

In scenario G3, the lowest possible adoption rates of GM DT wheat in Canada and the USA are 75% and 65% respectively, which is somewhat higher than the respective lowest possible adoption rates in scenarios G0 (63% and 51%), G1 (56% and 49%), and G2 (52% and 46%). Since Japanese, South Korean, and EU markets are now open to imports of GM DT wheat, the demand of GM DT wheat is higher. Provided that GM DT wheat is priced lower than conventional wheat, larger area planted to GM DT wheat is required to meet the demand in GM DT wheat.

Based on the lowest possible adoption rates of GM DT wheat from table 2.16 it is not possible to set the same rates as in scenarios G1 and G2 (i.e., 70% in Canada and 60% in the USA). For the purpose of scenario G3, 85% adoption rate (or 42.5% of total wheat planting area) in Canada and 75% adoption rate (or 45% of total wheat planting area) in the USA are assumed. Adoption levels are percentages of the drought prone wheat planting areas in the reference year. Results of scenario G3 are presented in table 2.17.

Table 2.17 Results for the scenario G3: welfare change from benchmark 1

Country	**Export price**		**Benchmark 1**		**Scenario G3**	
	Non-GM	**GM**	**Total PS**	**Total CS**	**Δ PS**	**Δ CS**
	in $US/tonne		in 1,000 $US		in 1,000 $US (%Δ)	
Argentina	203.15		1,696,022		119,401 (7)	
Australia	256.89		1,607,238		159,236 (10)	
Canada	275.28	234.67	2,533,381		97,929 (4)	
EU	228.28		1,929,907	265,351	131,669 (7)	2,026 (1)
USA	255.35	213.21	3,569,651		-27,607 (-1)	
Other	243.48		5,178,154		408,899 (8)	
Algeria				711,925		-17,243 (-2)
Brazil				2,013,770		1,085 (0)
Egypt				446,564		19,492 (4)
Indonesia				373,927		1,904 (1)
Japan				1,203,800		-138,856 (-12)
S. Korea				493,882		-40,445 (-8)
ROW				3,617,246		62,657 (2)
TOTAL			**16,514,353**	**9,126,465**	**889,527 (5)**	**-109,386 (-1)**

Note: PS – producer surplus, CS – consumer surplus
Changes in CS and PS are denoted in absolute values and % changes from benchmark 1

In scenario G3, export prices of conventional wheat varieties are higher and export prices of GM DT wheat are lower relative to benchmark 1 (see table 2.17). This is the same outcome as in scenarios G0 to G2 due to the existence of segregated markets of GM and non-GM wheat. The change in producer surplus in all wheat exporting countries except the USA is positive and total producer welfare gain is $US 890 million relative to benchmark 1. The change in consumer surplus is negative and is equal to $US -109 million. Figures B.2 and B.3 of appendix B conceptually illustrate changes in consumer surplus in scenario G0 that are similar to the changes in consumer surplus in scenario G3.

The distribution pattern of welfare change in G3 is different from the other scenarios. However, it is not possible to directly compare the outcomes, as the adoption rates in G3 are different. This scenario shows that GM DT wheat adoption can be welfare reducing under specific circumstances, since the producer surplus change in the USA is negative. One of the major reasons is that in this scenario there are no trade restrictions imposed on GM DT wheat that inflate conventional wheat prices as much as in the case of scenarios G1 and G2. Japan, South Korea and EU are now assumed to demand cheaper GM DT wheat. Japan and South Korea generally import large quantities of wheat from the USA. This implies that now the USA has to supply large quantities of both non-GM and GM wheat to these countries at a possibly lower average wheat price relative to benchmark 1.

The other reason of negative producer welfare in the USA is that the adoption rate of GM DT wheat assumed in this scenario is relatively low (75% for the USA, or 45% of total wheat planting area) when comparing with the lowest possible adoption rate (65%). The prices for GM DT wheat in the USA are lower compared to the prices of GM DT wheat in Canada. This indicates that higher volumes of cheaper GM DT wheat are flowing to the importing countries from the USA. Additional discussion of negative producer surplus is provided in section 2.4.6. Very low adoptions rates of GM DT wheat while all importing countries are assumed to demand this wheat can lead to negative producer surplus changes in all wheat exporting countries.

2.4.6 Sensitivity analysis

To observe how welfare changes in different scenarios when some parameters of the model are varied, each parameter that is subject to sensitivity analysis is assigned two alternative values. One of these alternative values is lower than the baseline value and another one is higher (see table 2.18). All numerical results of the sensitivity analyses are provided in tables A.6 to A.10 of appendix A.

Table 2.18 Baseline and alternative values of key parameters for sensitivity analysis

Sensitivity to:	Scenarios	Parameter	Value 1	Baseline	Value 2
Adoption rate[a] both in Canada and the USA*	G1, M1, G2	ρ^g (ρ^m) Canada	0.6	0.7	0.8
		ρ^g (ρ^m) USA	0.5	0.6	0.7
	G3	ρ^g Canada	0.75	0.85	0.95
		ρ^g USA	0.65	0.75	0.85
Yield loss[b] both in Canada and the USA*	G1, M1	β^g (β^m) Canada/USA	0	0.05	0.1
Segregation cost[c] both in Canada and the USA	G1	φ Canada/USA	0	3	6
Technology fee[d] both in Canada and the USA	G1	μ Canada/USA	5	15	25
Seed price[e] of MAS DT wheat both in Canada and the USA	M1	ω^mCanada/USA	0	0.3	0.6

* – sensitivity is performed for the parameters specified both in GM and MAS DT wheat model
a – fraction of drought prone area that may be planted with DT wheat
b –fraction of actual baseline wheat yield
c – in $US/t
d –in $US/ha
e – percent point increase relative to conventional wheat seed price

2.4.6.1 Adoption rate of DT wheat in Canada and the USA

Adoption rates are varied in the scenarios G1, M1, G2, and G3 as outlined in table 2.18. In scenarios G1 and G2 these values apply to the adoption of GM DT wheat in Canada and the USA simultaneously, with 0.6 and 0.5 (lower alternative value), 0.7 and 0.6 (current baseline value), and 0.8 and 0.7 (higher alternative value) respectively. In scenario M1, the same parameter values apply to the adoption of MAS DT wheat in Canada and the USA simultaneously. In scenario G3 these parameters are varied in Canada and the USA simultaneously, with 0.75 and 0.65 (lower alternative value), 0.85 and 0.75 (current baseline value), and 0.95 and 0.85 (higher alternative value) respectively. The sensitivity of welfare to the changes in DT wheat adoption rates are discussed for scenarios G1 and M1 first (as these two scenarios have a common benchmark), followed by scenario G2. Sensitivity results in G3 are discussed at the end of the section, since the choice of the parameter values for sensitivity analysis differs from the other three scenarios.

In G1, when the level of adoption is increasing in Canada and the USA simultaneously, the change in producer surplus in all exporting countries is positive and increasing. Consumer surplus increases in Brazil, Egypt, EU, Indonesia, and the ROW when there are increasing adoption levels for GM DT wheat. In contrast, consumer surplus decreases in Algeria, Japan, and South Korea. Consumer surplus overall increases with higher levels of GM DT wheat adoption (see table A.6 of appendix A). The graphical representation of changes in producer and consumer surplus is provided in figure 2.1.

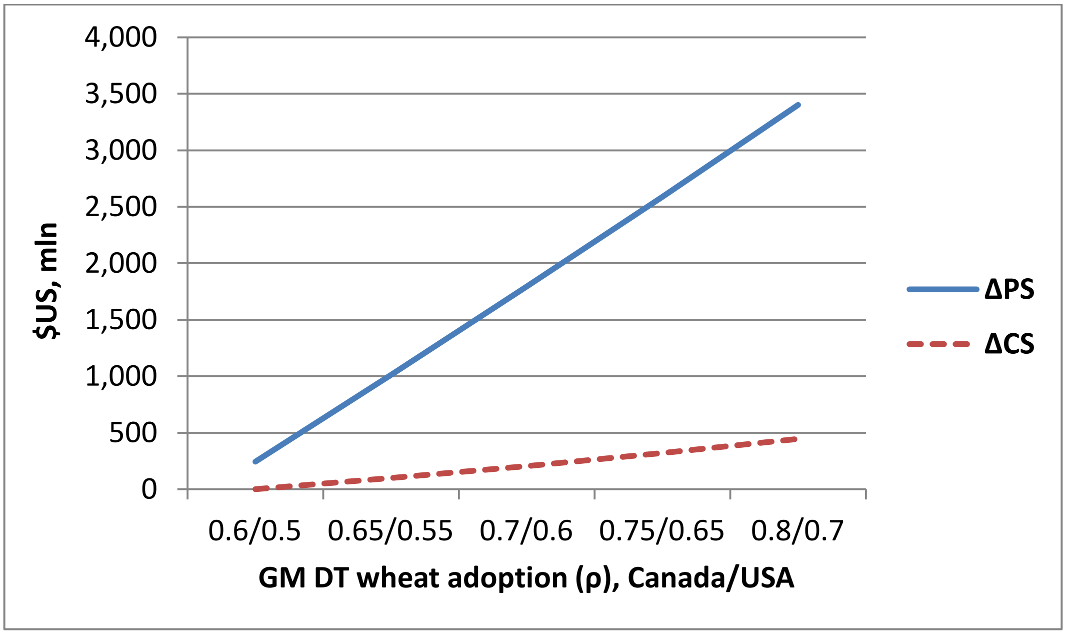

Figure 2.1 Sensitivity of producer surplus (PS) and consumer surplus (CS) change to the levels of GM DT wheat adoption: scenario G1

The model is very sensitive to the adoption level of GM DT wheat in the exporting countries. Relative to total consumer surplus, total producer surplus increases at a higher rate. This arises because producer surplus increases in all exporting countries, while consumer surplus increases in some countries and decreases in others. An implication of this result is that when adoption of GM DT wheat increases, the available wheat planting area decreases for conventional wheat. At the same time, all importing countries demand conventional wheat, and Japan, South Korea and EU demand only conventional wheat. The rising prices for conventional wheat that result from its deficit supply causes producer gains. However, the interpretation of this result should be treated with caution. Fixed adoption rates are assumed in the scenarios and the sensitivity analyses. The level of the rate of adoption is not a function of profit per hectare of the GM DT wheat compared to conventional wheat. In real life the choice to adopt or not adopt a new technology depends on its profitability. In this study fixed levels of adoption rates are considered to enable comparisons between scenarios of GM DT wheat and MAS DT wheat.

In M1, when adoption rate is increasing both in Canada and the USA, prices of MAS DT wheat are slightly decreasing in all wheat exporting countries (see table A.6 of appendix A). The producer surplus change from benchmark 1 in all wheat exporting countries is decreasing and negative. The consumer surplus change is positive and increasing in all importing countries except the EU and Indonesia, where consumer surplus change is negative and slightly decreasing. Total consumer surplus change is positive and increasing (see figure 2.2 for graphical results).

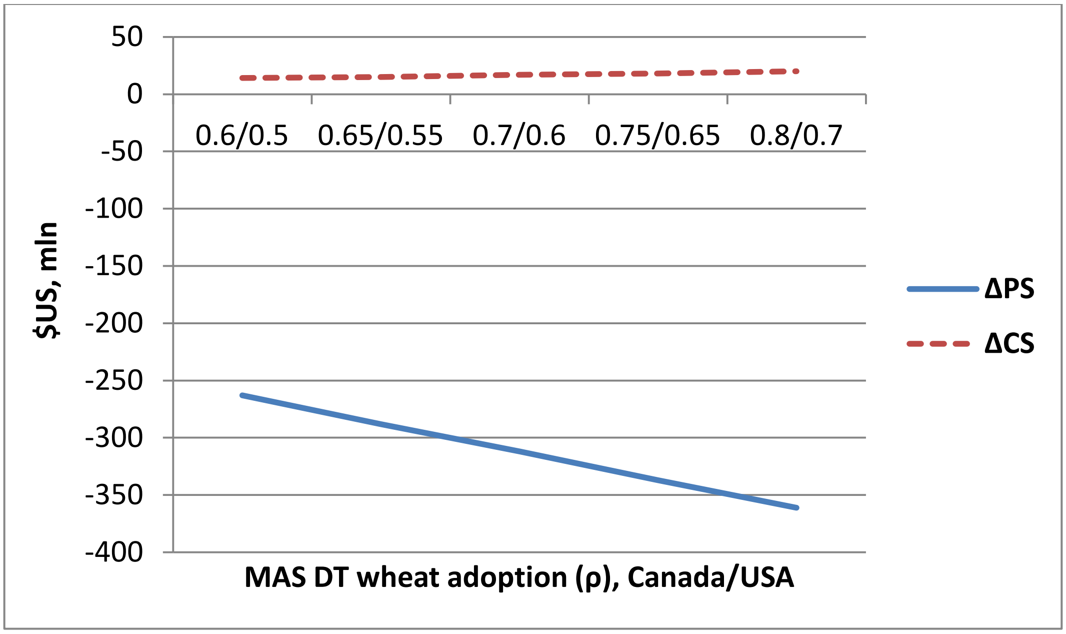

Figure 2.2 Sensitivity of producer surplus (PS) and consumer surplus (CS) change to the levels of MAS DT wheat adoption: scenario M1

The conclusion based on changes in MAS DT wheat adoption levels in scenario M1 is that producer surplus change is decreasing with higher adoption levels, and it is much less sensitive to the increase in adoption level compared to GM DT wheat (see sensitivity results in G1). In the case of GM DT wheat the magnitude of welfare change is about $US 1700 million when GM DT wheat adoption increases from 0.6 to 0.7 in Canada and from 0.5 to 0.6 in the USA simultaneously. In the case of MAS DT wheat the welfare change is about $US 45 million. The magnitude of consumer surplus change is slightly lower in the case of MAS DT wheat as well.

In G2, when the level of adoption is increasing in Canada and the USA simultaneously, the prices of non-GM wheat are increasing and the prices of GM DT wheat are decreasing (see table A.6 of appendix A). Prices of GM DT wheat are the same as in scenario G1, because Canada and the USA are experiencing the same wheat yield loss due to drought. The prices of non-GM wheat however are higher than in G1 and the changes of the prices with higher adoption rate are more pronounced compared to G1. This occurs because more non-GM wheat is lost due to drought in Argentina and Australia.

The change in producer surplus in all exporting countries is increasing as in G1. However, this time when the adoption of GM DT wheat in the USA is only 0.5, the surplus of the USA producers is equal to -$40.5 million. This means that with higher wheat yield losses worldwide and lower adoption rates of GM DT wheat in the USA, the welfare of the USA producers may deteriorate. Consumer surplus is increasing in Egypt, the EU, Indonesia, and the ROW while adoption level of GM DT wheat is increasing. Algeria, Brazil, Japan, and South Korea have decreasing consumer surplus. Changes in consumer surplus are comparable to G1 in magnitude and the direction of change. The total consumer surplus is increasing with higher levels of GM DT wheat adoption. Figure 2.3 displays the graphical representation of welfare changes under various DT GM wheat adoption rates in G2. The implication of the sensitivity in G2 is that when droughts occur on a larger territory, the trade welfare change is even more sensitive to the levels of GM DT wheat adoption. It is hard to see on a graph, however, the numerical values of welfare have a larger spread in the case of G2 than in G1 (see table A.6 of appendix A).

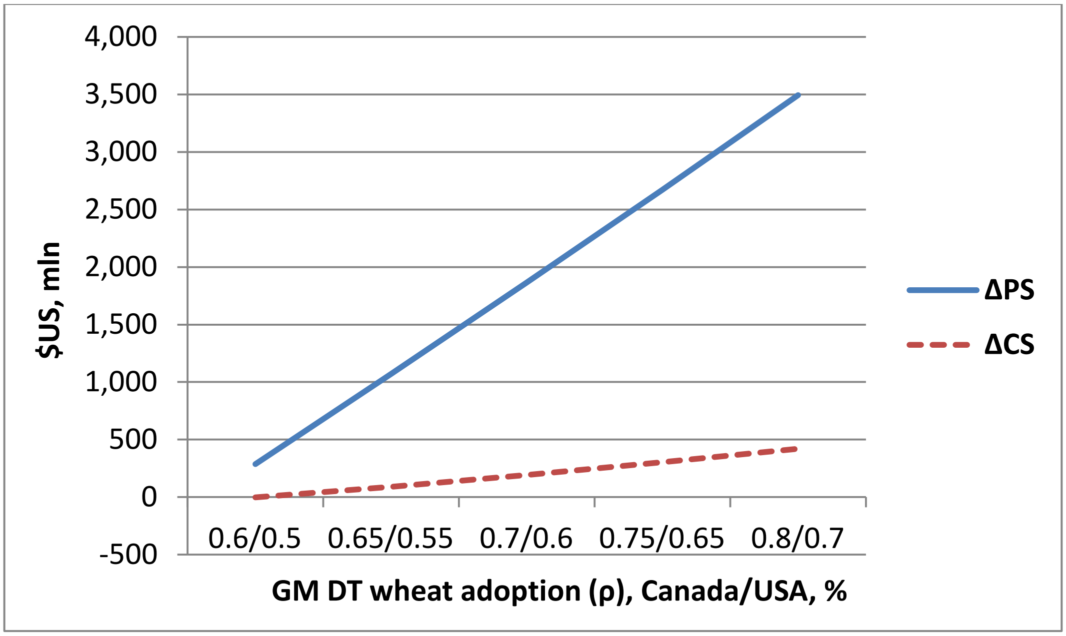

Figure 2.3 Sensitivity of producer surplus (PS) and consumer surplus (CS) change to the levels of GM DT wheat adoption: scenario G2

In scenario G3, the lower alternative values (i.e., value 1) for the adoption rate of GM DT wheat in Canada and the USA are intentionally chosen to be the lowest possible adoption rates that were calculated (see table 2.16). This allows estimating welfare effect changes in the extreme case when GM DT wheat prices and conventional wheat prices are equal. The numerical results of this sensitivity are presented in table A.6 of appendix A. Figure 2.4 displays the graphical results.

When the level of adoption increases in Canada and the USA simultaneously, the prices of non-GM wheat increase and the prices of GM DT wheat decrease (see table A.6 of appendix A) as in scenarios G1 and G2. However, in scenario G3 at the lowest possible level of GM DT wheat adoption, the change in producer surplus in all exporting countries is negative relative to benchmark 1. This occurs because at this level of adoption the prices for GM DT and conventional wheat are lower than the price in benchmark 1. Another reason for this result is that at the lower alternative level of adoption, the prices of conventional and GM DT wheat are equal. Under such circumstances GM DT wheat producers lose money on GM DT wheat, since they have to pay a technology fee, even though the price they receive for GM DT wheat is equal to the price of conventional wheat varieties. Conventional wheat producers also lose money as they have to segregate their wheat from GM DT wheat. As the adoption of GM DT wheat increases and so do prices for conventional wheat, the producer surplus in all exporting counties becomes positive.

Consumer surplus is increasing in Brazil, Egypt, the EU, Indonesia, Japan, and the ROW when adoption level of GM DT wheat is increasing. Algeria and South Korea have decreasing consumer surplus. The overall consumer surplus is increasing with higher levels of GM DT wheat adoption.

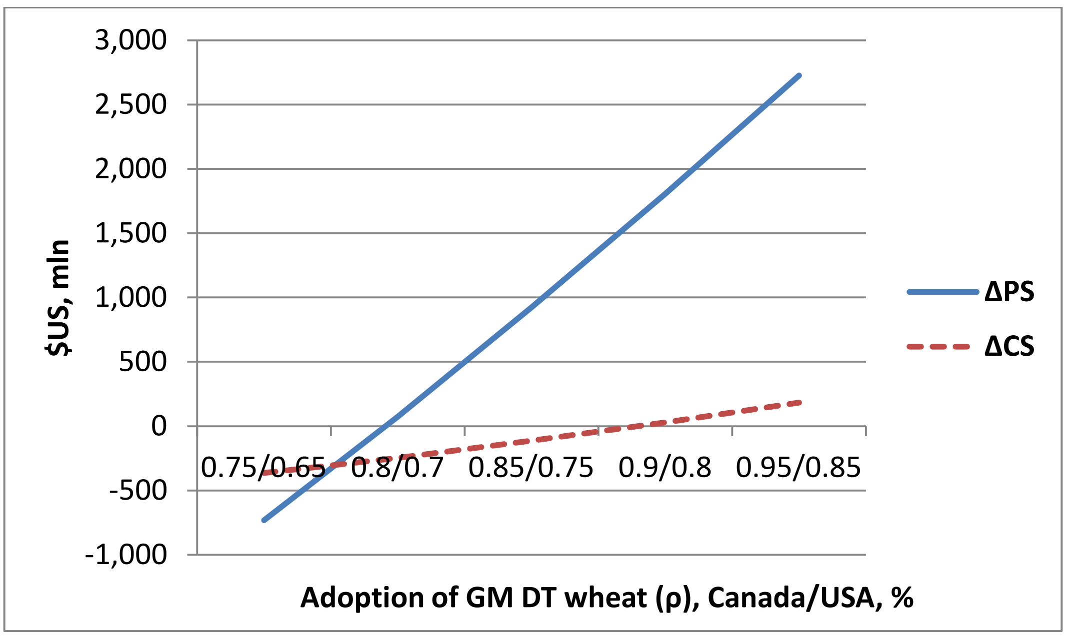

Figure 2.4 Sensitivity of producer surplus (PS) and consumer surplus (CS) change to the levels of GM DT wheat adoption: scenario G3

The implications of the sensitivity in scenario G3 is that under unrestricted GM DT wheat trade and at the lower end of adoption levels GM DT wheat adoption may be welfare reducing. However, once GM DT wheat and conventional wheat prices start to grow apart, wheat exporting countries benefit from higher prices for conventional wheat.

2.4.6.2 Yield loss of DT wheat in Canada and the USA

Yield loss is varied in the scenarios G1 and M1, as outlined in table 2.18. In scenario G1 the parameters of yield loss of GM DT wheat varieties are assumed to change simultaneously in Canada and the USA. One of the alternative values for yield loss is set to zero. This suggests that when conventional wheat varieties lose 10% of yield ($\tau^n = 0.1$), GM DT wheat varieties do not lose yield at all. The baseline value of yield loss remains at the same level of 0.05. The other alternative value of yield loss is 0.1. In this case there is no yield advantage for GM DT wheat over conventional non-DT wheat. Failure of GM DT wheat varieties to exhibit yield advantages over conventional wheat varieties under drought conditions voids the purpose of GM DT wheat variety and may demotivate its adoption in the future. However, this situation might happen in real life if the drought is very severe, or if there are other factors that nullify the yield advantage of DT wheat. In scenario M1, the same parameter values apply to the yield loss of MAS DT wheat in Canada and the USA simultaneously. The sensitivity of welfare to the changes in DT wheat yield loss are discussed for scenarios G1 and M1 first (as these two scenarios have a common benchmark), followed by scenario G2.

In G1, wheat prices and producer surplus in those exporting countries that are not adopters of GM DT wheat do not change (see table A.7 of appendix A). This is a consequence of having two separate demand functions for non-GM wheat and GM DT wheat in the importing countries. When the level of GM DT wheat yield loss increases (or in other words, when the level of GM DT wheat yield advantage decreases), prices of GM DT wheat increase slightly. The producer surplus overall in both Canada and the USA is positive and decreases, despite increasing prices for GM DT wheat. This arises because the magnitude of yield loss outweighs the price increase, and because increasing prices lead to lower export volumes of GM DT wheat.

Consumer surplus in the EU, Japan, and South Korea does not change, since these countries do not import GM DT wheat from either Canada or the USA, and the price of conventional non-GM wheat does not change. Consumer surplus in Algeria, Brazil, Egypt, Indonesia and the ROW is decreasing, because consumers in these countries are forced to pay GM DT wheat at somewhat higher prices. Trade welfare is positive and decreases with the declining yield advantage of GM DT wheat (see figure 2.5).

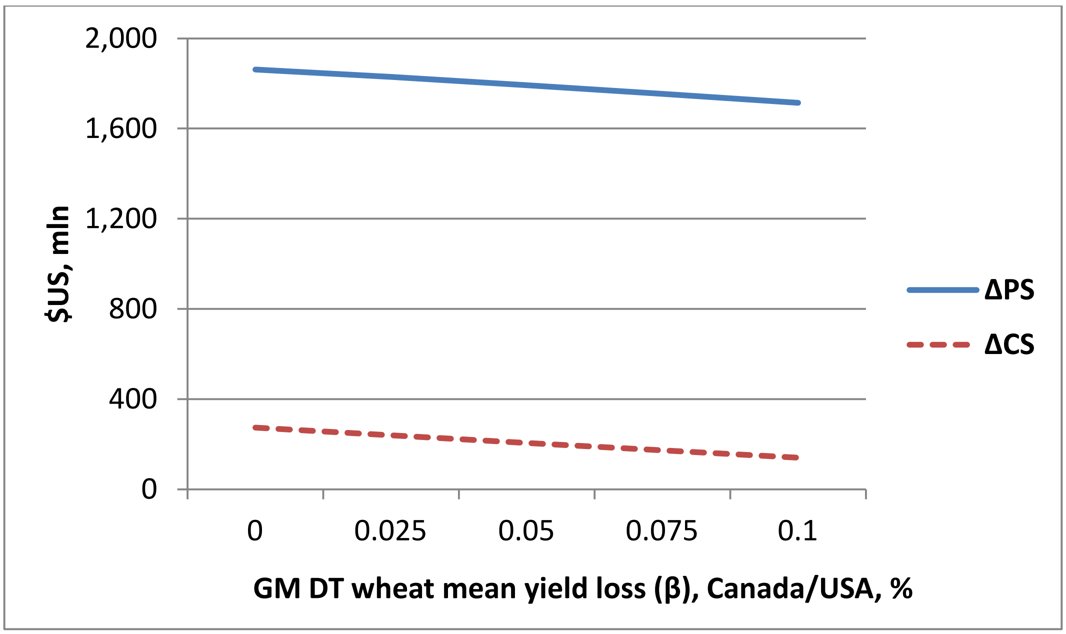

Figure 2.5 Sensitivity of producer surplus (PS) and consumer surplus (CS) change to the levels of GM DT wheat mean yield loss in Canada and the USA: scenario G1

Figure 2.5 shows that both total producer and consumer surpluses are moderately sensitive to changes in the GM DT wheat mean yield loss. The highest level of producer and consumer surplus is at the point when GM DT wheat exhibits no yield loss under drought conditions ($\beta^g = 0$) when compared to conventional wheat. This suggests that, all else equal, the stronger are the drought tolerance levels of new wheat varieties, the better off will be consumers and producers in terms of economic welfare.

In M1, when the yield advantage of MAS DT wheat is decreasing (i.e., the yield loss level is increasing), the prices of wheat in all exporting countries are increasing (see table A.7 of appendix A). Interestingly, producer surplus change is not only increasing, but becoming positive for Argentina, Australia, the EU, and Other when the mean yield loss of MAS DT wheat is at 10% level. In other words, had the yield advantage of MAS DT wheat over conventional wheat totally deteriorated, the producer welfare of the countries that do not export MAS DT wheat would become higher than in benchmark 1. This is as expected, since Canada and the USA are bearing the higher seed costs of MAS DT wheat while all other wheat exporting countries are not. Higher world prices compared to benchmark 1 enable those countries that export only conventional wheat to benefit. Producers in Canada and the USA have negative but increasing changes in surplus. Consumer surplus change is positive and decreases in most of the countries, and eventually becomes negative when the MAS DT wheat yield advantage deteriorates. In the EU and Indonesia, the consumer surplus change is negative, due to larger cross-price effects. However, consumer surplus increases when MAS DT wheat mean yield loss increases, and eventually becomes positive. Trade welfare change (i.e., PS + CS) in M1 is negative and decreasing (see figure 2.6).

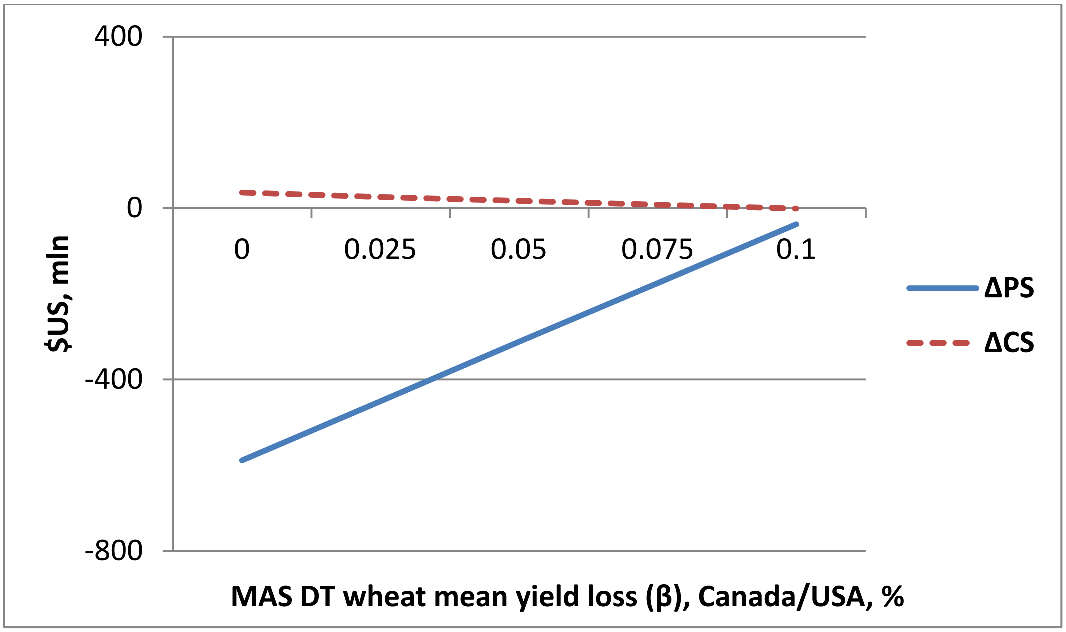

Figure 2.6 Sensitivity of producer surplus (PS) and consumer surplus (CS) change to the levels of MAS DT wheat mean yield loss in Canada and the USA: scenario M1

2.4.6.3 Segregation cost in Canada and the USA

Segregation cost in Canada and the USA is simultaneously changed from 0 to $US 3/t, and then to $US 6/t in scenario G1. The outcomes of this sensitivity analysis in G2 lead to very similar results. Therefore, this sensitivity analysis is reported only for scenario G1.

This increase in cost as a result of segregation is assumed to be incurred by non-GM wheat producers. Graphical results of this change are presented in figure 2.7, and numerical results are in table A.8 of appendix A. As a result, prices of GM DT wheat do not change and prices of non-GM wheat increase slightly. When country-exporters of GM DT wheat must bear higher costs of segregation, their producer surplus decreases. This becomes advantageous for other non-adopter exporting countries, where producer surplus increases. Importing countries that do not import GM DT wheat (with the exception of the EU) as well as Algeria lose consumer surplus because of higher prices of non-GM wheat. Consumer surplus in other country-importers of GM DT wheat increases. Total producer welfare is positive and slightly increasing, while total consumer welfare is positive and very slightly decreasing (see figure 2.7). This suggests that when designing segregation policies for the GM DT wheat market, the impact of different levels of segregation costs on the producer and consumer welfare may potentially differ only slightly.

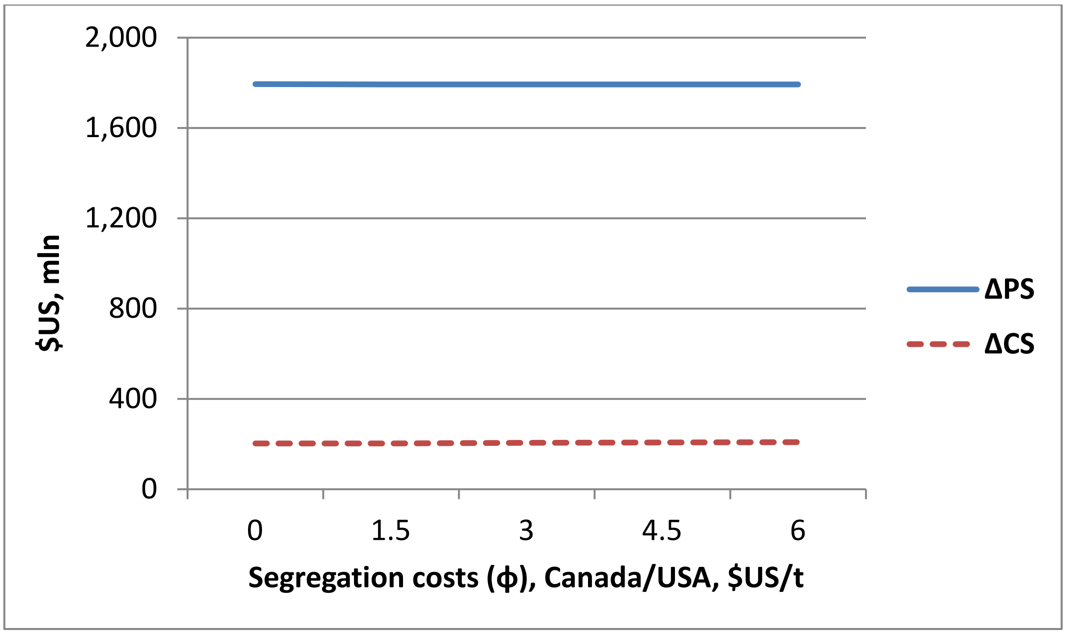

Figure 2.7 Sensitivity of producer surplus (PS) and consumer surplus (CS) change to the levels of segregation costs in Canada and the USA: scenario G1

2.4.6.4 Technology fee in Canada and the USA

The increase in the technology fee from $US 5/ha to $US 15/ha, and to $US 25/ha is modeled for both Canada and the USA simultaneously in scenario G1. The cost is incurred by GM DT wheat producers. As a result, the prices of non-GM wheat do not change whereas the prices of GM DT wheat increase slightly with increased technology fees. The producer surplus in Canada and the USA decreases, whereas that of other countries remains unchanged. Consumer surplus of the countries that import GM DT wheat decreases because the prices of GM DT wheat increase slightly. The consumer surplus in other countries does not change as they do not import GM DT wheat. The total producer and consumer surplus is positive and decreasing relative to benchmark 1. The explanation of this result is that the technology fee, charged by biotechnology companies to protect their intellectual property rights, is welfare-reducing to both producers and consumers. Producer surplus is more sensitive to the changes in technology fee levels than consumer surplus (see figure 2.8). Table A.9 of appendix A provides the numerical results of this sensitivity analysis.

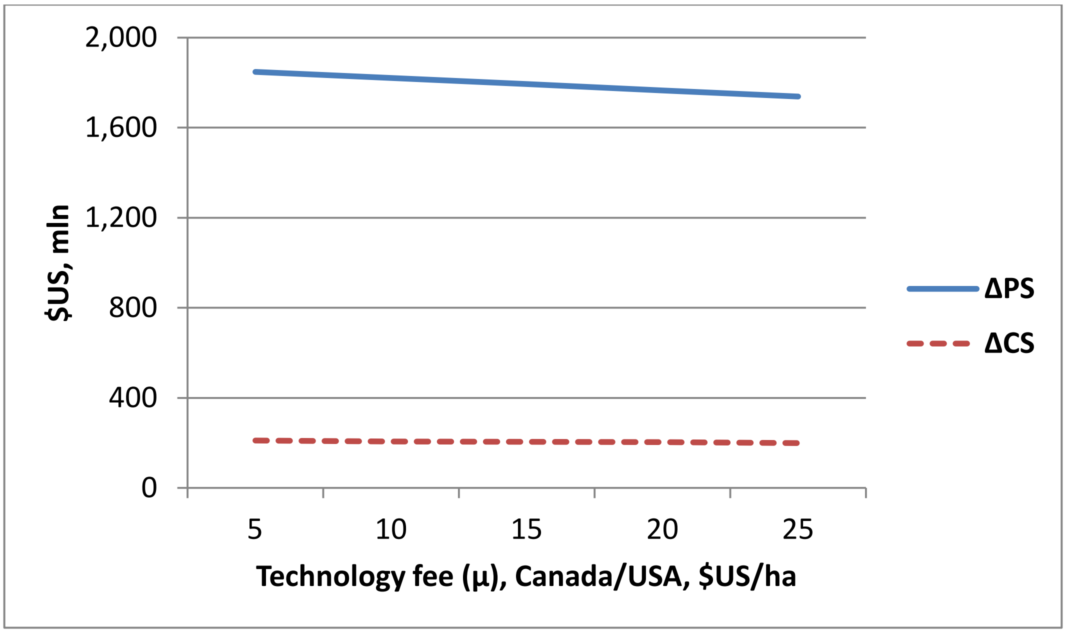

Figure 2.8 Sensitivity of producer surplus (PS) and consumer surplus (CS) change to the levels of technology fee in Canada and the USA: scenario G1

2.4.6.5 Seed price of MAS DT wheat in Canada and the USA

In scenario M1, seed prices of MAS DT wheat are varied in Canada and the USA simultaneously. MAS DT wheat seed price premiums are assumed to increase from 0 to 30%, and then to 60% over the price of seed for conventional wheat varieties. This leads to a very slight increase in the wheat prices in all wheat exporting countries. For each consecutive 30% step increase in MAS DT wheat seed price premiums, the wheat prices in wheat exporting countries increase by less than $US 1 (see table A.10 of appendix A). Graphical results are presented in figure 2.9.

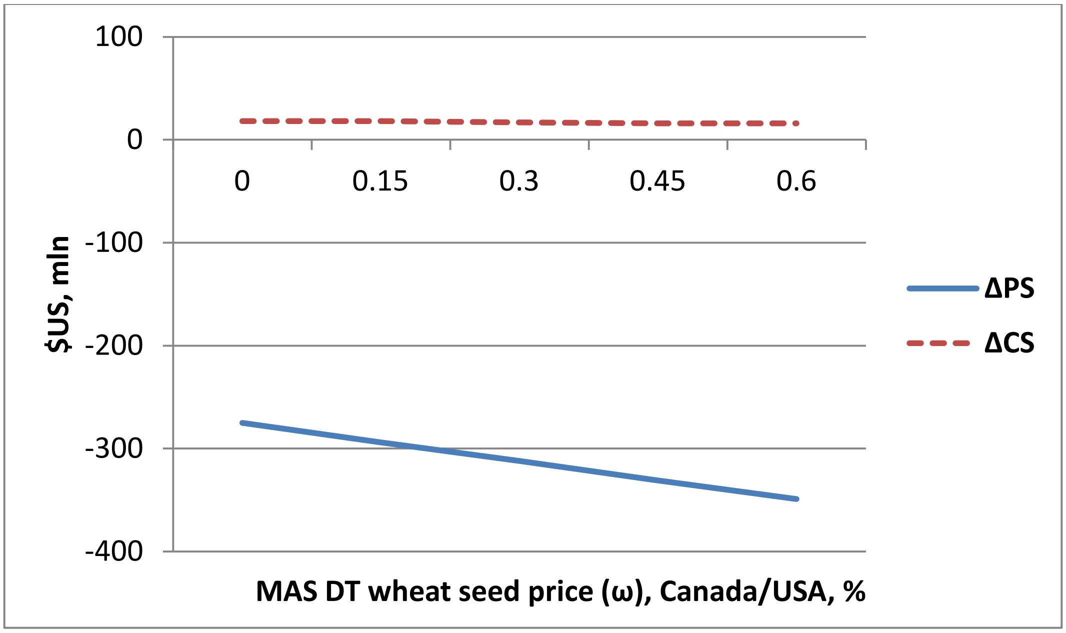

Figure 2.9 Sensitivity of producer surplus (PS) and consumer surplus (CS) change to the levels of MAS DT wheat seed price increase in Canada and the USA: scenario M1

With slightly increasing wheat prices, producer surplus change in Canada and the USA is nevertheless negative and decreasing. Producer surplus change of the exporting countries that are non-adopters of MAS DT wheat is negative and increasing. However, total producer surplus change in all exporting countries is decreasing and remains negative under alternative MAS DT wheat seed price premiums. In other words, the sum of decreasing producer surpluses in Canada and the USA outweighs the sum of increasing producer surpluses in Argentina, Australia, the EU, and Other. Consumer surplus of importing countries except the EU, Brazil, and Indonesia is positive and decreasing. Consumer surplus in the EU and Indonesia is negative and slightly increasing, while consumer surplus in Brazil is positive and increasing. Trade welfare change is decreasing and remains negative.

The conclusion of this sensitivity analysis is that price premiums paid for the seed of MAS DT wheat varieties decrease trade welfare. Even though this does not impact consumers, producers bear the cost of higher seed prices. However, producer surplus change has a relatively low sensitivity to the changes in wheat seed prices.

2.5 Conclusions

This study compares selected welfare effects from introducing GM DT wheat and MAS DT wheat on the world market. A partial equilibrium world wheat trade model is developed that links important variables that may influence distribution of welfare. Based on the analysis conducted and according to the assumptions employed in the model, the following major conclusions are drawn.

<u>1. Adoption of GM DT wheat is generally welfare increasing</u>

Under the assumptions of this study, positive welfare changes from GM DT wheat adoption are driven by higher non-GM wheat prices. This is the case because some countries (i.e., EU, Japan, and South Korea in our model) refuse to import GM DT wheat in favor of importing only non-GM wheat. When drought causes yield losses of non-GM wheat, this also drives up non-GM wheat prices. The existence of two segregated markets for GM DT and non-GM wheat causes wheat price difference on these two markets. As a result, producer surplus in exporting countries increases and overweighs the influence of decreases in consumer surplus from decreased output associated with drought. It should be noted that segregation is assumed to be entirely effective so that no issue of contamination can arise.

The analysis presented here shows that vertically differentiated markets for GM DT and conventional wheat enable increases in trade welfare, even when there is no yield advantage for GM DT wheat relative to conventional wheat (i.e., in the years without droughts). Likewise, when droughts occur in larger areas of wheat plantings worldwide, world prices of conventional wheat can rise appreciably, leading the increase in producer surplus to overweigh consumer surplus decreases.

Under hypothetical circumstances of no restrictions on GM DT wheat trade and relatively low adoption levels, GM DT wheat adoption can be welfare reducing. When there are no trade restrictions, the prices of conventional wheat are not inflated by higher levels of demand for conventional wheat. However, low adoption and consequent low supplies of GM DT wheat bring GM wheat prices closer to the price levels for conventional wheat. This might lead both GM DT and conventional wheat prices to fall below the benchmark price. This would make it unprofitable for wheat exporters to adopt GM DT wheat.

2. Adoption of MAS DT wheat is welfare reducing

The negative welfare change in the case of MAS DT wheat adoption is essentially driven by the additional supply of better performing MAS DT wheat in the drought years. The additional supply of wheat drives wheat prices down. Although this benefits consumers, producer surplus in exporting countries decreases and outweighs the increased consumer surplus. Drought tolerance in MAS wheat is essentially a technological advancement that allows producing more wheat (i.e., losing less wheat if drought occurs) at a lower price; the result here reflects the assumptions of inelastic demand and static demand that does not grow relative to the increases in supply.

The welfare outcomes of MAS DT wheat adoption differ from GM DT wheat adoption. In the case of GM DT wheat adoption, the price premium paid on non-GM wheat allows wheat exporters to benefit. Essentially this occurs if some importing countries reject better performing but cheaper GM DT wheat in favor of more expensive conventional wheat. In the case of MAS DT wheat adoption, there is only one price for both conventional wheat and the MAS DT wheat. Therefore, if some portion of the wheat planted area is sown to MAS DT wheat, this will produce better yields than conventional wheat. However, when sold at the same price as conventional wheat, overall, the wheat price will be lower than the benchmark price due to the higher levels of wheat supplies.

The analysis shows that even when there is no yield advantage for MAS DT wheat (i.e., in the years without drought), relative to conventional wheat, trade welfare change is negative compared to the benchmark. This is attributed to higher wheat prices that result from higher seed costs for MAS DT wheat.

3. Welfare effects are sensitive to the adoption levels of DT wheat.

In this study adoption levels are exogenously chosen to enable comparisons across MAS and GM DT wheat scenarios. Sensitivity analysis shows that welfare effects are very sensitive to the adoption levels of DT wheat in GM model, and moderately sensitive in MAS model. In reality the nature and magnitudes of welfare changes can largely be expected to depend on the adoption levels for drought tolerant wheat in each country.

4. Welfare effects are moderately sensitive to the mean yield loss changes of DT wheat

In GM DT wheat model increases in mean yield loss of GM DT wheat compared to conventional wheat leads to reduction of trade welfare. In MAS DT wheat model increases in mean yield loss of MAS DT wheat compared to conventional wheat leads to reduction of consumer welfare, but increase of producer welfare. As a result trade welfare increases. Such opposite effect in these two models is caused by the presence of segregated markets for DT wheat in GM DT wheat model, and single wheat market in MAS DT wheat model.

5. Welfare effects have a relatively low sensitivity to the levels of segregation costs and technology fee in GM DT wheat model

The impact of different levels of segregation costs on both producer and consumer welfare changes in the GM DT wheat model is very low. However, increases in segregation cost levels leads to positive changes in producer surplus in the countries that are non-adopters of GM DT wheat.

The technology fee charged by biotechnology companies to protect their intellectual property rights is welfare-reducing to both producers and consumers. Producer surplus is more sensitive to the changes in technology fee levels than is consumer surplus. However, the sensitivity of welfare effects to the technology fee levels is relatively low.

6. Welfare effects are relatively insensitive to the levels of wheat seed costs in the MAS DT wheat model

Higher price premiums paid for the seed of MAS DT wheat varieties decrease trade welfare. Overall, this does not greatly impact consumers as producers bear the cost of higher seed prices. Even so, changes in producer surplus have relatively low sensitivity to the changes in wheat seed prices.

Caution should be exercised in interpreting results of this study. Positive changes in trade welfare in the GM DT wheat model may only hold true when the segregation system for GM DT and conventional wheat markets is well designed and functions without errors. Without such system there would only be one market for wheat. In this case it appears highly likely that welfare gains could be nullified.

There are only a few studies that use similar to our study's methodology (i.e., partial equilibrium world trade model) to calculate changes in welfare after the introduction of GM wheat variety. In our study, trade welfare gain in 2006/2007 in scenario G1 is equal to $1,964 million, in scenario G2 this is $2,026 million, and in scenario G3 the gain is $780 million. Wilson et al. (2008) estimated annual producer and consumer surplus after introducing Roundup Ready® wheat. Total surplus amounted to $553 million per year with partial acceptance and $788 million per year with full market acceptance of GM wheat. The Roundup Ready® wheat trade model of Berwald et al. (2006) predicted positive total economic surplus ranging from $2,158 to $3,596 million annually depending on the scenario. Result of scenario G1 and G2 in our study are very close in magnitude to the results in Berwald et al. (2006). The base year in Wilson et al. (2008) is 2003 and the wheat prices used in their model are 30-40% lower than the prices in our model, which correspond to a 2006/2007 base year. This factor, and other differences in assumptions, can explain differences in the magnitude of welfare gains. Studies that measure welfare changes of producers and consumers as a result of introducing MAS DT wheat on the market have not been located.

Our study employs a one year static trade model. Therefore, it can be only speculated by how much welfare gain in drought years would offset the added costs of GM DT or MAS DT wheat in the years without drought. The probability and severity of drought in wheat exporting countries is not known. Adoption of GM or MAS DT wheat would lead to a shift in wheat supply curve in the long run. However, scenarios G1 and G0 can be discussed as an example with additional assumptions in place. Assuming there is 5% mean yield loss for GM DT wheat while there is 10% mean yield loss for conventional wheat in drought years, the change in producer and consumer benefits in the 2006/2007 year would be \$1,752 and \$212 million respectively (scenario G1, table 2.12). Assuming there is no wheat yield loss without drought, and GM DT wheat mean yield is not different from mean yield of conventional wheat, the change in producer and consumer surplus in 2006/2007 would be \$1,825 million and \$164 million respectively (scenario G0, table 2.9). It is also possible to assume that trade flows would not change considerably and world wheat prices would stay at the same level. When this is the case, welfare gains from introducing GM DT wheat will always offset additional costs of GM DT wheat regardless whether drought occurs once in ten years or ten times in ten years. The reported changes in producer surplus and consumer surplus in scenarios G1 and G0 account for the presence of technology fee costs. Moreover, in the years without drought (scenario G0) producer surplus is higher than in the years with drought (scenario G1). This occurs because, even when a yield advantage of DT wheat is not present (in the absence of drought), the vertically differentiated market for wheat (GM versus non-GM) creates welfare gains (see section 2.4.2.1). When looking at scenarios G2 and G3, welfare gains from introducing GM DT wheat will still offset additional costs of GM DT wheat. The only difference from G1 is that producer welfare in G2 and G3 (with drought) is lower than in G0 (without drought).

In the case of MAS DT wheat there are welfare losses under no drought (table 2.10), and there are even higher losses under drought (table 2.13). This indicates that there are always going to be trade welfare losses when introducing MAS DT wheat under the assumptions of this study, specifically the higher cost of seed.

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Appendix A. Baseline values, calibrated parameters and results of sensitivity analyses

Table A.1 Baseline values and calibrated parameters of supply equations in the base case wheat trade model

Exporting country	$\boldsymbol{S^0}$	$\hat{y}$	$\boldsymbol{P(S)^0}$	$\boldsymbol{c}$	$\boldsymbol{d}$
Argentina	11,941,046	2.63	188	4,776,418	38,109.72
Australia	11,331,741	0.92	232	1,133,174	43,959.34
Canada	15,002,437	2.61	234	7,501,219	32,056.49
EU	11,612,303	5.06	206	5,806,152	28,185.20
USA	23,964,287	2.60	219	9,585,715	65,655.58
Other	31,002,731	2.83	219	12,401,092	84,938.99

Note: $\boldsymbol{S^0}$ – baseline value of wheat supply in an exporting country (tonnes); $\hat{y}$ - baseline value of wheat yield (t/ha); $\boldsymbol{P(S)^0}$ – Free on Board (FOB) export price ($US/t); $\boldsymbol{c}$ and $\boldsymbol{d}$ – intercept and slope coefficients of the supply equations

Table A.2 Baseline values and calibrated parameters of demand equations in the base case wheat trade model

Trade flow	D^0	F	a	b own	bAR	bAU	bCAN	bEU	bUS	bOTH
From Argentina to:										
Algeria	49,072	36.76	58,886	-861.67		0	0	758.47	1.19	47.82
Brazil	7,374,295	27.77	8,849,154	-13644.67		0	1045.67	11.07	125.47	4747.77
Egypt	74,998	36.76	98,247	-992.58		31.95	61.65	60.85	247.27	380.56
EU	13,993	36.76	19,170	-186.20		2.70	36.81	0	17.01	90.68
ROW	4,428,688	28.91	5,757,294	-58188.44		4283.93	7440.69	5439.66	11220.54	16004.89
From Australia to:										
Egypt	282,761	40.37	370,417	-2994.00	31.95		232.44	229.41	932.27	1434.82
EU	65,466	40.37	89,688	-708.44	2.70		172.23	0	79.59	424.24
Indonesia	2,669,247	29.43	3,470,021	-18099.32	0		7196.02	25.93	3902.95	3559.69
Japan	1,129,660	29.43	1,242,626	-3504.42	0		752.56	4.98	2298.69	15.81
Korea S	988,274	29.43	1,344,053	-3013.31	0		109.33	0.66	859.33	705.67
ROW	6,196,333	32.89	8,055,233	-64181.89	4283.93		10410.53	7610.83	15699.05	22393.00
From Canada to:										
Brazil	86,754	26.88	104,105	-985.32	1045.67	0		0.13	1.48	55.85
Egypt	545,700	29.73	714,867	-5758.91	61.65	232.44		442.73	1799.19	2769.05
EU	893,179	23.09	1,223,655	-8072.73	36.81	172.23		0	1085.91	5788.11
Indonesia	1,532,736	45.47	1,992,557	-12321.17	0	7196.02		14.89	2241.15	2044.05
Japan	1,040,882	45.47	1,144,970	-3031.06	0	752.56		4.59	2118.04	14.57
Korea S	140,866	45.47	191,578	-488.46	0	109.33		0.09	122.49	100.58
ROW	10,762,320	36.37	13,991,017	-101333.66	7440.69	10410.53		13219.13	27267.46	38894.08
From the EU to:										
Algeria	3,191,544	20.30	3,829,853	-7084.32	758.47	0	0		77.25	3110.22
Brazil	918	40.00	1,102	-11.20	11.07	0	0.13		0.02	0.59
Egypt	538,571	21.90	705,528	-6652.76	60.85	229.41	442.73		1775.68	2732.88
Indonesia	5,524	40.00	7,181	-67.31	0	25.93	14.89		8.08	7.37
Japan	6,890	40.00	7,578	-27.98	0	4.98	4.59		14.02	0.10
Korea S	849	40.00	1,155	-3.45	0	0.66	0.09		0.74	0.61
ROW	7,868,007	21.52	10,228,409	-94080.34	5439.66	7610.83	13219.13		19934.42	28434.29

Table A.2 Continued

Trade flow	D^0	F	a	b own	bAR	bAU	bCAN	bEU	bUS	bOTH
From the USA to:										
Algeria	4,998	30.22	5,998	-80.10	1.19	0	0	77.25		4.87
Brazil	10,410	25.96	12,492	-127.31	125.47	0	1.48	0.02		6.70
Egypt	2,188,664	37.46	2,867,150	-18386.49	247.27	932.27	1799.19	1775.68		11105.95
EU	412,770	26.82	565,495	-4535.63	17.01	79.59	1085.91	0		2674.89
Indonesia	831,320	37.40	1,080,716	-8511.47	0	3902.95	2241.15	8.08		1108.64
Japan	3,179,375	36.62	3,497,313	-5968.34	0	2298.69	2118.04	14.02		44.50
Korea S	1,107,199	37.40	1,505,791	-3355.59	0	859.33	122.49	0.74		790.59
ROW	16,229,551	34.77	21,098,416	-150739.00	11220.54	15699.05	27267.46	19934.42		58652.17
From Other to										
Algeria	201,227	30.22	241,472	-3033.65	47.82	0	0	3110.22	4.87	
Brazil	393,898	25.96	472,678	-4570.43	4747.77	0	55.85	0.59	6.70	
Egypt	3,368,475	37.46	4,412,702	-22311.10	380.56	1434.82	2769.05	2732.88	11105.95	
EU	2,200,140	26.82	3,014,192	-12592.96	90.68	424.24	5788.11	0	2674.89	
Indonesia	758,206	37.40	985,668	-7860.40	0	3559.69	2044.05	7.37	1108.64	
Japan	21,868	36.62	24,055	-85.24	0	15.81	14.57	0.10	44.50	
Korea S	909,217	37.40	1,236,535	-2896.94	0	705.67	100.58	0.61	790.59	
ROW	23,149,700	34.77	30,094,610	-190004.08	16004.89	22393.00	38894.08	28434.29	58652.17	

Note: D^0 - baseline value of wheat demand in an importing country (tonnes); F – ocean freight rate ($US/t); a – intercept coefficients of the demand equations; b – own and cross price slope coefficients of the demand equations.

Table A.3 Baseline elasticities used for calibration of the base case wheat trade model

Importing country	Price elasticity of demand (η)	Substitution elasticity (σ)	Exporting country	Price elasticity of supply (ε)
Algeria	-0.20	4.00	Argentina	0.6
Brazil	-0.20	3.00	Australia	0.9
Egypt	-0.31	3.00	Canada	0.5
EU	-0.37	3.00	EU	0.5
Indonesia	-0.30	3.00	USA	0.6
Japan	-0.10	1.00	Other	0.6
South Korea	-0.36	1.00		
ROW	-0.30	3.00		

Source: Haley (1995)

Table A.4 Value shares of wheat in each importing country

Importing country	Value share imported from						
	AR	AU	CAN	EU	USA	OTH	Total
Algeria	0.0141	0	0	0.9204	0.0016	0.0639	1.0
Brazil	0.9288	0	0.0132	0.0001	0.0015	0.0563	1.0
Egypt	0.0094	0.0431	0.0806	0.0687	0.3143	0.4838	1.0
EU	0.0035	0.0200	0.2572	0	0.1136	0.6057	1.0
Indonesia	0	0.4546	0.2790	0.0009	0.1389	0.1266	1.0
Japan	0	0.2100	0.2069	0.0012	0.5779	0.0400	1.0
South Korea	0	0.3170	0.0483	0.0003	0.3483	0.2861	1.0
ROW	0.0555	0.0949	0.1682	0.1035	0.2381	0.3397	1.0

Note: Value share of wheat in each importing country is a share of a monetary value of wheat imported from specific exporting country in the total monetary value imported from all countries. For example, a value share of Argentinean wheat in Algeria is equal to 0.0141. This is calculated as a product of value imported from Argentina (in metric tonnes) multiplied by wheat price in Argentina, divided by a product of total value imported from all exporting countries (in metric tonnes) multiplied by a weighted average of wheat prices in all exporting countries.

Table A.5 Calibrated own and cross-price elasticities of demand, by country of destination

Trade flow	AR	AU	CAN	EU	USA	OTH
AR – Algeria	-3.95	0	0	3.50	0.01	0.24
AU – Algeria	0.05	-4.00	0	3.50	0.01	0.24
CAN – Algeria	0.05	0	-4.00	3.50	0.01	0.24
EU – Algeria	0.05	0	0	-0.5	0.01	0.24
USA – Algeria	0.05	0	0	3.50	-3.99	0.24
OTH – Algeria	0.05	0	0	3.50	0.01	-3.76
AR – Brazil	-0.40	0	0.04	0	0	0.16
AU – Brazil	2.60	-3.00	0.04	0	0	0.16
CAN – Brazil	2.60	0	-2.96	0	0	0.16
EU – Brazil	2.60	0	0.04	-3.00	0	0.16
USA – Brazil	2.60	0	0.04	0	-3.00	0.16
OTH – Brazil	2.60	0	0.04	0	0	-2.84
AR – Egypt	-2.97	0.12	0.22	0.18	0.85	1.30
AU – Egypt	0.03	-2.88	0.22	0.18	0.85	1.30
CAN – Egypt	0.03	0.12	-2.78	0.18	0.85	1.30
EU – Egypt	0.03	0.12	0.22	-2.82	0.85	1.30
USA – Egypt	0.03	0.12	0.22	0.18	-2.15	1.30
OTH – Egypt	0.03	0.12	0.22	0.18	0.85	-1.70
AR – EU	-2.99	0.05	0.68	0	0.03	1.59
AU – EU	0.01	-2.95	0.68	0	0.03	1.59
CAN – EU	0.01	0.05	-2.32	0	0.03	1.59
EU – EU	0.01	0.05	0.68	-3.00	0.03	1.59
USA – EU	0.01	0.05	0.68	0	-2.70	1.59
OTH – EU	0.01	0.05	0.68	0	0.03	-1.41
AR – Indonesia	-3.00	1.23	0.75	0	0.37	0.34
AU – Indonesia	0	-1.77	0.75	0	0.37	0.34
CAN – Indonesia	0	1.23	-2.25	0	0.37	0.34
EU – Indonesia	0	1.23	0.75	-3.00	0.37	0.34
USA – Indonesia	0	1.23	0.75	0	-2.63	0.34
OTH – Indonesia	0	1.23	0.75	0	0.37	-2.66
AR – Japan	-1.00	0.19	0.19	0	0.52	0
AU – Japan	0	-0.81	0.19	0	0.52	0
CAN – Japan	0	0.19	-0.81	0	0.52	0
EU – Japan	0	0.19	0.19	-1.00	0.52	0
USA – Japan	0	0.19	0.19	0	-0.48	0
OTH – Japan	0	0.19	0.19	0	0.52	-1.00
AR – South Korea	-1.00	0.20	0.03	0	0.22	0.18
AU – South Korea	0	-0.80	0.03	0	0.22	0.18
CAN – South Korea	0	0.20	-0.97	0	0.22	0.18
EU – South Korea	0	0.20	0.03	-1.00	0.22	0.18
USA – South Korea	0	0.20	0.03	0	-0.78	0.18
OTH – South Korea	0	0.20	0.03	0	0.22	-0.82
AR – ROW	-2.85	0.26	0.45	0.28	0.64	0.92
AU – ROW	0.15	-2.74	0.45	0.28	0.64	0.92
CAN – ROW	0.15	0.26	-2.55	0.28	0.64	0.92
EU – ROW	0.15	0.26	0.45	-2.72	0.64	0.92
USA – ROW	0.15	0.26	0.45	0.28	-2.36	0.92
OTH – ROW	0.15	0.26	0.45	0.28	0.64	-2.08

Table A.6 Adoption rate of DT wheat in Canada and the USA: welfare changes from benchmark 1 in scenarios G1, M1, and G3, and from benchmark 2 in scenario G2 (in 1,000 $US)

	Country	**Alternative 1**			**With baseline parameters**			**Alternative 2**		
		Export price	**Δ PS**	**Δ CS**	**Export price**	**Δ PS**	**Δ CS**	**Export price**	**Δ PS**	**Δ CS**
G1 (Adoption in CA/US)	**ρ^g(CA,US)**	**0.6 in CA / 0.5 in US**			**0.7 in CA / 0.6 in US**			**0.8 in CA / 0.7 in US**		
	Argentina	197.25	25,065		207.13	183,534		218.22	365,435	
	Australia	247.22	34,110		263.38	243,942		281.44	482,029	
	Canada	259.97/**249.81**	58,320		286.08/**237.69**	288,596		315.30/**226.20**	503,644	
	EU	219.63	27,557	44,829	234.06	201,373	46,069	250.11	395,418	48,058
	USA	240.97/**234.03**	8,752		264.53/**214.80**	204,454		290.29/**196.50**	324,326	
	Other	233.89	80,294		249.90	629,920		267.74	1,248,352	
	Algeria			-5,913			-24,777			-45,351
	Brazil			412			1,264			1,984
	Egypt			-4,053			21,498			51,025
	Indonesia			-17,995			6,961			35,252
	Japan			80,953			73,590			66,435
	S. Korea			28,398			10,676			-8,529
	ROW			-124,757			76,672			309,021
	TOTAL		**234,098**	**1,872**		**1,751,819**	**211,952**		**3,319,203**	**457,896**
M1 (Yield loss in CA/US)	**ρ^m(CA,US)**	**0.6 in CA / 0.5 in US**			**0.7 in CA / 0.6 in US**			**0.8 in CA / 0.7 in US**		
	Argentina	194.02	-26,017		193.71	-30,787		193.41	-35,535	
	Australia	241.87	-34,687		241.38	-41,048		240.88	-47,381	
	Canada	249.49	-27,739		248.75	-33,364		248.01	-39,014	
	EU	214.90	-29,179	-315	214.45	-34,550	-363	214.01	-39,902	-410
	USA	234.14	-47,113		233.36	-55,845		232.58	-64,645	
	Other	228.84	-91,632		228.35	-108,477		227.85	-125,256	
	Algeria			3,245			3,843			4,440
	Brazil			73			99			124
	Egypt			250			310			371
	Indonesia			-989			-1,165			-1,340
	Japan			1,618			1,966			2,314
	S. Korea			2,975			3,529			4,082
	ROW			6,572			7,909			9,262
	TOTAL		**-256,367**	**13,430**		**-304,070**	**16,128**		**-351,732**	**18,843**

Table A.6 Continued

	Country	Alternative 1			With baseline parameters			Alternative 2		
		Export price	Δ PS	Δ CS	Export price	Δ PS	Δ CS	Export price	Δ PS	Δ CS
G2 (Adoption in CA/US)	**ρ^g(CA,US)**	**0.6 in CA / 0.5 in US**			**0.7 in CA / 0.6 in US**			**0.8 in CA / 0.7 in US**		
	Argentina	215.62	38,483		226.43	194,164		238.53	372,276	
	Australia	275.87	44,722		293.22	221,511		312.56	421,542	
	Canada	274.52/**249.81**	53,113		302.11/**237.69**	296,005		332.91/**226.20**	522,557	
	EU	230.53	45,759	45,794	245.82	230,464	46,891	262.77	436,176	48,750
	USA	252.91/**234.03**	-40,446		277.55/**214.80**	158,366		304.44/**196.50**	278,849	
	Other	246.01	138,835		262.99	726,344		281.86	1,385,699	
	Algeria			-7,792			-27,512			-48,956
	Brazil			164			-1,171			-2,873
	Egypt			-3,067			22,702			52,534
	Indonesia			-23,051			344			26,878
	Japan			83,232			75,299			67,523
	S. Korea			27,111			8,301			-12,028
	ROW			-124,100			74,503			303,929
	TOTAL		**280,467**	**-1,709**		**1,826,853**	**199,356**		**3,417,100**	**435,757**
G3 (Adoption in CA/US)	**ρ^g (CA,US)**	**0.75 in CA / 0.65 in US**			**0.85 in CA / 0.75 in US**			**0.95 in CA /0.85 in US**		
	Argentina	192.24	-57,144		203.15	119,401		216.01	328,890	
	Australia	238.99	-75,825		256.89	159,236		277.86	434,547	
	Canada	245.38/**245.38**	-136,562		275.28/**234.67**	97,929		310.09/**224.48**	326,173	
	EU	212.28	-64,304	-12,238	228.28	131,669	2,026	246.91	356,729	18,586
	USA	229.72/**229.72**	-197,286		255.35/**213.21**	-27,607		284.79/**196.84**	72,253	
	Other	225.74	-208,674		243.48	408,899		264.19	1,124,842	
	Algeria			4,261			-17,243			-41,285
	Brazil			-244			1,085			2,301
	Egypt			-4,889			19,492			48,252
	Indonesia			-24,403			1,904			32,445
	Japan			-164,198			-138,856			-111,552
	S. Korea			-35,725			-40,445			-46,487
	ROW			-133,319			62,657			292,567
	TOTAL		**-739,796**	**-370,757**		**889,527**	**-109,386**		**2,643,433**	**194,828**

Note: Export prices in bold font are prices for GM DT wheat. Export prices are quoted in $US/tonne. Adoption rate ρ is a fraction of drought-prone wheat planting area.

Table A.7 Yield loss of DT wheat in Canada and the USA: welfare changes from benchmark 1 (in 1,000 $US)

	Country	Alternative 1			With baseline parameters			Alternative 2		
		Export price	Δ PS	Δ CS	Export price	Δ PS	Δ CS	Export price	Δ PS	Δ CS
G1 (Yield loss in CA/US)	**β^g (CA,US)**	**0**			**0.05**			**0.1**		
	Argentina	207.13	183,534		207.13	183,534		207.13	183,534	
	Australia	263.38	243,942		263.38	243,942		263.38	243,942	
	Canada	286.08/**231.90**	327,675		286.08/**237.69**	288,596		286.08/**243.51**	246,287	
	EU	234.06	201,373	46,069	234.06	201,373	46,069	234.06	201,373	46,069
	USA	264.53/**207.62**	235,334		264.53/**214.80**	204,454		264.53/**222.04**	167,426	
	Other	249.90	629,920		249.90	629,920		249.90	629,920	
	Algeria			-24,761			-24,777			-24,792
	Brazil			1,490			1,264			1,052
	Egypt			28,420			21,498			14,876
	Indonesia			11,179			6,961			2,962
	Japan			73,590			73,590			73,590
	S. Korea			10,676			10,676			10,676
	ROW			133,594			76,672			22,529
	TOTAL		**1,821,777**	**280,256**		**1,751,819**	**211,952**		**1,672,482**	**146,962**
M1 (Yield loss in CA/US)	**β^m(CA,US)**	**0**			**0.05**			**0.10**		
	Argentina	191.62	-63,678		193.71	-30,787		195.83	2,654	
	Australia	237.94	-85,005		241.38	-41,048		244.85	3,545	
	Canada	243.39	-47,292		248.75	-33,364		254.14	-21,150	
	EU	211.36	-71,664	-752	214.45	-34,550	-363	217.58	2,957	48
	USA	228.08	-78,160		233.36	-55,845		238.68	-36,892	
	Other	224.92	-224,814		228.35	-108,477		231.81	9,308	
	Algeria			7,992			3,843			-329
	Brazil			168,			99			14
	Egypt			759			310			-15
	Indonesia			-2,378			-1,165			107
	Japan			4,022			1,966			-82
	S. Korea			7,332			3,529			-292
	ROW			17,125			7,909			-529
	TOTAL		**-570,613**	**34,267**		**-304,070**	**16,128**		**-39,577**	**-1,078**

Note: Export prices in bold font are prices for GM DT wheat. Export prices are quoted in $US/tonne. Yield loss of DT wheat β is a fraction of baseline wheat yield.

Table A.8 Segregation cost in Canada and the USA: welfare changes from benchmark 1 (in 1,000 $US)

	Country	**Alternative 1**			**With baseline parameters**			**Alternative 2**		
		Export price	**Δ PS**	**Δ CS**	**Export price**	**Δ PS**	**Δ CS**	**Export price**	**Δ PS**	**Δ CS**
G1 (Segregation in CA/US)	**φ (CA,US)**	**0**			**3**			**6**		
	Argentina	206.69	176,449		207.13	183,534		207.57	190,661	
	Australia	262.66	234,575		263.38	243,942		264.10	253,361	
	Canada	284.74/**237.69**	308,708		286.08/**237.69**	288,596		287.43/**237.69**	268,600	
	EU	233.43	193,745	45,957	234.06	201,373	46,069	234.70	209,039	46,183
	USA	263.63/**214.80**	237,567		264.53/**214.80**	204,454		265.43/**214.80**	171,464	
	Other	249.20	605,654		249.90	629,920		250.61	654,311	
	Algeria			-23,955			-24,777			-25,603
	Brazil			1,164			1,264			1,363
	Egypt			21,132			21,498			21,867
	Indonesia			6,153			6,961			7,774
	Japan			73,601			73,590			73,578
	S. Korea			11,408			10,676			9,941
	ROW			73,126			76,672			80,244
	TOTAL		**1,756,696**	**208,585**		**1,751,819**	**211,952**		**1,747,436**	**215,348**

Note: Export prices in bold font are prices for GM DT wheat. Export prices are quoted in $US/tonne. Segregation cost φ is in $US per metric tonne.

Table A.9 Technology fee in Canada and the USA: welfare changes from benchmark 1 (in 1,000 $US)

	Country	**Alternative 1**			**With baseline parameters**			**Alternative 2**		
		Export price	**Δ PS**	**Δ CS**	**Export price**	**Δ PS**	**Δ CS**	**Export price**	**Δ PS**	**Δ CS**
G1 (Technology fee in CA/US)	**μ (CA,US)**	**5**			**15**			**25**		
	Argentina	207.13	183,534		207.13	183,534		207.13	183,534	
	Australia	263.38	243,942		263.38	243,942		263.38	243,942	
	Canada	286.08/**237.16**	311,129		286.08/**237.69**	288,596		286.08/**238.23**	266,256	
	EU	234.06	201,373	46,069	234.06	201,373	46,069	234.06	201,373	46,069
	USA	264.53/**214.36**	237,153		264.53/**214.80**	204,454		264.53/**215.24**	171,931	
	Other	249.90	629,920		249.90	629,920		249.90	629,920	
	Algeria			-24,776			-24,777			-24,778
	Brazil			1,283			1,264			1,244
	Egypt			21,927			21,498			21,062
	Indonesia			7,275			6,961			6,644
	Japan			73,590			73,590			73,590
	S. Korea			10,676			10,676			10,676
	ROW			80,360			76,672			72,935
	TOTAL		**1,807,051**	**216,404**		**1,751,819**	**211,952**		**1,696,956**	**207,441**

Note: Export prices in bold font are prices for GM DT wheat. Export prices are quoted in $US/tonne. Technology fee μ is in $US per hectare.

Table A.10 Seed price of MAS DT wheat in Canada and the USA: welfare changes from benchmark 1 (in 1,000 $US)

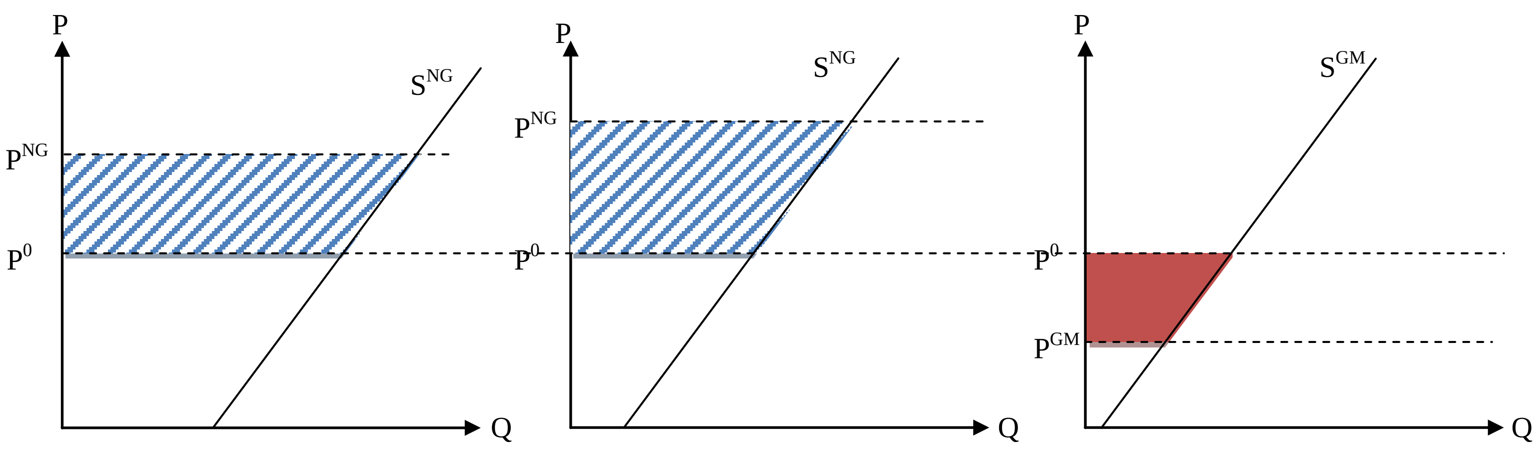
	Country	Alternative 1			With baseline parameters			Alternative 2		
		Export price	**Δ PS**	**Δ CS**	**Export price**	**Δ PS**	**Δ CS**	**Export price**	**Δ PS**	**Δ CS**
M1 (Seed price in CA/US)	**ω^m (CA,US)**	**0**			**0.3**			**0.6**		
	Argentina	193.54	-33,437		193.71	-30,787		193.88	-28,085	
	Australia	241.10	-44,596		241.38	-41,048		241.66	-37,431	
	Canada	248.27	-12,040		248.75	-33,364		249.24	-54,348	
	EU	214.21	-37,520	-410	214.45	-34,550	-363	214.71	-31,523	-315
	USA	232.97	-18,940		233.36	-55,845		233.75	-92,403	
	Other	228.07	-117,810		228.35	-108,477		228.63	-98,964	
	Algeria			4,175			3,843			3,506
	Brazil			83			99			114
	Egypt			333			310			286
	Indonesia			-1,269			-1,165			-1,060
	Japan			2,049			1,966			1,880
	S. Korea			3,823			3,529			3,229
	ROW			8,498			7,909			7,312
	TOTAL		**-264,343**	**17,283**		**-304,070**	**16,128**		**-342,755**	**14,952**

Note: Export prices are quoted in $US/tonne. Price of MAS DT seed ω is a percent point increase from conventional wheat seed price.

Appendix B. Graphical illustration of producer and consumer surplus changes

Figure B.1 Total producer surplus increase in G0

P^0 is an initial wheat price in benchmark 0. P^{NG} is a price of non-GM wheat. This may be different in the countries that are non-adopters of GM DT wheat (panel 1), and in the countries adopters of GM DT wheat, but where some percentage of producers grow non-GM wheat (panel 2). P^{GM} is a price of GM DT wheat in the countries-adopters of GM DT wheat (panel 3). Blue area (with stripes) is an increase in PS relative to the benchmark. Red area (with a solid fill) is a decrease in PS relative to the benchmark. Total PS change is positive.



Producers of non-GM wheat in countries non-adopters of GM wheat

Panel 1

Producers of non-GM wheat in CA/US

Panel 2

Producers of GM wheat in CA/US

Panel 3

Figure B.2 Consumer surplus decrease in G0 in Algeria

D^0 is an initial demand curve. D^1 is a demand curve at a new equilibrium. Red areas (with solid fill) are a net effect of decrease in CS caused by shift of a demand curve leftwards and increase in price P^1 relative to benchmark 0 price P^0. Higher prices cause demand quantities in Algeria to go down.

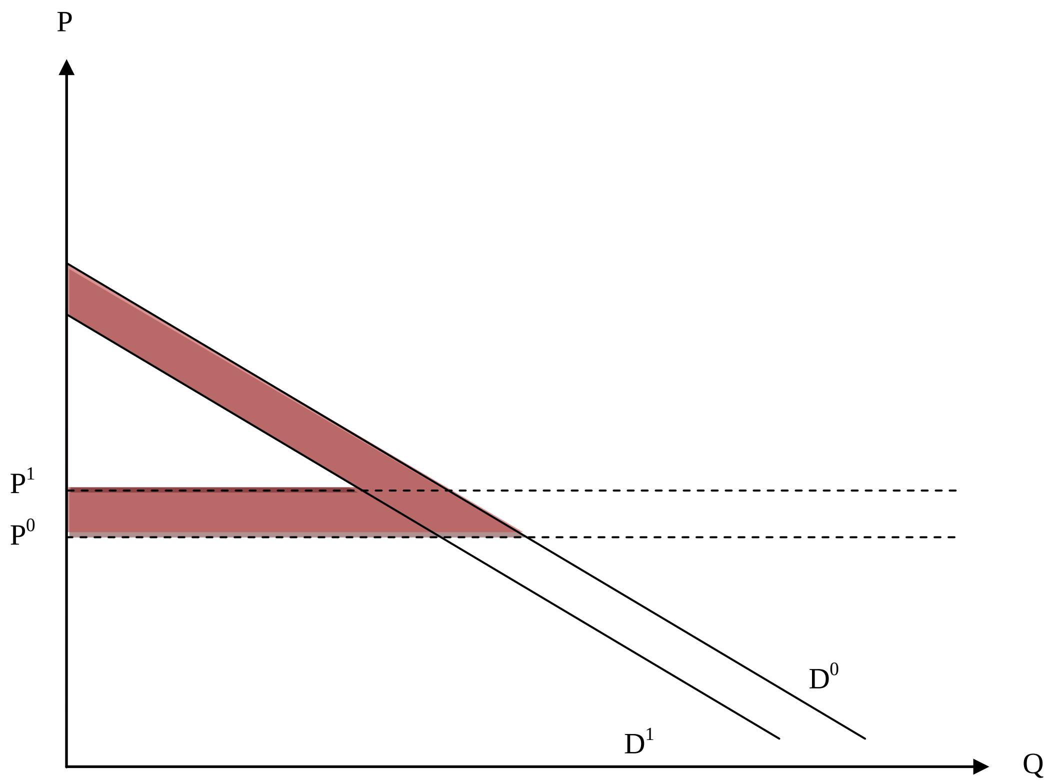


Figure B.3 Consumer surplus increase in G0 in Japan, EU, and South Korea

D^0 is an initial demand curve. D^1 is a demand curve at a new equilibrium. Red area (with solid fill) is a net decrease in CS caused by price increase. Blue area (with stripes) is a net increase in CS caused by a shift in demand curve. Positive cross price effects that outweigh negative own price effects cause increases in demand of wheat in these countries even at a higher price.

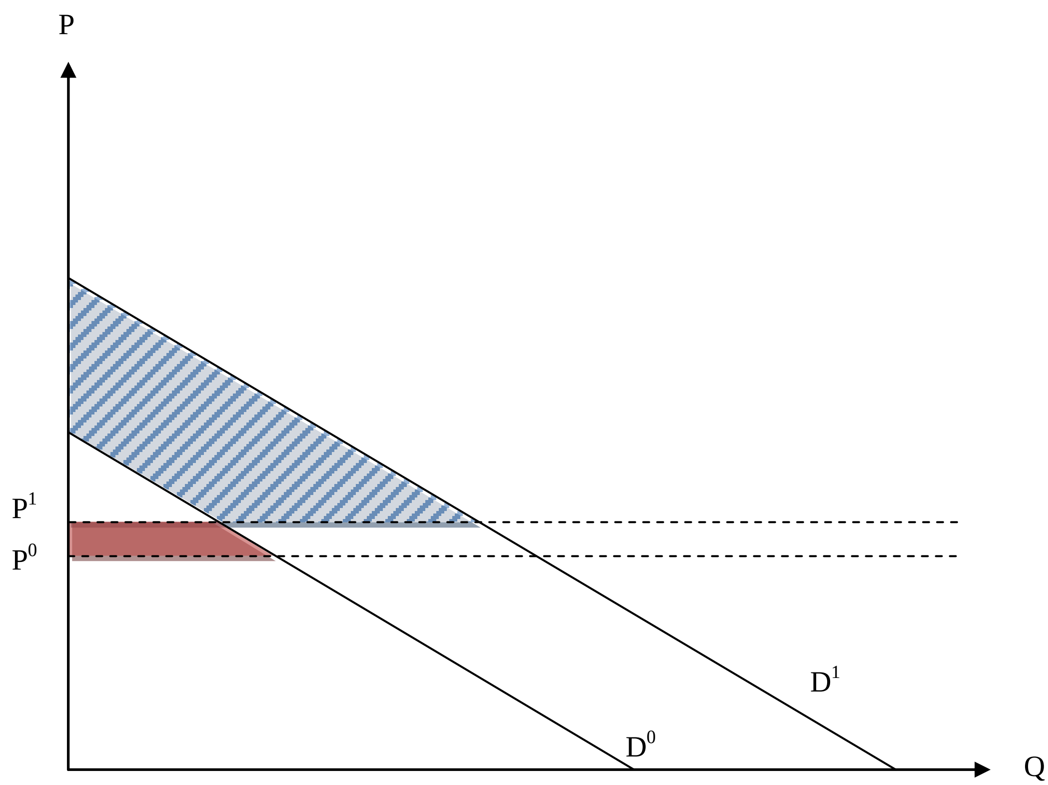


Figure B.4 Producer surplus increase in M0 in countries that are non-adopters of MAS DT wheat

P^0 is a benchmark 0 price. P^1 is a new equilibrium price in each wheat exporting country. Blue area (with stripes) is an increase in producer surplus. Exporting countries that are non-adopters of MAS DT wheat grow only non-MAS wheat and do not incur higher wheat seed prices relative to producers in Canada and the USA. Profit per hectare in countries that are non-adopters of MAS DT wheat goes up, and so does area planted to wheat. This leads to an increased supply of wheat. World wheat prices increase slightly due to higher costs of MAS DT wheat seed in Canada and the USA.

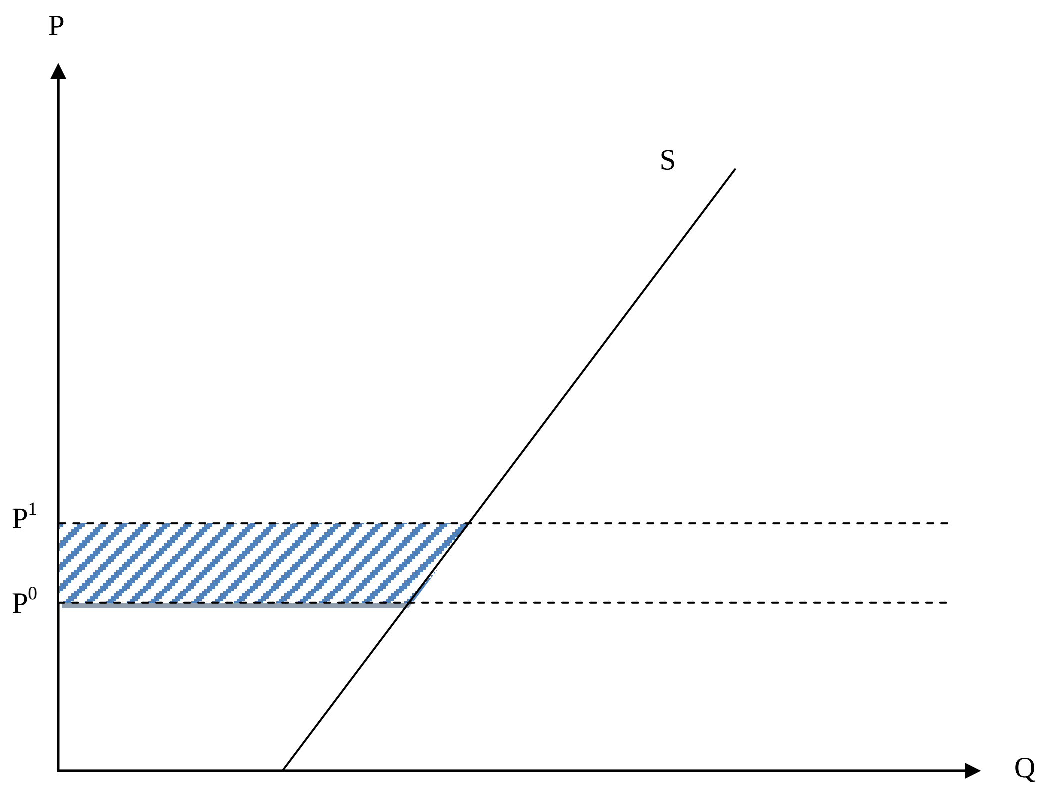


Figure B.5 Producer surplus decrease in M0 in Canada and the USA

S^0 is an initial supply curve in benchmark 0. S^1 is a supply curve at a new equilibrium as a result of a slight increase of price P^1 relative to benchmark price P^0. S^1 describes supply of both non-MAS and MAS DT wheat in Canada and the USA. The total area planted to both MAS DT and non-MAS wheat in Canada and the USA is smaller than in benchmark 0 scenario. Supply of wheat by these two countries in a world market declines due to decreased wheat planting area. Area planted to wheat depends on the level of profit per hectare. Profit of MAS DT wheat per hectare is smaller than profit of non-MAS wheat, since MAS DT wheat does not exhibit yield advantage, but has higher seed cost. This also causes supply curve to shift leftwards.

Red area (with solid fill) is a net decrease in PS caused by a leftward shift of supply curve. Blue area (with stripes) is a net increase in PS caused by price increase. The net effect of price increase and supply curve shift is negative producer surplus in Canada and the USA relative to benchmark 0.

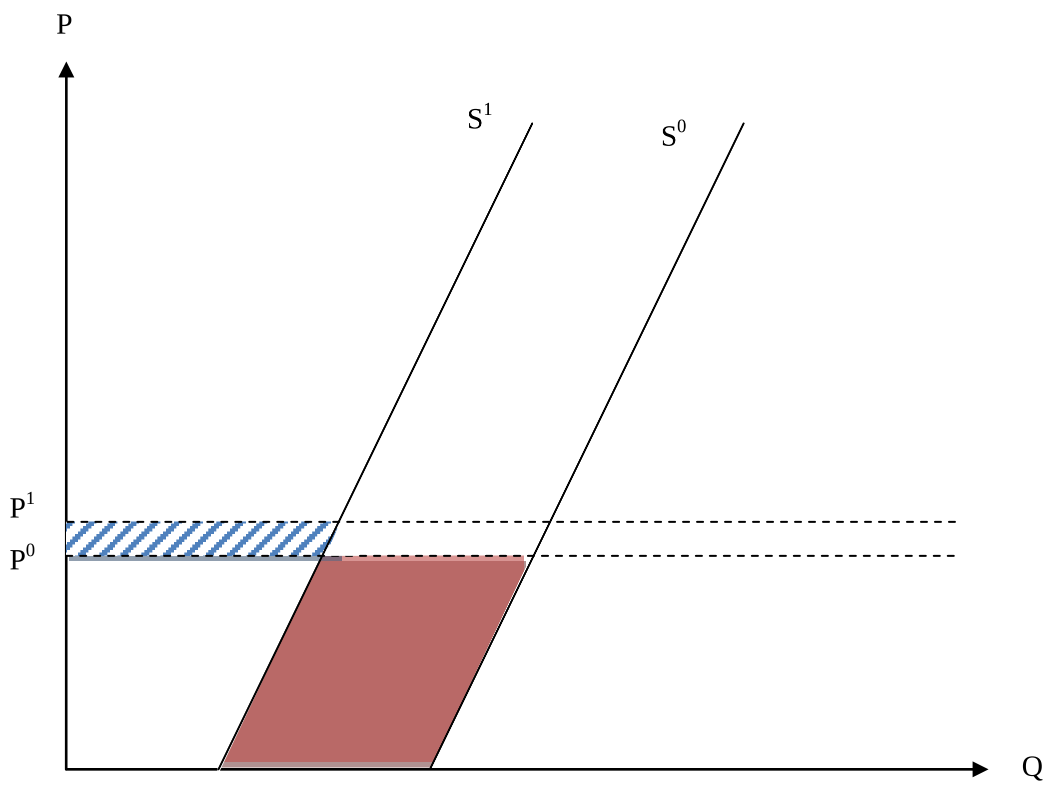


Figure B.6 Consumer surplus decrease in scenario M0 in Algeria, Egypt, S. Korea, Japan, and ROW

D^0 is an initial demand curve. D^1 is a demand curve at a new equilibrium. Red area (with solid fill) is a net decrease in CS caused by a leftward shift of demand curve and price increase.

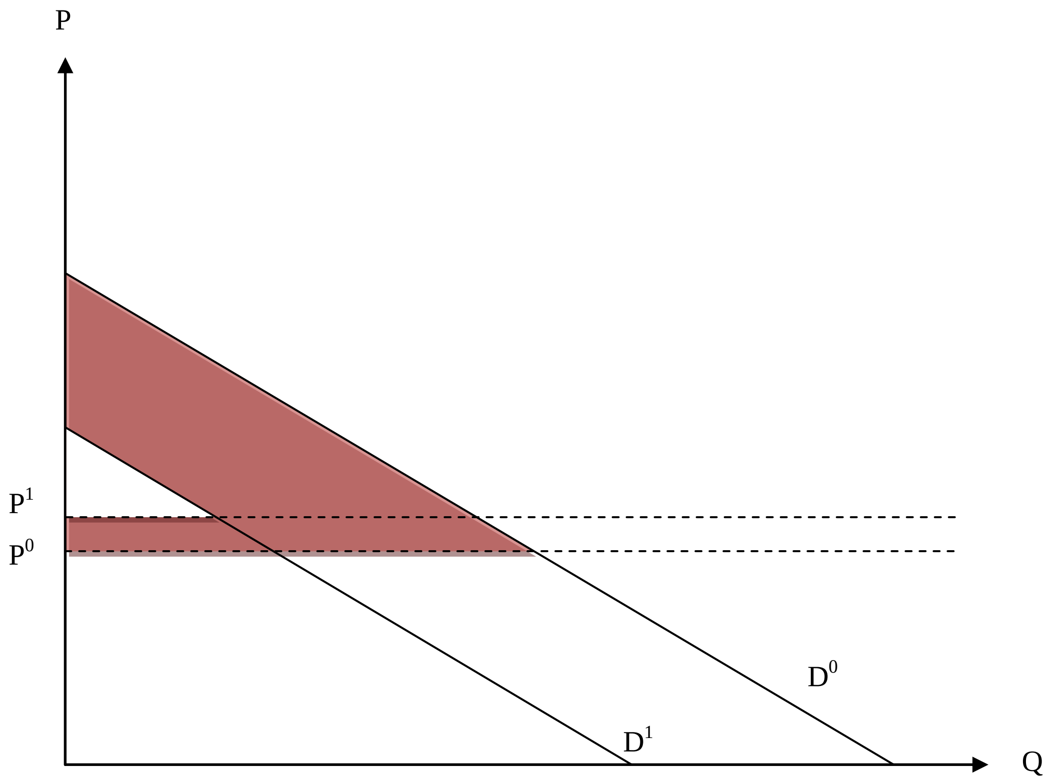
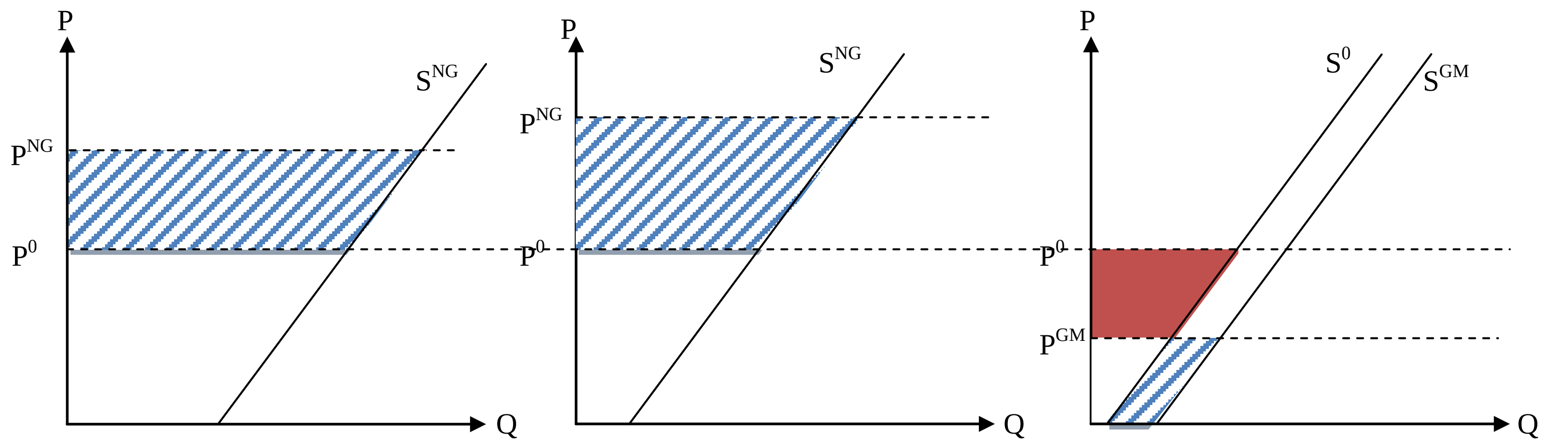


Figure B.7 Total producer surplus increase in G1

P^0 is an initial wheat price in benchmark 1. P^{NG} is a price of non-GM wheat. This may be different in the countries that are non-adopters of GM DT wheat (panel 1), and in the countries adopters of GM DT wheat, but where some percentage of producers grow non-GM wheat (panel 2). P^{GM} is a price of GM DT wheat in the countries-adopters of GM DT wheat (panel 3). Blue area (with stripes) is an increase in PS relative to the benchmark. Red area (with a solid fill) is a decrease in PS relative to the benchmark. Total PS change is positive. In panel 3, there is a shift in supply curve relative to benchmark 1 as GM DT wheat has 5% yield advantage relative to non-GM wheat.



Producers of non-GM wheat in countries non-adopters of GM wheat

Panel 1

Producers of non-GM wheat in CA/US

Panel 2

Producers of GM wheat in CA/US

Panel 3

Figure B.8 Producer surplus decrease in scenario M1 in countries that are non-adopters of MAS DT wheat

P^0 is a benchmark 1 price. P^1 is a new equilibrium price in each wheat exporting country. Red area (with solid fill) is a net effect of PS decrease as a result of decreased price. Supply of wheat in these countries decreases because of the decreased wheat price relative to benchmark 1.

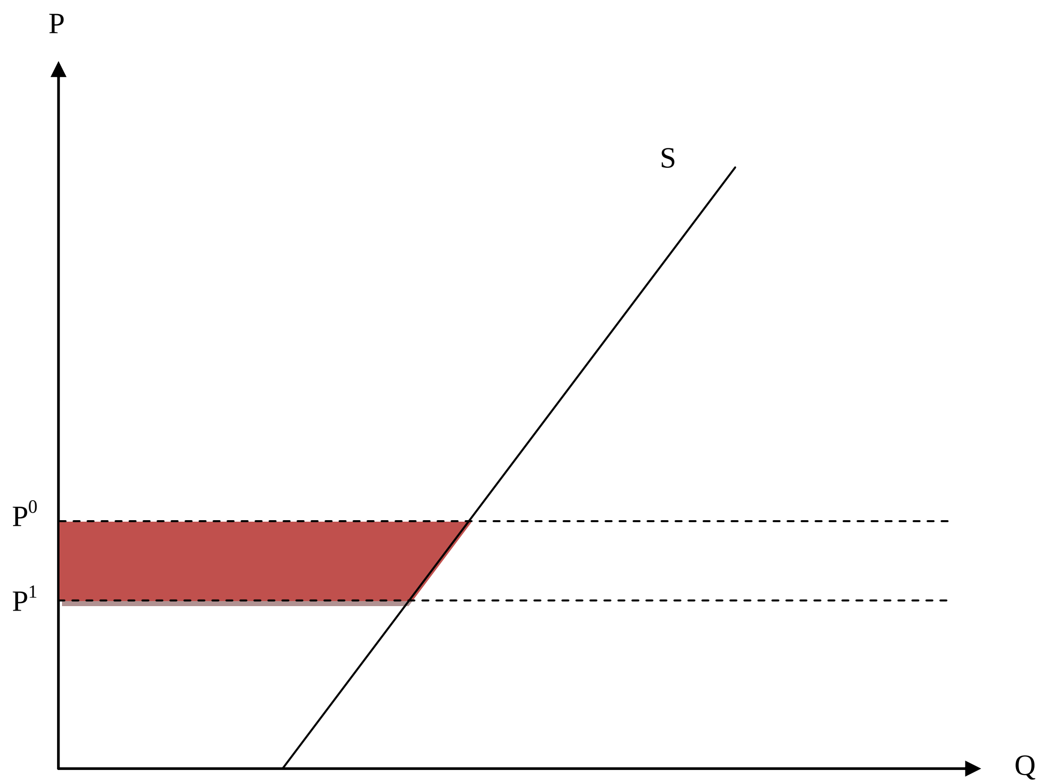


Figure B.9 Producer surplus decrease in scenario M1 in Canada and the USA

S^0 is an initial supply curve. S^1 is a supply curve at a new equilibrium. Red area (with solid fill) is a net decrease in PS caused by price decrease. Blue area (with stripes) is a net increase in PS caused by a rightward shift of supply curve. The net effect of price decrease and supply curve shift is negative producer surplus in Canada and the USA relative to benchmark 1.

Supply of wheat in these countries increases because of the presence of better performing MAS DT wheat. However, yield gain of MAS DT wheat is relatively small compared to the effect of declined prices. This leads to a negative producer surplus in Canada and the USA. In addition in Canada and the USA, there are non-adopters of MAS DT wheat too. Their producer surplus change will look like in Figure B.8. This leads to a negative producer surplus overall in Canada and the USA for both non-MAS and MAS DT wheat producers.

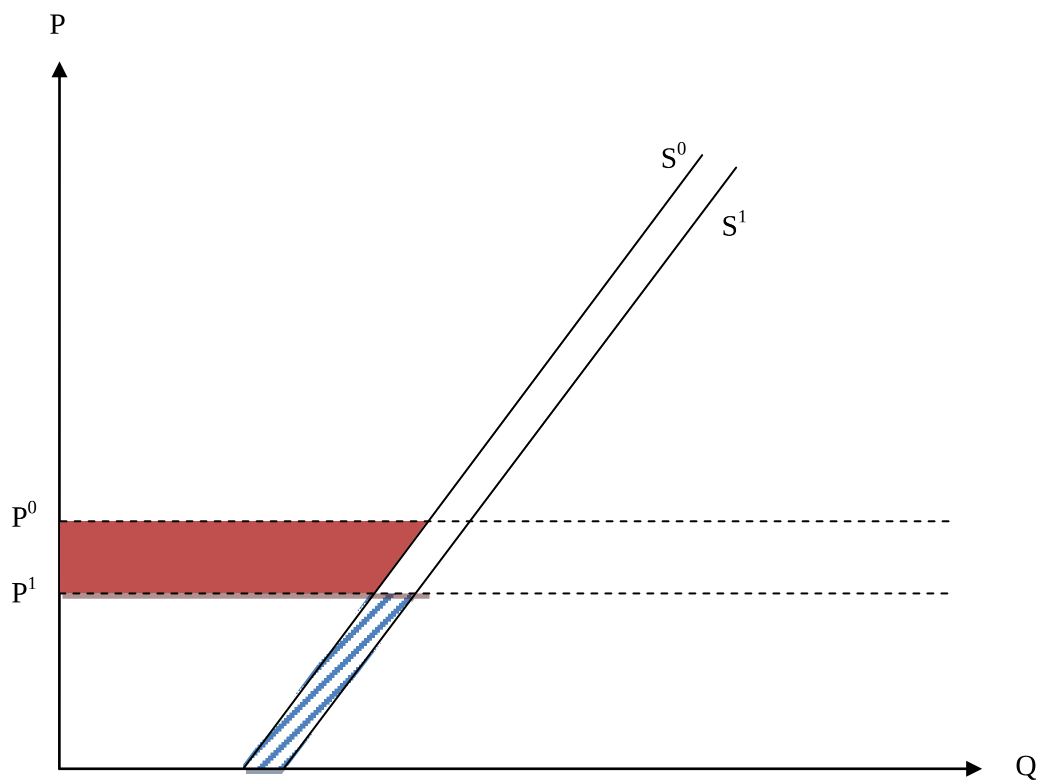


Figure B.10 Consumer surplus increase in scenario M1 in Algeria, Brazil, Egypt, Japan, South Korea, and ROW

D^0 is an initial demand curve. D^1 is a demand curve at a new equilibrium. Blue are (with stripes) is a net effect of CS increase caused by decreased price and a rightward shift of demand curve. Consumers in these countries benefit from lower prices of wheat.

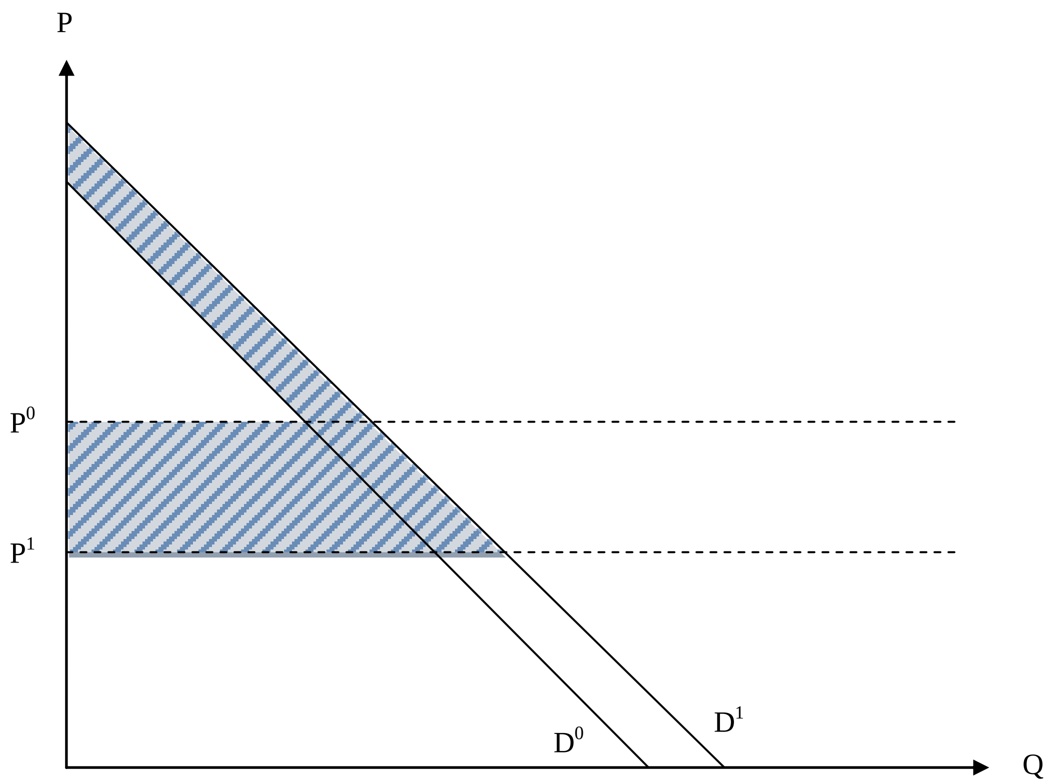
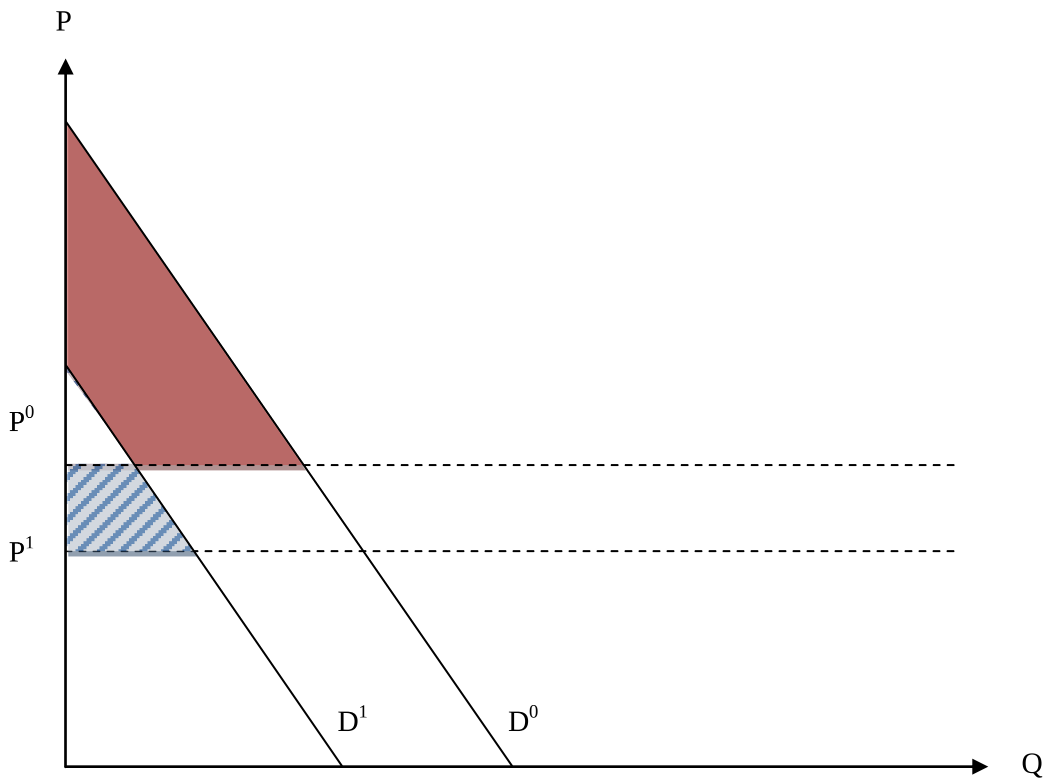


Figure B.11 Consumer surplus decrease in scenario M1 in EU and Indonesia

D^0 is an initial demand curve. D^1 is a demand curve at a new equilibrium. Red area (with solid fill) is a net effect of CS decrease caused by leftward demand curve shift. Blue area (with stripes) is a net effect of CS increase caused by decreased price. The total net effect of demand curve shift and price decrease is negative CS. Positive cross price effects that outweigh negative own price effects cause decreases in demand of wheat in these countries even at a lower price.



CHAPTER 3. Economic returns from transferring transgenic drought-tolerant maize technology to low income countries under humanitarian license (the case of Kenya)

3.1 Introduction and statement of the problem

Many countries are in need of improved agricultural staple crop varieties which can withstand severe weather conditions. The introduction of varieties tolerant to drought is important in developing countries where water sources are scarce and agriculture depends on rainfall in the growing season. A large proportion of the population in many developing countries is dependent on agricultural activities for sustenance. Reliable and consistent yields are critical for many smallholder farmers to survive.

Drought is considered one of the most devastating constraints of African agriculture, affecting the yields of many crops, including maize, the most important staple crop (WEMA, 2010). As a response to this issue, the Water Efficient Maize for Africa (WEMA) project was launched in 2008 in collaboration between African Agricultural Technology Foundation (AATF), the International Maize and Wheat Improvement Centre (CIMMYT), the company Monsanto, and the national agricultural research systems (NARS) in five WEMA project countries: Kenya, Mozambique, Republic of South Africa, Tanzania and Uganda. Such public-private partnerships are based on the expertise contributed by all parties involved: AATF, with its leadership and project management; CIMMYT, with maize varieties adapted to local conditions; Monsanto, with proprietary maize germplasm, breeding tools and drought tolerance transgenes (developed jointly with BASF); and the NARS, with field trials and means for distribution of seeds. In this initiative, conventional selection methods, marker assisted selection, and biotechnology (transgenic methods) are being used in developing improved maize varieties. The long-term goal of the project partners is that the technology will be distributed royalty-free (i.e. under a humanitarian license) to seed companies in participating countries, so that smallholder farmers may obtain access to the seeds at lower costs than otherwise (WEMA, 2010).

Drought tolerance in maize is to be achieved by both conventional and transgenic methods. These new varieties, if developed successfully, are estimated to produce 20-35% higher yields under moderate drought stress compared to the 2008 maize hybrid varieties (Vanessa Cook, WEMA project lead, Monsanto, personal communication, January 22, 2012). This is expected to translate into an additional two million tonnes of maize produced in a drought year in the five participating countries, providing 14-20 million people with more food (Monsanto, 2012). The costs of meeting biosafety requirements of the new varieties are still to be estimated in each country based on the local regulations (Monsanto, 2012).

The scientists and collaborators of the WEMA project are already working to improve drought tolerance of maize. However, it is important to know ahead of time whether these new DT maize varieties will provide economic benefits in the recipient countries. It is not known how much of the benefits will accrue to the smallholder farmers that will use the seeds under humanitarian license of technology transfer. Only a few studies that estimate benefits from introducing transgenic DT maize in Kenya and several other African countries exist so far (Kostandini et al., 2009; Kostandini et al., 2011). These studies, however, employ only one year static models, do not study dynamics of technology adoption, do not assume humanitarian licensing, and do not include research related costs to develop transgenic DT maize varieties (see section 3.3.1 for more details).

Even though most of the existing economic impact studies report benefits of various GM crops in developing countries (see section 3.2.3 for more details), their results should be interpreted with caution. These studies are usually based on a relatively few country cases, few crops, a limited number of surveyed farmers, and data from a limited number of years. While many economic impact studies use data only from the early years of technology adoption, early adopters of technologies tend to benefit more compared to late adopters (FAO, 2004), which may lead to overestimation of benefits of the transgenic crops. None of these studies consider the humanitarian use technology transfer, a practice which is still relatively new. Our study addresses some of these issues, while being applicable specifically to Kenya smallholder maize producers.

This chapter presents analysis of the economic impact of transgenic drought-tolerant maize varieties. One country case – Kenya – is selected for the following reasons: (a) it experiences severe droughts, (b) it is part of the WEMA project; (c) the harvested area and production volume of maize is relatively large compared to other participating countries; (d) the regulatory environment to introduce transgenic DT varieties is relatively favourable, and (e) confined field trials are ongoing. The inclusion of all participant countries goes beyond the scope of the study.

The objective of this chapter is to assess future economic returns from the introduction of transgenic drought-tolerant maize varieties on smallholder farms under humanitarian license in Kenya based on:

- the impact of yield advantage (i.e., decreased maize yield losses) as a result of increased drought tolerance (different scenarios are developed to capture potential yield advantages of transgenic DT maize varieties);
- the area to benefit from the technology (depending on the level of adoption of transgenic DT maize varieties in each proposed scenario);
- the level of maize prices.

The following section provides background information about: WEMA project objectives and progress; a general overview of maize production in Kenya and problems faced by smallholder farmers; information on the existing studies that researched benefits of GM crops in Kenya and the biosafety framework in Kenya; the definition of a humanitarian license and when it is used. This section sets a stage for further analysis and assists readers to understand the importance of the issue. Section 3.3 contains an overview of existing methodologies that are available to achieve the objectives of the research. Approaches that are used in this study are then discussed. Sections 3.4 and 3.5 present the data for this study, necessary data adjustments and building blocks of the empirical simulation model. The results and conclusions of the study are provided in the sections 3.6 and 3.7.

3.2 Background

3.2.1 WEMA details and progress

The target population of the WEMA project is smallholder farmers in all participating countries. Smallholder farmers are the most vulnerable to severe droughts, since their food supply and livelihoods are heavily dependent on how much maize they harvest. Apart from droughts, these farmers also encounter many other issues that increase yield losses, including maize storage pests. Therefore, additional requirements to the maize varieties resulting from WEMA project include the following:

- High-yielding (relative to maize hybrid varieties that existed in 2008);
- Disease resistant (Grey Leaf Spot, Northern Leaf Blight, Maize Streak Virus);
- Insect resistant;
- Improvements of other agronomic traits (e.g., lodging, height, maturity).

The first conventional drought tolerant maize hybrids are estimated to be available to farmers in spring 2014. Conventional DT maize varieties with improved insect resistance and transgenic DT maize are estimated to be available in 2015 and 2017 respectively, with necessary biosafety regulations in place (Vanessa Cook, WEMA project lead, Monsanto, personal communication, January 22, 2012).

At the initial stages of the project the conventional maize varieties of CIMMYT were crossed with the proprietary inbred maize lines of Monsanto to explore undiscovered abilities of different combinations of elite germplasm pools. Under the optimum water conditions of 2010/2011 harvesting season, the ten best new hybrids from these crosses have yielded 19-27% more than the 2008 hybrid maize control varieties. It is expected that inbred lines of conventional DT maize will yield 37-59% more under water stress than the 2008 maize control varieties (Stephen Mugo, CIMMYT, personal communication, January 22, 2012).

Thirteen conventional and six transgenic variety testing locations have been established in WEMA countries. Regulatory approval for confined field trials of transgenic DT maize in Kenya was secured in 2010. The first transgenic DT maize confined trial was conducted in Kiboko from December 2010 to April 2011 (Vanessa Cook, WEMA project lead, Monsanto, personal communication, January 22, 2012). It is expected that five hybrid transgenic maize lines (with stacked insect resistance and drought tolerance traits) will be developed by 2017 (Stephen Mugo, CIMMYT, personal communication, January 22, 2012).

Drought tolerance in transgenic maize is obtained from cold shock protein B (*cspB*) of *Bacillus subtilis*, a common soil microorganism. Research has shown that *cspB* helps plants to cope with water deficiency stress. This was used in developing the DT maize variety MON87460. MON87460 has been approved for food and feed uses in Australia, Canada, and New Zealand (ISAAA, 2012).

3.2.2 Maize production in Kenya and drought

Maize, which is now the most important staple crop in Kenya, was introduced into East Africa at the end of the fifteenth century (De Groote et al., 2011). Up to 80% of Kenyan maize is produced by smallholder farmers (AATF, 2010). Many poor people from small farming villages in Kenya replace the word "maize" with the word "food" in their everyday conversations, while still talking about different fruits, vegetables and meat using the proper names of these types of food. Evidently, maize is considered to be very important food in these smallholders' diets.

In 2005-2009 the average production of maize in Kenya was 2.78 million tonnes and the average yield during the same period of time was 1.57 t/ha. Maize supply per capita in 2007 was 79.8 kg (FAO, 2011; IGC, 2011). In 2007, the production area of maize in Kenya was 1.62 million hectares, which is 79.2% of land under cereal production and 31.2% of total arable land in Kenya (World Bank, 2011).

Based on population data for Kenya (World Bank, 2011) and total maize consumption (IGC, 2011), associated maize consumption per capita in 2007 and 2008 would have amounted to 80.3 and 92.9 kg respectively. Kenya Maize Development Programme reports per capita maize consumption in Kenya to be 98 kg (USAID Kenya, 2011). The average annual population growth per year is 2.6% (World Bank, 2011), which roughly adds one million more people annually. The average annual growth in maize production is, however, just around 2% (AATF, 2010). This has potential for Kenya to become a consistent net importer of maize. As pointed out by Karanja et al. (2003), population growth in Kenya and a relatively fixed amount of arable land pushes people to settle in areas that are only marginally suitable for agriculture and have very low yield potential. Apart from these problems, other constraints that prevent achieving high levels of maize productivity and, therefore, improved food security in Kenya, include soil erosion and water scarcity, infestation of crops with pests and diseases, high production costs, distorted markets and lack of financing (Hoisington and Ngichabe, 2003).

In the past 15 years (see Table 3.1) there have been severe droughts in the country which, together with the other issues noted earlier, contributed to reduced food security and dependence on maize imports and foreign food aid. Drought may pose a considerable threat to maize production in Kenya since more than 80% of land in the county is arid or semi-arid, receiving less than 800 mm of rainfall annually (AATF, 2010).

Table 3.1 Consequences of droughts, 1997-2009

January 1997	The Kenyan Government declared a state of national disaster after a severe drought threatened the livelihoods of 2 million people.
December 2000	4 million people were in need of food aid after Kenya was hit by its worst drought in 37 years.
March 2004	The long rains (March–June) failed and the subsequent crop failure left more than 2.3 million people in need of assistance.
December 2005	President Kibaki declared yet another "national catastrophe" in reference to the famine that affected 2.5 million in northern Kenya.
January 2009	President Kibaki declared drought and famine in the country a national disaster and announced that 10 million people are food insecure and in need of support.

Source: AATF 2010, Kandji 2006

3.2.3 Benefits from adoption of GM crops in developing countries

Until now the only two GM food crops that are commercially grown in developing countries are GM maize and GM soybean (GMOCompass, 2011a). Smale et al. (2009) conducted a comprehensive review of 137 peer-reviewed articles on economic impacts of biotechnology in developing countries that were published during the period of 1996-2007. These authors conclude that, overall, GM crops are promising, and that the most researched GM crop is *Bt* cotton. In-depth investigation of the economic impact of other GM crops has begun only recently. Most of the studies reviewed do not incorporate analysis of positive and negative externalities associated with adoption of GM crops, such as health and environmental impacts, inequality, and spill-over effects (Smale et al., 2009).

Overall there is a large literature that investigates the impact of different agricultural biotechnologies in both developed and developing countries. Examples of the GM crops in developing countries for which economic impact studies (both ex post and ex ante) have been conducted are: *Bt* maize (De Groote, 2003; Yorobe Jr. and Quicoy, 2006), *Bt* rice (Mamaril and Norton, 2006), HT rice (Demont et al., 2009), "golden rice" (Zimmerman and Qaim, 2002), pest resistant corn (Alston et al., 2002), *Bt* eggplant (Krishna and Qaim, 2008), disease resistant papaya (Napasintuwong and Traxler, 2009), HT soybean (Qaim and Traxler, 2005), *Bt* cotton (Gouse et al., 2004; Pray et al., 2001; Qaim et al., 2006; Thirtle et al., 2003). These studies report considerable benefits of new improved GM crops in terms of reductions in pesticide and herbicide use, increase in yields, and increase in incomes of farmers. Some differences in the levels of these benefits exist depending on agroclimatic zone, weather conditions, level of weed or pest pressure, and management practices on the farm.

3.2.4 GM crops and their economic impact in Kenya

Currently, there are no commercially grown GM crops in Kenya. Field trials are being conducted for the following GM crops: biofortified cassava, virus resistant cassava, insect resistant (IR) cotton, insect resistant maize, drought tolerant maize, and biofortified sorghum (Biosafety, 2011). Due to recent developments in its regulatory system for biosafety of crops (for more details see section 3.2.5), Kenya may become the fourth country in Africa[33] that allows commercial production of GM crops (Biosafety, 2011; Njagi, 2010).

Smale et al. (2009) reported that only two studies on potential economic impacts of GM crops in Kenya had been conducted by 2007. The first paper, by Qaim (2001), evaluates ex ante economic impact of virus- and weevil-resistant sweet potato in Kenya. This author projects 5.4 and 9.9 million $US of annual welfare gains (calculated as annuities starting from 2002 and for a period of 16 years) from hypothesized adoption of virus- and weevil-resistant sweet potato respectively. The welfare gain estimates are presented in the form of gross benefits only, since the cost of research is not included in the calculation. In the second paper, by De Groote et al. (2003), ex ante impact of *Bt* (insect resistant) maize in Kenya is assessed. The authors incorporate geographic information system (GIS) data in an economic surplus[34] model and calculate surplus that results from the decrease in crop losses due to stem borers. The present value of returns to adoption of *Bt* maize over 25 years is estimated to be $208 million, relative to costs around $7 million.

A few other studies investigate different aspects of introducing GM crops in Kenya. Andreu et al. (2006) assess the economic impact of maize tolerant to streak virus employing a partial equilibrium displacement model. These authors differentiate between at home consumption of maize and selling the marketable

[33] Three other African countries produce GM crops commercially: Burkina Faso (IR (insect resistant) cotton), Egypt (IR maize), and South Africa (various GM cotton, maize, and soybean varieties).

[34] Economic surplus (also known as economic welfare) refers to consumer surplus and producer surplus. Consumer surplus is the monetary gain to consumers that are able to buy units of product at a lower price than the maximum price they would be willing to pay for the last unit of that product consumed. Producer surplus is the monetary gain of producers that sell for a higher price than the lowest price they would be willing to sell successive units of their product (Just et al., 2004).

surplus, recognizing small and large producers of maize. Changes in both consumer and producer surplus are concluded to have been positive under conservative and best case yield increase scenarios one year after adoption if maize tolerant to streak virus had been introduced in 1999. The consumer surplus change estimates range between $6.4 and $16.8 million. The range of aggregate producer surplus is from $3.5 to $14.2 million, and from $0.6 to $0.7 million for small scale and large scale farmers respectively.

The success of introduction of transgenic DT maize will be influenced by whether or not Kenyan consumers exhibit aversion to GM crops. Few studies have explored Kenyan consumers' preferences to GM food. Two of these are based on the same survey of 604 urban consumers in Nairobi (Kimenju and De Groote, 2008; Kimenju et al., 2005). The third study, by Keter et al. (2007), applies a similar approach to a sample of rural consumers. Kimenju and De Groote (2008) and Kimenju et al. (2005) found that, at the time when their survey was administered in 2003, only 38% of the sampled consumers were aware of GM crops. This seems to have influenced the estimates by Kimenju and De Groote (2008) of willingness to pay (WTP) for GM maize meal by sampled consumers in Nairobi. The mean WTP was 58 Kenyan Shillings (KSh), 13.8% higher than the average price of 51 KSh then paid for a 2 kg package of regular maize meal. From their sample of consumers, 80% would buy GM maize meal at a 50% discount, 68% - at the same price as regular maize meal, 50% would pay a 5% premium over regular maize meal, and 26% - a high premium of 50% over regular maize meal. The authors do not explicitly discuss why some respondents stated that they are willing to pay premiums for GM foods. However, they reveal that consumers in Kenya in general have a perception of reduced pesticide use on GM crops, which in turn may result in potential human health benefits for those consuming these GM crops. The newest study by De Groote et al. (2011) estimated consumer willingness to pay for maize fortified with provitamin A. In this study, the revealed preferences of consumers were obtained through experimental auctions with the possibility to buy the product, paying cash. This was the first study on

African consumers' attitudes to maize that employed experimental auctions. It was concluded that Kenyan consumers would be willing to pay 24% on average a premium for bio-fortified maize.

Keter et al. (2007) conducted a survey of 121 rural consumers in 2006 in Western Kenya on WTP for insect resistant GM food products. Of the sampled consumers, 89% stated that they would buy GM maize meal at the same price as for regular maize meal (e.g. 40 KSh per 2 kg at the time of the survey) while 65% of respondents would buy GM maize meal at a 25% premium. The mean reported WTP is estimated to be equal to 79 KSh, a 98% premium over the price for a regular maize meal. However, since only 13.2% of the respondents to the survey were familiar with or aware of GM crops, the WTP figures should be interpreted with caution.

From the few studies available it appears that the prospects of introducing and adopting GM crops in Kenya may be promising both from producer and consumer points of view. However, more research is necessary to be able to draw a comprehensive conclusion on the economic impact of GM technologies in Kenya, since the existing studies are either case based or cover relatively small samples of survey respondents.

3.2.5 Biosafety framework in Kenya

An explicit regulatory framework to assess biosafety of novel GM crop varieties, and food and feed products derived from these crops is needed before these novel GM crop varieties can be introduced in Kenya or elsewhere. Such a framework is necessary to ensure that GM crops and their products do not pose any health risks to humans and animals, and are not harmful for the environment.

The history of establishing biosafety regulations in Kenya started in 1991 when Monsanto proposed to license a royalty-free transgenic virus-resistant sweet potato to the Kenya Agricultural Research Institute (KARI). For this to be done, a rigorous regulatory framework should have been first established. By 1996 a National Biosafety Committee (NBS) was established in Kenya, and in 1998 “Regulations and Guidelines for Biosafety in Biotechnology in Kenya” were published (Cohen and Paarlberg, 2004). In 2000, Kenya signed the Cartagena Protocol on Biosafety[35], which came into force in 2003. In 2009 the Biosafety Act was passed (Kingiri, 2010). The National Biosafety Authority was established to undertake coordination of biosafety assessment under the Biosafety Act of 2009 (Kingiri, 2010). A more detailed step-by-step description of biosafety regulatory processes is provided elsewhere (Cohen, 2005; Kingiri, 2011a; Mugo et al., 2005).

Despite some progress in establishing a regulatory framework, the need to improve its efficiency has been pointed out. More experts in genetic engineering and biotechnology need to be trained in the Universities, a lack of research funding needs to be addressed, and bureaucratic and regulatory capacity issues need to be resolved (Cohen and Paarlberg, 2004; Kingiri, 2010). Criticism has also been directed to the slowness of the regulatory decision process because approval has to be obtained on three levels: approval for confined trials, larger scale (national) trials, and commercialization (Cohen and Paarlberg, 2004). There are discrepancies in how scientific and non-scientific participants interpret biosafety regulations (Kingiri, 2011b).

Some critics in Kenya have called into question the reliability of the process that led to the establishment of biosafety regulation, inclusiveness of stakeholders in the regulatory processes, and wider public awareness about biotechnologies (Kingiri, 2010; Kingiri, 2011b). However, it is beyond the scope of this study to assess the efficacy of the process that governs the biosafety assessment of new transgenic crops. It is very difficult to predict how fast and/or efficient the biosafety assessment of transgenic DT maize will be since the final product(s)

[35] The Cartagena Protocol on Biosafety is an international agreement that governs and ensures safe handling, transportation and usage of living modified organisms (LMOs) that are products of biotechnology.

generated by the WEMA project are not expected until 2017. I assume that biosafety approval for commercial release of transgenic DT maize varieties will be granted by the time the final product is available in 2017.

3.2.6 Drought tolerance research for maize

The development of both conventionally-bred and genetically modified (transgenic) DT maize varieties are aimed at improving food security in the regions of marginal agricultural potential from increased yields/decreased yield losses under drought stress. Drought tolerance in crops is a complex phenomenon and there are multiple ways to achieve this (see table 3.2).

Table 3.2 Opportunities for enhancing drought tolerance

Strategy	Examples
Drought escape	Short duration and enhanced seedling vigor (good for the areas with expected drought early or late in the season; improvement can be achieved by conventional breeding and genetic modification)
Drought avoidance	Long and dense roots able to penetrate deep into the soil (yield penalty associated with longer roots)
Drought tolerance	1) Enhanced ability of plant cells to retain water 2) Osmotic adjustment in roots and leaves to retain water 3) Hydrophobic barriers in roots and leaves to loss of water into soil and atmosphere 4) Aquaporins (water-channel proteins) to speed water movement 5) Altered hormonal signaling among roots, leaves and seeds

Source: adapted from CGIAR 2003

Historically research on DT maize has been funded mainly by the public sector with improved varieties obtained by conventional breeding (Kostandini et al., 2011). Several studies describe research and breeding efforts directed to developing improved varieties of maize for drought prone areas (Bänziger et al., 2000; Betran et al., 2003; Monneveux et al., 2005; Ruta et al., 2010). For example, since 1997 CIMMYT has run a maize drought tolerance breeding program targeted to countries in southern Africa. With an average maize yield of 1.3 t/ha and a yield potential of over 10 t/ha in southern Africa, there is room for yield improvement (Bänziger et al., 2006). In the trials conducted by CIMMYT in 2000-2002 across different sites, 42 CIMMYT maize hybrids were compared with

41 maize hybrids from different private seed companies. Under managed drought stress conditions, CIMMYT hybrids had a 19% yield advantage over other hybrids (Bänziger et al., 2006). Some conventionally-bred DT maize varieties are already produced commercially in South Africa and Ethiopia (Kostandini et al., 2009). In 2007, the Drought Tolerant Maize for Africa (DTMA) project was initiated by CIMMYT in collaboration with other private and public organizations in 13 African countries[36]. As of September 2010, 60 conventionally bred DT maize varieties were available for commercial use in the project countries and 74 more varieties were in the process of release (DTMA, 2010).

It is believed that further improvements in drought tolerance of maize may be achieved by transgenic technologies as compared to conventional breeding (CGIAR, 2003; Gosal et al., 2009; Kostandini et al., 2011). In 2010, Food Standards Australia New Zealand (FSANZ) approved the importation of food products derived from the DT GM maize variety MON87460 developed by Monsanto (FSANZ, 2010). In 2011 Health Canada approved sales of food derived from MON87460 in Canada (Health Canada, 2012). MON87460 is reported to be nutritionally equivalent to conventional varieties of maize (Harrigan et al., 2009). Monsanto has also completed regulatory submission for GM DT maize in the United States (GMOCompass, 2011b; Kostandini et al., 2011), and the European Union (GMOCompass, 2012).

3.2.7 Humanitarian use license and technology transfer

Humanitarian licenses are a particular practice of intellectual property rights (IPR) that can be used for development purposes in order to provide access to certain technologies on a non-commercial basis. Humanitarian licensing is an attempt to ease the restrictions of IPRs for development purposes, based on agreements between technology developers and public and private research organizations

[36] Country participants of the DTMA project are Angola, Benin, Ethiopia, Kenya, Malawi, Mali, Mozambique, Nigeria, Tanzania, Uganda, Zambia, Zimbabwe, and Ghana.

(Louwaars et al., 2006). This type of licensing is currently being applied for some innovations in the fields of pharmaceuticals and agricultural biotechnology.

Organizations such as AATF, the International Service for the Acquisition of Agri-biotech Applications (ISAAA), and the Consultative Group on International Agricultural Research (CGIAR) are noted as having relevant experience in humanitarian use technology transfers (Brewster et al., 2005). Brewster et al. (2005) discuss one of the best known examples of humanitarian licensing: “golden rice”, a transgenic approach to enrichment of rice with vitamin A. The innovation-related patents were licensed by inventors to Syngenta, which could grant sublicenses of the innovation to research organisations in developing countries. Farmers in developing countries whose sales are less than $10,000 a year, should be able to use “golden rice” royalty-free (Brewster et al., 2005). The inventors had to overcome enormous legal and procedural difficulties and many steps in order to make this innovation legally available, free of charge, to local rice breeders and research institutions in developing countries (Potrykus, 2001). Other examples of humanitarian use technology transfer are available (Brewster et al., 2005; Lybbert, 2002).

Lybbert (2002) emphasized that humanitarian licensing requires “an objective case-by-case evaluation methodology”. Humanitarian use technology transfers are intended for poor farmers but there are no benchmarks of how poor is poor. This author argued that definition of this practice should include either some maximum farm size, minimum degree of subsistence, or maximum farm income as a benchmark. The approaches to benchmark recipients of humanitarian licenses might include: geographic target, to farmers within some specific region (there is a threat of leakage to unintended regions); country target, to farmers within some specific country (where success would depend on the concentration of poor farmers in the country and additional restrictions on the export of seed varieties); and an existing program participation target, to farmers within program participant countries (however, not all poor farmers might get access to such a program).

The aim of WEMA is to distribute the seeds of transgenic DT maize varieties via local seed suppliers to smallholder farmers[37] in WEMA countries royalty free. The transgenic DT maize varieties will be licensed to AATF, which will grant sublicenses to the approved seed companies. Farmers will not have to pay a direct price premium for maize varieties with improved drought tolerance. That is, the seeds should not be more expensive than available maize varieties.

3.2.8 Background summary

Based on the overview of this chapter it is possible to arrive at some conclusions in support of the proposed research. First, droughts are fairly frequent in Kenya. These negatively impact the level of maize production. Developing transgenic maize varieties tolerant to droughts in Kenya seems to have promise, especially since the aim of WEMA partners is to introduce these as royalty free varieties. This means the seed costs of these transgenic DT maize varieties will not be higher than other hybrid or conventional maize varieties already available in those markets. WEMA's efforts to develop transgenic DT maize are well under way and there is a need to assess whether introduction and adoption of transgenic DT maize varieties in Kenya makes economic sense.

[37] Smallholder farmers are defined as all farmers in the WEMA countries, except in the Republic of South Africa (RSA). In the RSA, only farmers with less than 3 ha under maize are to be included in the project (Stephen Mugo, CIMMYT, personal communication, February 7, 2011).

3.3 Methodology

3.3.1 Overview of existing studies that quantify economic impacts of drought tolerant crops

There are very few studies that assess the economic impact of drought tolerant crops or drought tolerant maize in particular. Kostandini et al. (2009) estimate the economic impacts of transgenic versus conventional DT maize, rice, and wheat research in eight countries (Bangladesh, India, Indonesia, the Philippines, Ethiopia, Kenya, Nigeria, and South Africa). These authors use extensive GIS data [10×10 km pixels] to estimate the spatial distribution of crop production within three drought risk zones and sixteen agroecological zones in each country. This spatial distribution shows that 50% and 52% of maize production quantity and maize production areas respectively are in a high drought risk zone in Kenya.

Kostandini et al. (2009) calculates economic benefits of mean yield increases of transgenic DT crops using the economic surplus approach summarized in Alston et al. (1995). This approach is based on quantification of the aggregate net benefits of a rightward shift of the supply curve resulting from innovation. Kostandini et al. (2009) employs the following assumptions. Regional markets are assumed to be closed. Therefore, no trade occurs between regions and countries. Research on drought tolerance of crops generates mean yield increases, expressed as a unit cost reduction of the producer's marginal cost, as well as yield variance reductions. In particular, for conventional and transgenic DT maize, 16% and 18% mean yield increase is assumed respectively in African countries. The adoption rate of DT maize in terms of the areas sown in high drought risk zones is assumed to be 50% for the typical agricultural year, whereas in the medium and low drought risk zones 30% of the area is assumed to be sown to transgenic DT maize varieties. Producers of crops are assumed to be risk averse to changes in income that result from variability in crop yields. Consumers are assumed to benefit from crop price stabilization resulting from decreases in yield variability. A further assumption is that in transgenic seed markets, seed companies behave as monopolists and charge price premiums for seeds of DT crops.

The results of the study by Kostandini et al. (2009) are presented in the form of producer and consumer surplus estimates in each agroecological zone, as well as by the estimated profit of seed companies. Geographically, most benefits accrue to South Africa from adoption of DT maize. The study does not, however, take into account costs associated with conducting DT research and meeting biosafety regulations to introduce transgenic DT crops in each country. Dynamic characteristics of technology adoption are not investigated.

In the most recent paper by Kostandini et al. (2011) the authors use a similar analysis to assess the economic impact of conventional and transgenic DT research for maize, millet and sorghum in Kenya, Uganda and the Amhara region of Ethiopia. The authors employ GIS data and their previous methodology to evaluate consumer and producer surplus of DT crop varieties based on assumed mean yield increases and decreases in yield variance. In addition, however, household survey datasets are used to calculate benefits for small, medium, and large farmers. For Kenya, for example, the 2000 Rural Household Survey dataset is used for this purpose.

The assumptions employed in Kostandini et al. (2011) are slightly different from those in Kostandini et al. (2009). For example, the mean yield increase of conventional DT maize is differentiated by drought risk zones and is assumed to be 18%, 13%, and 10% in high, medium, and low drought risk areas respectively. The mean yield increase for transgenic DT maize is assumed to be 25%, 20% and 15%, respectively, in the specified drought risk areas. The adoption rate of both conventional and transgenic DT maize in Kenya is assumed to be 50% in the high drought risk areas and a level of 40% is used in the medium drought risk areas. It is also assumed that the adoption rate within a specific drought risk area does not depend on the farm size.

The analysis of Kostandini et al. (2011) estimates that the total annual benefit to producers in aggregate generated by transgenic DT maize research in Kenya ranges between $3 and $20 million, depending on the farm size. Annual consumer benefit estimates are $12.5 million, and $28 million accrues to private seed companies. An interesting result is obtained from the calculation of DT maize research benefits at the household level as a percentage of the total household income. In Kenya, Uganda and Amhara region of Ethiopia respectively these benefits constitute 0.4–2%, 2–9%, and 9–12% of the household farmers' total income. Kostandini et al. (2011) explain that the smaller household-level benefits in Kenya are due to higher household incomes and smaller areas sown to maize than in Uganda and Ethiopia.

Similar to the earlier study by Kostandini et al. (2009), Kostandini et al. 2011 do not consider costs associated with DT research in crops, nor do they assess spillovers that DT technology may produce, and dynamics are not incorporated into the modeling of adoption of DT technology.

La Rovere et al. (2010) provide the most comprehensive study of the potential impact of drought tolerant research so far. This is a component of the Drought Tolerant Maize for Africa (DTMA) project of CIMMYT and the International Institute for Tropical Agriculture (IITA). This study assesses the cumulative impact (from 2007 to 2016) of conventionally-bred DT maize varieties in 13 DTMA countries. GIS data from different sources is used to estimate production of maize and yields in each country. FAOSTAT statistics and various surveys are employed to collect prices, adoption rates of improved varieties, and other economic data.

To estimate drought risk in each country the concept of the probability of a failed season (PFS) is used by La Rovere et al. (2010). According to this concept the percentage of years in which the harvest is most likely to fail completely can be calculated, and each specific region or area can be assigned to one of the PFS ranges. In such a way the severity of drought risk can be captured based on PFS ranges of 0–5%, 5–10%, 10–20%, 20–40%, and 40–100%, as compared to consideration only of three drought risk zones by Kostandini et al. (2009) and Kostandini et al. (2011). Population density in each PFS range is taken into account to better estimate the number of people affected by drought.

La Rovere et al. (2010) use an economic surplus model and consider various scenarios of improvements of yield of DT maize over traditional maize varieties: from 3% for conservative scenarios, to 30% for best case scenarios. The yield variance reduction is assumed to be 10% and 15% for conservative and best case scenarios respectively. Adoption rates of DT maize in Kenya are projected to be 46% by 2016. Assumptions on mean yield increase, yield variance reduction and adoption rates are conservative, even for the base case scenario in La Rovere et al. (2010), compared to Kostandini et al. (2009) and Kostandini et al. (2011). The other distinction in the study of La Rovere et al. (2010) is that the costs associated with the DTMA project (e.g., genetic research, breeding, DT maize trials) are included in the economic analysis.

Lybbert and Bell (2010) employ a stochastic adoption model of transgenic DT varieties in general and compare estimated benefits of other crops to those for *Bt* cotton technology adoption. These authors argue that the diffusion of DT technology will be slower than for other existing GM crop varieties such as *Bt* cotton. It is assumed that maximum adoption may be reached in 40 years from the date of the variety release, which is approximately twice as long as for *Bt* cotton. The major reasons for this assumption are that *Bt* technology provides full protection against pests and even under extreme pest pressure confers unconditional benefits to farmers. However, under conditions of extreme drought both DT and non-DT varieties fail, and therefore become indistinguishable. This may result in disadoption of DT varieties by farmers. Therefore extreme pest pressure facilitates faster learning about *Bt* cotton by farmers, whereas extreme drought may nullify the relative merits of DT varieties, especially for vulnerable farmers. These assumptions of Lybbert and Bell (2010), however, should be interpreted recognizing that the probability distribution of drought, used in the model, is quite simplistic and cannot fully describe complex nature of drought occurrence and severity. Spatial aspects of technology adoption are not incorporated, therefore, the results cannot be directly extrapolated to a specific country or location.

3.3.2 Overview of approaches that quantify economic impact of biotechnologies

The objective of this brief overview is to describe some approaches that quantify estimates of economic impacts of different biotechnologies. An objective is to identify an approach that is best suited for this study. This should be able to address some gaps in the literature on the economic impacts of biotech crops.

Smale et al. (2009) provides a comprehensive overview of methods used in specific studies. According to Smale (2009), the most common methods used in ex ante studies are economic surplus and cost-benefit analysis (CBA), international trade modeling, and stochastic simulation. Other methods include linear programming, crop loss estimation, partial budgeting analysis, farm survey analysis choice experiments, and others.

Many studies employ an economic surplus approach summarized in Alston et al. (1995). This approach became well-established in economic literature as it allows partitioning surpluses between consumers and producers from Marshallian research-induced surplus generated in output markets (Falck-Zepeda et al., 2000). Falck-Zepeda et al. (2000) calculate welfare distribution from introducing *Bt* cotton in the USA in 1996 by following the approach summarized in Alston et al. (1995). Falck-Zepeda et al. (2000) adjust this approach by adding calculation of monopoly profits accruing to biotechnology companies.

Mamaril and Norton (2006) build a partial equilibrium trade model of GM pest-resistant rice; welfare benefits for the Philippines (small importer), Vietnam (large exporter) and the ROW are evaluated for the years 2000-2020. Projections of expected benefits are based on an assumed technology diffusion rate, a projected consumption pattern based on population growth, and projected supply changes based on area planted and rice yield. The authors also follow an approach summarized in Alston et al. (1995) to calculate welfare benefits. The Global Trade Analysis Project (GTAP) general equilibrium trade model is used by Anderson and Yao (2003) to investigate economic effects of introducing various GM crops with and without the adoption of these by China. Many examples are given by Smale et al. (2009).

Falck-Zepeda et al. (2007) employ an economic surplus approach summarized in Alston et al. (1995) and augments this by stochastic simulation[38] to assess the benefit of introducing *Bt* cotton into West Africa. Stochastic simulation using @Risk© software is applied to some uncertain parameters such as yields, adoption rates, technology fees and others, for which the data are either scarce or do not exist. The results are presented as consumer, producer and innovator benefits for various scenarios for a period of 25 year.

Hareau et al. (2002) and Hareau et al. (2006) estimate economic benefits from introducing a transgenic herbicide resistant rice variety in Uruguay. The economic surplus approach, together with stochastic simulation of some key model parameters is used to measure benefits. These parameters include output price, expected increase in rice yield, and the maximum adoption rate. The Net Present Value (NPV) of the estimated surplus change is then measured to estimate the benefits of herbicide resistance rice.

Cabanilla et al. (2005) estimate potential benefits from adoption of *Bt* cotton in Mali. A linear programming model incorporates maximization of the expected profit on a typical farm, subject to resource availability. The profit function

[38] Alston's (1995) approach to estimation of economic surplus is based on a set of equations in which all parameters are deterministic. Falk-Zepeda et al. (2007) model some of these parameters as stochastic by employing simulation techniques.

includes assumed levels of insect infestation and yield advantage of *Bt* cotton. The calculated profit on a typical farm is aggregated to the national level based on the number of hectares under *Bt* cotton and the level of adoption.

Based on this literature, the following decisions are made regarding the modeling approach to be taken in this study. To be able to address the stochastic nature of yields and prices of maize, a stochastic simulation analysis similar to Falck-Zepeda et al. (2007) is chosen. By employing this analysis it is also possible to incorporate dynamics of the benefits from adoption of transgenic DT maize as well as WEMA project costs into the cash flows. To calculate costs and benefits of transgenic DT maize over time, the NPV approach is applied. To aggregate benefits to a national level, an approach similar to Cabanilla et al. (2005) is used.

3.3.3 Approaches used in this study

3.3.3.1 Cost-benefit analysis and net present value

Cost-benefit analysis as applied to public programs is sometimes referred to in the literature as social cost-benefit analysis. This differs from long run investment appraisal of costs and benefits incurred by a private firm. Private firms tend to calculate only those costs (expenditures) and only those benefits (revenues) that accrue to them. A social CBA accounts for cost and benefits that accrue to a society and usually applies to policy implementations, projects, and regulations that impact society (Boardman et al., 2011).

Social CBA involves all the steps of the long run investment decision by a private company: from selecting alternative projects, to selecting what costs and benefits will make an impact on the project outcome, to discounting costs and benefits and calculating NPV of the projects, and to performing sensitivity analyses and deciding what project to go with. However, the discount rate in social CBA differs from the private discount rate that is used to calculate net present value of the private firms' projects.

In social CBA, the NPV is the difference between the sum of discounted benefits and the sum of discounted costs over a period of time (Boardman et al., 2011):

$$NPV = \sum_{t=0}^{n} \frac{B_t}{(1+i)^t} - \sum_{t=0}^{n} \frac{C_t}{(1+i)^t} \ or \ \sum_{t=0}^{n} \frac{NB_t}{(1+i)^t} \ or \ \sum_{t=1}^{n} \frac{NB_t}{(1+i)^t} - I_0 \quad (3.1)$$

where B_t and C_t denote benefits and costs occurring in the period t, where $t \in [0; n]$; i is the social discount rate; $NB_t = B_t - C_t$ and denotes net benefit in the period t; I_0 is the initial investment.

WEMA project partners are developing transgenic DT maize that will be available to smallholder farmers under humanitarian license. This is a large scale project that will benefit society in the participant countries. WEMA project costs to develop transgenic DT maize varieties are viewed as investment costs that occur over the five year period of the project (2008-2012). The benefit to society is the future private benefits of the representative farms (see section 3.4.2) discounted with a social discount rate and aggregated to a national level (see section 3.5.8). This study investigates societal benefits in Kenya. However, there is potential for the analysis to be extended to other WEMA countries if similar data are available.

In a private CBA, NPV is a discounted value of the future net cash flows of the private firm. This approach is often used for investment decision purposes as it enables comparing different investments, projects and/or simply cash flows in terms of their value today. Projects may be accepted when NPV ≥ 0, and rejected when NPV < 0. That is, when the future discounted net cash flow is positive, the project is feasible. The NPV is specified in equation 3.1, where *NB* in this case indicates the net cash flow, and *i* is the private discount rate. The net cash flows consist of monetary inflows and outflows. In this study, inflows are the receipts/revenue/return of representative farms from their production of maize[39]. Outflows are input costs of the representative farms. Private CBA is used to assess costs and benefits of the smallholder farms in this study.

[39] It is recognized that many small scale farmers use their produce for self-consumption. Thus, the opportunity cost of self-consumption instead of the forgone sales on the market is considered to be "revenue" (i.e., the maize yield multiplied by the maize price is taken as the revenue).

3.3.3.2 Stochastic Monte Carlo simulation

Stochastic simulation enables incorporating risk and uncertainty of maize yields and prices into the calculation of NPV in the CBA. Yield is an uncertain variable since this is influenced by uncertain weather. Prices are subject to fluctuations in the market, as from changes in supply shortages, inflation, exchange rates, and many other factors. In this study, probability distributions for the stochastic variables of precipitation, temperature of the growing season and maize prices are specified (see sections 3.5.2 and 3.5.4).

Monte Carlo simulation of the @Risk© Excel add-in software is employed in this study. During Monte Carlo simulation the software draws samples from specified distributions of the uncertain variables, and then recalculates the formulas of the model based on these draws (Palisade Corporation, 2012). Monte Carlo simulation is based on random sampling and the results of the model are subject to sampling error. This error can be minimized by increasing the number of iterations (Evans and Olson, 2002). The model was initially run with 500, 1,000, 5,000 and 10,000 iterations. When the model was run with 10,000 iterations, the means of the simulated variables did not differ from the means of those variables when the model was run with 5,000 iterations. With lower numbers of iterations (i.e., 1,000 and 500) means differed from the mean of the model with 5,000 iterations. The number of iterations for the analysis is set at 5,000, since this is the lowest number of iterations that allows for higher precision of the results without consuming excess computing power. NPV of the net cash flows is an output of the Monte Carlo simulation and is expressed as a distribution of outcomes of all iterations.

The elements of the structural design of the simulation model are presented in figure 3.1. The elements in ovals are stochastic. These impact the respective variables in the directions noted by arrows. Maize yield is expressed as a function of weather variables in the base case model and is adjusted in the transgenic DT maize model to reflect improved drought tolerance of maize under drought conditions (for more details see section 3.5.5). Maize revenue is measured as cash inflows.

Maize input costs are measured as cash outflows. These are assumed to be predetermined and to remain constant through time (for the input cost summary see table 3.3). The WEMA project investment costs are included in the cash outflow only in the social CBA (for more details see section 3.5.8).

Cash inflows and outflows combined provide the net cash flow estimates that are the main element of the NPV calculation. Cash inflows and the input costs of the cash outflows are calculated in $US/ha[40], which allows aggregating to the level of agroclimatic zones[41] in Kenya (based on the number of hectares planted to maize in each specific agroclimatic zone), and consequently to the national level.

The discounted net cash flows are calculated for the base case scenario (i.e., where no transgenic DT maize is available on the market). Then the discounted net cash flows are recalculated for the situation in which transgenic DT maize is assumed to have been adopted. The differences in the discounted net cash flows of transgenic DT maize and the discounted net cash flows of the base case scenario are calculated on an annual basis and summed over the period of 2017-2038 (i.e., from the year when transgenic DT varieties are expected to be available and for a period of 22 years). The resulting figure is the estimate of the difference between the NPV of transgenic DT maize and the base case NPV. The NPV differences for different scenarios are reported in the results section along with the base case NPVs.

[40] All calculations in this study are done in $US, since official statistics and price data are available in $US and the WEMA project obtains funding in $US.
[41] Definition of the agroclimatic zone in Kenya is provided in section 3.4.1.

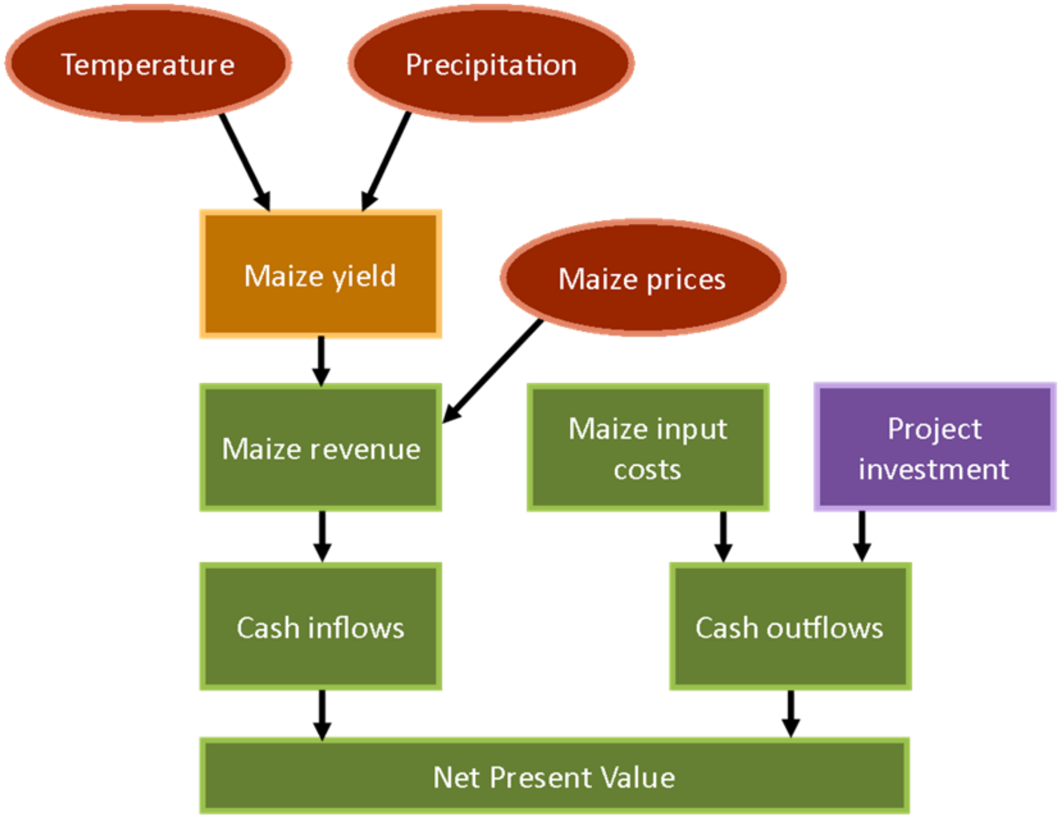


Figure 3.1 Structural elements of the Kenyan maize production simulation model

3.3.3.3 Maize yield model and weather

Levels of crop yields depend on many factors that are complex by nature and may change over time. These factors include, but are not limited to:

- weather/climate conditions;
- types of soil (fertility, salinity, etc.);
- variety of the planted crop (some varieties may be higher yielding or more resistant to some diseases, pests, or weeds);
- types and amounts of fertilizer and other inputs used;
- methods of land cultivation;
- crop rotations.

In Kenya, where the majority of smallholder farmers use minimal inputs due to lack of financial resources, and predominantly grow maize as a monoculture, weather may have a major impact on maize yield levels.

Average monthly or daily weather data and growing degree days (GDD) over the growing season are often used in yield regression specifications of crop yield variation. One must be cautious when using weather variables as predictors of yield. As technological advances improve crop varieties through time, there may be yield gains even when weather impacts are assumed to be constant (Robertson, 2012).

Robertson (2012) builds on the work of Schlenker and Roberts (2006) to estimate non-linear impacts of temperatures on crop yield in Western Canada. Robertson (2012) expresses yield as a function of temperatures, precipitation, district (area) dummies, and time trend. Temperature is incorporated into her regression in three different ways. The first alternative is average monthly temperatures expressed as a separate variable for each month of the growing season. Average monthly temperatures are calculated from the daily minimum and maximum temperatures. The second alternative is GDD calculated for the whole growing season. The third alternative is based on the study of Schlenker and Roberts (2006). This incorporates a more sophisticated calculation of crop exposure to different levels of temperature during each day of the growing season.

Lobell et al. (2011) estimate the impact of weather on yields of the field trials of maize conducted in Africa in 1999-2007. They regress yield on weather variables for a specific trial, use dummy variable for weather stations, and include a time trend. Weather variables consist of three different variables: GDD between 8 and 30^0C, GDD above 30^0C, and total precipitation for the period of 21 days during maize flowering. The calculation of GGD and precipitation was possible due to the availability of daily weather data.

Cortus et al. (2011) and Koeckhoven (2008) regress yields of various crops grown in Western Canada on a linear and a quadratic ratio of total growing season precipitation to GDD. The linear element of the ratio allows incorporating a relative measure of water supply (precipitation) to water demand (GDD, assuming that the higher is the temperature, the higher is the need for precipitation). The quadratic element of the ratio allows modelling extreme weather conditions (e.g., too much heat relative to the levels of precipitation, or vice versa) that may be potentially damaging for the crops. Daily weather data are available for the Western provinces of Canada in these two studies. Following methods adapted from Cortus et al. (2011) and Koeckhoven (2008) the yield regression model specification is established for our study (see section 3.5.1 for more details).

3.3.3.4 Technology adoption

Once transgenic DT maize is available in Kenya, it is unlikely to be adopted by smallholder farmers right away or it may not be completely adopted. The rate of farm-level adoption of transgenic DT maize varieties influences CBA estimation. This section provides theoretical background on the adoption of novel transgenic DT maize varieties.

A wide range of literature is dedicated to the issue of technology adoption, specific behaviors of different adopters, reasons for non-adoption and disadoption. The focus of this study is not adoption itself, but private and social economic benefits that are incurred by the adopters under different levels of adoption. For this reason more complex models of technology adoption were not considered. An approach of Rogers (2003) is used to calculate private NPVs of different adopter categories (see section 3.5.6 for more details).

Rogers (2003) defined adopter categories mathematically based on a bell-shaped curve of adoption (figure 3.2) and tested this on a sample of Iowa farmers adoption of 2,4-D weed spray. His work has been widely used in the studies of communications and diffusion of innovations through social networks. His categorization of adopters has also been used in other economics studies to investigate adoption of agricultural technologies (e.g., Berger, 2001; Padel, 2001).

According to Rogers (2003) there are five categories of adopters that behave differently when a new technology is marketed:

1) **Innovators**. This category of the population is generally very open to new ideas and favors progress. Innovators usually require a short period of time to make a decision regarding new technologies and are the first to adopt. Their decision is based on very accurate information about the new technology as they tend to contact inventors and scientist directly. Rogers (2003) assesses that innovators constitute approximately 2.5% of the total population (see figure 3.2).
2) **Early adopters**. These adopters are respected by others and are opinion leaders. Other potential adopters look to them for advice and follow their choices. When these individuals adopt a technology, this usually triggers a critical mass. They are believed to constitute some 13.5% of the population.
3) **Early majority**. Those in this category do not hold positions of opinion leadership and adopt a new technology only just before the average member of the population. Early majority is a link between early and late adopters. They are believed to represent 34% of the total population.
4) **Late majority**. This category is usually very sceptical about new ideas. They adopt a new technology either out of economic necessity, or because they feel pressure from others who have already adopted. Uncertainties about the new technology must be eliminated before they agree to adopt. Those in this category are represented as constituting 34% of the population and they adopt just after the average member of the population.
5) **Laggards**. Those in this category are the last to adopt. They are very suspicious of innovation and conservative in their choices. Laggards are seen as sticking to their own social networks and interacting with the same

type of people, who have very traditional values. This category is believed to constitute 16% of the population.

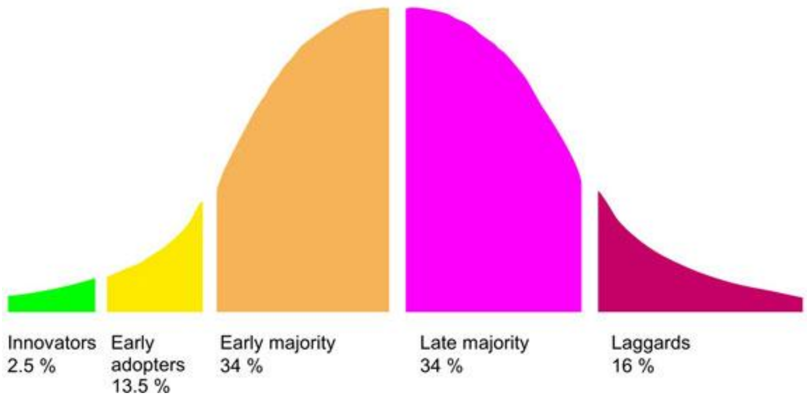


Figure 3.2 Categories of adopters according to Rogers (2003)

The categories of adopters presented in figure 3.2 are used to define the level of adoption of transgenic DT maize varieties by Kenya farmers. The timing of adoption is assumed to be determined by drought occurrence (see section 3.5.6 for more details).

3.4 Data and data adjustments

<u>3.4.1 Agroclimatic zones in Kenya</u>

Hassan (1998) defined major agroclimatic zones (ACZ) in Kenya based on maize production, elevation, and availability of moisture among other climatic constraints. This zoning is frequently used in research studies related to maize in Kenya (see figure 3.3). They are as follow:

1) Lowland tropics (LT) – below 700 meters above sea level (masl), at the Indian Ocean coast;
2) Dry Mid-altitude (DM) – 700-1400 masl;
3) Dry Transitional (DT) – 1100-1700 masl;
4) Highland Tropics (HT) – 1600-2900 masl;
5) Moist Transitional (MT) – 1200-2000 masl, transitional between mid-altitudes and highlands;
6) Moist Mid-altitude (MM) – 1150-1500 masl, around Lake Victoria;
7) Rest of the land area; this accounts for less than 0.5% of maize production.

According to De Groote et al. (2003), the first three zones listed above cover around one third of the production area of maize in Kenya, but is characterized by relatively low yields (< 1.5 t/ha) and supplies 11% of all Kenyan maize. The HT and MT zones cover another third of the maize production area, have higher yields (> 2.5 t/ha) and supply 80% of Kenyan maize. The MM zone covers less than a quarter of the maize production area, is characterized by moderate to low yields (around 1.44 t/ha) and produces 9% of Kenyan maize.

CIMMYT researchers utilize this classification of ACZs in developing improved maize varieties, including DT maize for WEMA project. All these zones, except for the Highland Tropics and the area under less than 0.5% of maize production are targeted for introduction of transgenic DT maize. The Highland Tropics are not targeted because of their relatively high maize yields as a result of the moderate temperatures (maximum temperatures $<24^0$C) and high levels of agricultural season precipitation (>1000 mm). The area under less than 0.5% of maize production is not a significant contributor to maize production in Kenya (Vanessa Cook, WEMA project lead, Monsanto, personal communication, January 22, 2012).

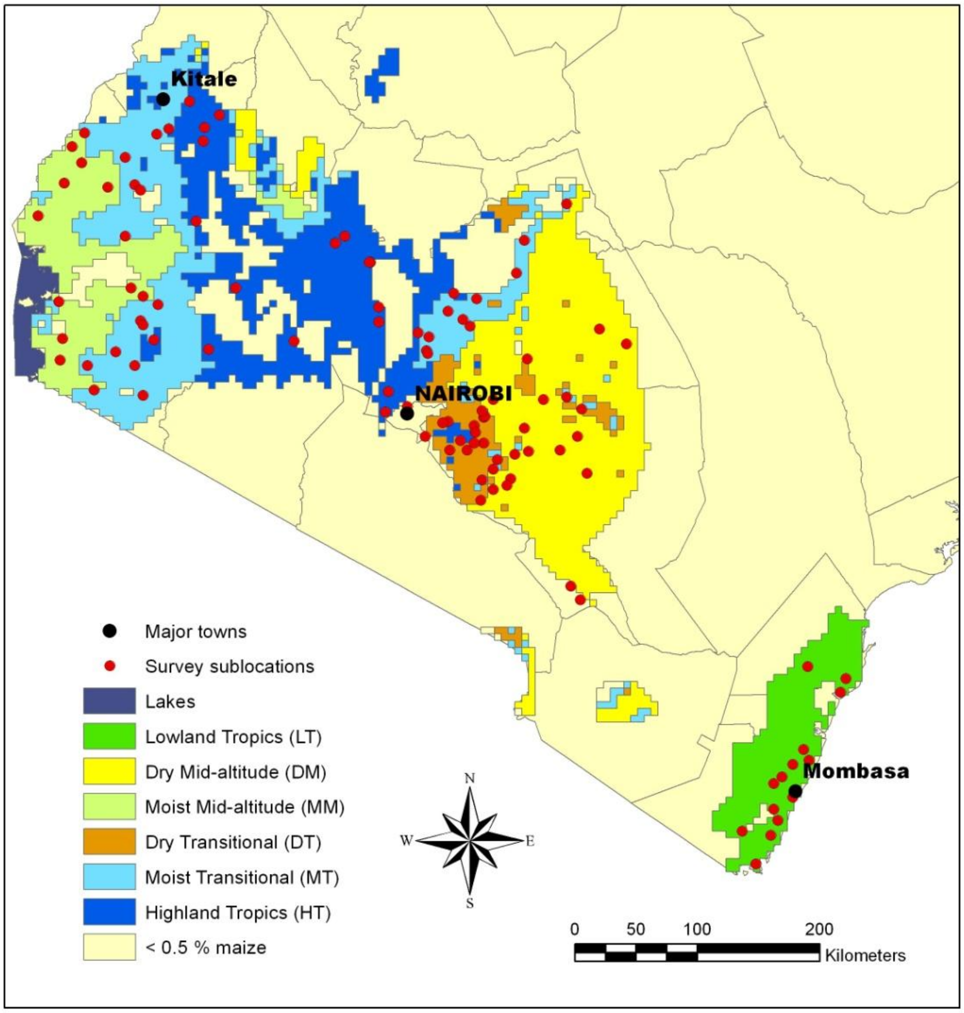


Figure 3.3 Agroclimatic zones of maize production in Kenya

(Source: GIS maps of Kenya provided by CIMMYT, compiled by the author)

3.4.2 Criteria for the representative farms and the household survey

To model economic impacts of introducing transgenic DT maize in the ACZs specified above, a representative (reference) farm is established for each of the ACZs. A representative farm is understood in this study as a farm with typical characteristics of the size and maize production volumes for any given ACZ. All scenarios and sensitivity analyses that involve modeling economic impact of transgenic DT maize are compared to the benchmark data of a representative farm which does not grow transgenic DT maize.

It was challenging to locate a reliable, comprehensive and recent source of secondary information to identify characteristics for the representative farm in each ACZ. The results of a farmers' household survey in Kenya are obtained from CIMMYT. This Maize Storage Household Survey in Kenya was conducted in October 2010 – January 2011 by researchers from KARI with technical support of the International Food Policy Research Institute (IFPRI) and CIMMYT. Households were selected using a stratified two-stage sampling technique, with the strata being agroclimatic zones in Kenya. The first stage of sampling was to select sublocations[42] in each strata, and the second was to randomly select households in each sublocation. In total, 1344 households were interviewed in the source survey. The sample is representative of Kenyan household maize producers in the major maize producing area. The survey includes components on different aspects of maize post-harvest practices and storage, however for the purpose of this study only those parts that pertain to household characteristics, maize production and sales are obtained and used.

The survey of farmers' households specifically targeted maize growers. Benchmark data on the representative farms are presented in table 3.3. These data are used in the cash flow model. Input costs are assumed to remain constant every year, whereas maize yields and prices are simulated.

[42] A sublocation is a fifth-level administrative unit in Kenya, below Provinces, Districts, Divisions, and Locations. Sampled sublocations for the household survey are presented in figure 3.3.

Table 3.3 Benchmark data of representative farms by Agroclimatic zones

	Agroclimatic zones (ACZ)				
	LT	**DM**	**DT**	**MT**	**MM**
Inflow					
Maize yield (t/ha)[a]	0.904	0.485	0.846	2.300	1.780
Maize price ($US/t)[b]	319.34	319.34	319.34	319.34	319.34
Maize sales ($US/ha)[c]	**284.50**	**154.88**	**270.16**	**734.48**	**568.43**
Outflow[d] (input costs/variable expenses in $US/ha)					
Seed	9	15	23	31	15
Fertilizer	32	33	52	99	73
Manure/compost	7	10	17	136	18
Pesticides/fungicides	10	15	8	27	8
Machinery/livestock rental	46	39	40	64	56
Labor (paid)	122	91	114	168	129
Total expenses	**226**	**203**	**254**	**525**	**299**
Net cash flow ($US/ha)	**58.50**	**-48.12**	**16.16**	**209.48**	**269.43**

Note: LT – Lowland Tropics, DM – Dry Mid-altitude, DT – Dry Transitional, MT – Moist Transitional, MM – Moist Mid-altitude
[a] - mean of the simulated yield in the year 30
[b] - mean of the simulated price in the year 30 (real 2010 $US)
[c] - calculated as yield multiplied by price, assuming all produce is either sold or valued at the market price
[d] - values are averages by ACZ obtained from Maize Storage Household Survey in Kenya (2010)

Source: Maize Storage Household Survey in Kenya (2010) and own calculations

Table 3.4 summarizes the distribution of average farm sizes by ACZ and the percentage of the farm area planted to maize. In all ACZs, on average two thirds to three quarters of the total planting area is under maize, indicating that maize is a very important part of crop planting decisions. The mean maize planting area in each ACZ is used to model the size of the representative farm in terms of area under maize.

Table 3.4 Farm sizes by Agroclimatic zones

Agroclimatic zone (ACZ)	**Number of farms**	**Mean farm size (ha)**	**Mean maize planting area (ha)**	**% maize area on the farm**
Lowland Tropics (LT)	91	1.68	1.18	70
Dry Mid-altitude (DM)	215	0.90	0.78	87
Dry Transitional (DT)	210	0.82	0.67	82
Moist Transitional (MT)	337	0.98	0.64	65
Moist Mid-altitude (MM)	253	1.06	0.61	58

Source: Maize Storage Household Survey in Kenya (2010) and own calculations

3.4.3 Weather data

Monthly averages of minimum, maximum, average daily temperatures in degrees Celsius and monthly precipitations in millimeters are obtained to model yields of maize. The data, in the form of GIS maps, are available for the years 1901-2009 from the University of East Anglia Climate Research Unit and are obtained in a compiled form from CIMMYT (Kai Sonder, CIMMYT, personal communication, August 29, 2011). Tables C.1 to C.5 of appendix C contain historical weather data for the Kenya districts that are chosen as representative of each ACZ.

3.4.4 Maize yields and production data

Maize production data on areas planted to maize, total production and maize yields by district are obtained for the years 1975-2009 in an excel spreadsheet (Kai Sonder, CIMMYT, personal communication, March 30, 2011). The data available in this spreadsheet are originally from the hard copies of annual reports of the Ministry of Agriculture of Kenya. Table C.6 of appendix C contains historical maize yield data for the Kenya districts that are representative of each ACZ.

3.4.5 Maize prices

Price data for maize in Kenya are obtained from Regional Agricultural Trade Intelligence Network (RATIN) of the Eastern Africa Grain Council (RATIN, 2012). Specifically, monthly price data on maize are available from RATIN for the years 1997 – 2011. This 15-year series of price data for maize is used to perform the analysis (see table C.7 of appendix C). Price data are adjusted for inflation by multiplying each price data point by the respective value of the Kenya Consumer Price Index (CPI). The CPI for Kenya is obtained from the Kenya National Bureau of Statistics (KNBS, 2012). The prices are expressed in the terms of real 2010 values.

3.5 Building blocks of the empirical simulation model

3.5.1 Maize yield regression

Based on available approaches and data, various yield regression specifications were constructed and tested for this study. The yield regression used in the simulation model is adapted from Cortus et al. (2011) and Koeckhoven (2008) and specified as follows:

$$y_{nt} = \sum_k \alpha_k \frac{R_{knt}}{T_{knt}} + \sum_k \beta_k \left(\frac{R_{knt}}{T_{knt}}\right)^2 + \sum_n \gamma_n D_n + \varepsilon \qquad (3.2)$$

where y_{nt} is maize yield in tonnes per hectare in the district *n* and year *t*; subscript k denotes the month in the maize growing season and ranges from March until July; R_{knt} and T_{knt} are the amount of precipitation and average monthly temperature respectively in a specific month *k*, district *n* and year *t*; D_n is a dummy variable for a specific district n; a_k, β_k, γ_n are the model parameters to be estimated; and ε is the error term of the regression.

The inclusion of precipitation to temperature ratios in the model is similar to those used in Cortus et al. (2011) and Koeckhoven (2008). In these studies daily values of temperature and precipitation were available and it was possible to calculate GDD for the growing season. Therefore, the authors used one ratio of precipitation to temperature for the growing season and one squared ratio of precipitations to temperature. In our study, daily temperature and precipitation are not available. The ratios of precipitations to temperature are calculated for each month of the maize growing season in Kenya, which is established to be from March until July (during the long rain season[43]). The respective squared terms of ratios are calculated and used in the regression to account for extreme weather impacts when there is too much precipitation or very high temperatures. Therefore, the coefficients of these squared terms are expected to be negative.

Individual regressions for specific ACZs produced inconsistent results among the zones and had low explanatory power. Therefore, all data were pooled into one

[43] In Kenya there are two agricultural seasons, called the "long rains" (approximately from March to November), and the "short rains" (approximately from September to February).

regression. The intercept term is omitted from this regression and dummy variables for each district are included. Thus the impact of the specific fixed effects of each district is represented by the estimated coefficient of the dummy variable for that district. The specification may be potentially limiting. However, pooling the data into one regression creates more data points and better explanatory power. Cortus et al. (2011) and Koeckhoven (2008) worked with only one district while our study investigates five ACZs with several districts in each zone, allowing for data pooling.

Table 3.5 shows the maize yield regression results. The coefficients of the district dummy variables are reported only for those districts where the larger part or all of the district area lies within the boundaries of one ACZ. Districts that lie in multiple ACZs may not be representative of one specific ACZ and are excluded from further analysis.

<u>3.5.2 Validation and adjustment of the yield regression model</u>

3.5.2.1 Selecting distributions for weather variables

The yield model simulates maize yields for the period of 2017-2038 using @Risk© Excel add-in simulation software. Standard errors of maize yields for each year are drawn from the normal probability distribution ~N(1,0) and corrected by multiplying each value of the draw by the adjusted standard deviation (for more details see section 3.5.2.2) of the historical maize yields for each specific district that represents a specific ACZ. The representative districts of each ACZ are: Kilifi (Lowland Tropics), Makueni (Dry Mid-altitudes), Machakos (Dry Transitional), Kisumu (Moist Mid-altitudes), and Bungoma (Moist transitional). These districts are selected based on the availability of the historical weather and yield data for modeling purposes and since their total territory (or at least the most part of it) is situated within the boundaries of one specific ACZ[44].

[44] Many districts in Kenya lie in multiple ACZs, which would make it difficult to use them as the districts with representative weather pattern and yield potential for one specific ACZ.

The representative farms for each ACZ are assumed to be located in these representative districts.

Table 3.5 Maize yield pooled regression results

Variable	Coefficient	SD	Variable	Coefficient	SD
Weather			**Moist Transitional (MT)**		
α_3	0.0074	(0.0086)	$\gamma_{BUNGOMA}$	1.696***	(0.254)
β_3	-0.0002	(0.0006)	γ_{GUCHA}	2.112***	(0.186)
α_4	0.0293***	(0.0076)	$\gamma_{KAKAMEGA}$	1.804***	(0.141)
β_4	-0.0009***	(0.0003)	$\gamma_{KISII-CENTRAL}$	2.641***	(0.135)
α_5	0.0077	(0.0064)	$\gamma_{KISII-NORTH}$	2.138***	(0.213)
β_5	-0.0005**	(0.0003)	γ_{KURIA}	2.288***	(0.151)
α_6	0.0285**	(0.0143)	γ_{LUGARI}	2.671***	(0.151)
β_6	-0.0028**	(0.0013)	$\gamma_{MT-ELGON}$	2.338***	0.3291
α_7	0.0246	(0.0190)	γ_{NANDI}	2.184***	(0.114)
β_7	0.0029*	(0.0015)	$\gamma_{TRANS-MARA}$	1.723***	(0.203)
Lowland Tropics (LT)			$\gamma_{TRANS-NZOIA}$	2.452***	(0.193)
γ_{KILIFI}	0.585***	(0.088)	γ_{VIHIGA}	1.082***	(0.094)
γ_{KWALE}	0.742***	(0.088)	$\gamma_{WEST-POKOT}$	1.756***	(0.187)
$\gamma_{MALINDI}$	0.504***	(0.096)	**Dry Transitional (DT)**		
$\gamma_{MOMBASA}$	0.612***	(0.091)	$\gamma_{KAJIADO}$	1.398***	(0.089)
Moist Mid-altitude (MM)			$\gamma_{MACHAKOS}$	0.848***	(0.292)
γ_{BONDO}	0.298	(0.225)	$\gamma_{MARAGUA}$	0.502***	(0.105)
γ_{BUSIA}	1.036***	(0.100)	γ_{THIKA}	0.489***	(0.096)
$\gamma_{BUTERE-MUMIAS}$	1.775***	(0.114)	**Dry Mid-altitude (DM)**		
γ_{KISUMU}	1.264***	(0.107)	γ_{KITUI}	0.370***	(0.089)
γ_{NYANDO}	1.117***	(0.094)	$\gamma_{MAKUENI}$	0.312***	(0.083)
$\gamma_{RACHUONYO}$	1.001***	(0.152)	γ_{MBEERE}	0.386***	(0.076)
γ_{SIAYA}	0.895***	(0.110)	$\gamma_{MERU-SOUTH}$	0.506***	(0.152)
γ_{TESO}	0.750***	(0.114)	γ_{MWINGI}	0.227***	(0.088)
			$\gamma_{THARAKA}$	0.454***	(0.131)
Std. Error	0.9969		Buse R^2	0.719	

Note: *** - significant at 1%, ** - at 5%, * - at 10%
α - coefficients for the ratio of precipitation to temperature
β - coefficients for the squared ratio of precipitation to temperature
γ - coefficients for district dummy variables
Subscripts 3 - 7 denote months of March to July respectively

The probability distributions of rain and temperature had to be defined to incorporate the stochastic nature of weather. For each specific variable, the best fit distributions were generated in @Risk© based on the historical weather data (1975 – 2009) taken from a representative district of each specific ACZ. The best fit distributions in @Risk© are ranked according to the Chi-Squared, Anderson-Darling, and Kolmogorov-Smirnov goodness of fit test statistics. These test statistics determine whether the dataset can be described by a particular distribution with a certain degree of confidence. The null hypothesis is that a dataset belongs to a specific distribution. If the calculated test statistic is larger than the critical test, the null hypothesis is rejected. In general, the closer the test statistic is to zero, the better fit the data have to that specific distribution (Palisade Corporation, 2012). Since rainfall cannot be negative and the average temperature during the growing season has a very low likelihood of being negative, the distributions for these weather variables should be capable of being truncated at zero. Triangular and Weibull distributions, among others, potentially have such a property. To simplify the analysis other distributions were not considered. Table 3.6 displays the chosen triangular or Weibull probability distributions for each variable based on the results of Chi-Squared, Anderson-Darling, and Kolmogorov-Smirnov goodness of fit test statistics and the nature of the data (see tables D.1 to D.3 of appendix D for test statistics results).

Table 3.6 Distributions for weather variables by representative districts

Variable	Distribution				
	Kilifi (LT)	**Makueni (DM)**	**Machakos (DT)**	**Bungoma (MT)**	**Kisumu (MM)**
T3	Triangular	Triangular	Weibull	Weibull	Triangular
T4	Weibull	Weibull	Triangular	Weibull	Weibull
T5	Triangular	Triangular	Weibull	Triangular	Weibull
T6	Triangular	Weibull	Weibull	Weibull	Triangular
T7	Triangular	Triangular	Weibull	Weibull	Weibull
R3	Weibull	Triangular	Weibull	Triangular	Triangular
R4	Weibull	Weibull	Weibull	Weibull	Weibull
R5	Triangular	Weibull	Weibull	Triangular	Triangular
R6	Weibull	Weibull	Weibull	Weibull	Weibull
R7	Triangular	Triangular	Triangular	Weibull	Weibull

Note: T – average monthly temperature in ^{0}C, R – monthly precipitation in mm, numbers 3 to 7 denote months of March through July respectively.
LT – Lowland Tropics, DM – Dry Mid-altitude, DT – Dry Transitional, MT – Moist Transitional, MM – Moist Mid-altitude.

3.5.2.2 Adjusting the standard error of the maize yield regression

In the simulation models the standard error draw is usually adjusted by multiplying it by the standard error of the yield regression. This is possible when yield regressions are available for each specific district. However, in this study the standard error of the yield regression would be misleading since this is calculated based on the entire dataset from all Kenyan districts. To avoid this problem, historical maize yield data (1975 – 2009) of a representative district for each ACZ is used to calculate an estimated standard deviation of the mean maize yield in that zone. This standard deviation is then multiplied by a respective yield error draw for each year. However, the standard deviation needs to be further adjusted (i.e., usually increased), as the yield variability of an individual representative farm would be higher than the yield variability on a district level.

The aggregated district level data averages out yield variability of an individual farm (Marra and Schurle, 1994). To correct for this aggregation bias, Marra and Schurle (1994) propose adjusting the county-level standard deviation of yield upwards by 0.1% for each 1% difference of the individual farm acreage compared to the county acreage. This proposition is based on the results of a meta-analysis of Kansas wheat farms with extensive agriculture and high levels of mechanisation. When this approach was applied to Kenyan data, unrealistically high increases of standard deviation of yield in the magnitude of 500-600 t/ha were obtained. The method of Marra and Schurle (1994) cannot be applied in the case of Kenya, as the average size of an individual farm is very small relative to the total size of the district and there is likely to be less variation among smallholders' resources than in highly mechanized farming situation.

Consequently, the standard deviations of yields from Maize Storage Household Survey in Kenya are calculated for each representative district and used in the maize yield regression model instead of the standard error of the original yield regression. Given the cross-sectional nature of the survey data, it is not ideal to use the standard deviation of yield variability to estimate the variability of historical yields on a district level. However, this is the best and most recent data on individual farm levels in Kenya that is available. The farm level and district level maize yield standard deviations for each representative district are provided in table 3.7. The ratio of farm level to historical level standard deviation of maize mean yield is shown for comparison purposes. The size of this ratio is comparable to the magnitude of the standard deviation adjustments by Trautman (2012) and Koeckhoven (2008). In these studies the farm level standard deviations of mean yields of various crops were increased by 1.03 to 1.53 and 1.70 to 1.96 respectively.

Table 3.7 District and farm level standard deviations of maize mean yields

	Standard deviation of mean maize yield				
	Kilifi (LT)	**Makueni (DM)**	**Machakos (DT)**	**Bungoma (MT)**	**Kisumu (MM)**
Historical yield (district level), t/ha	0.219	0.247	0.535	0.647	0.327
Household survey yield (farm level), t/ha	0.572	0.602	0.813	1.595	0.618
Ratio of farm level to district level	1.9	1.9	1.2	1.9	1.7
Note: LT – Lowland Tropics, DM – Dry Mid-altitude, DT – Dry Transitional, MT – Moist Transitional, MM – Moist Mid-altitude					

Source: CIMMYT yield data, Maize Storage Household Survey in Kenya (2010), and own calculations

3.5.2.3 Adjusting mean maize yield in the simulation model

Due to the stochastic nature of the maize yield model and the distributional assumptions for weather variables there was a potential to obtain negative yields in the process of simulation. To avoid this problem, yield outcomes are truncated at zero, following the approach in Koeckhoven (2008). As a result of this truncation, the mean of the distribution may shift toward higher values. This can be avoided by adjusting the intercept[45] of the regression so that the simulated mean maize yield is shifted back to its original level (i.e., so this is equal to the historical mean maize yield).

Table 3.8 summarizes the historical and simulated means, standard deviations and 90% confidence intervals of the maize yield model after all adjustments are employed. Simulated and historical means are equal or very close. Simulated standard deviations are higher than the historical district yields, to reflect the

[45] The intercept of maize yield regression is zero. However, dummy variables of each representative district technically become intercepts of the regression.

higher yield variability at the farm level compared to the aggregated district level. The lower bound of 90% confidence interval for the Makueni (DM) and Machakos (DT) districts are equal to zero. These two districts are characterized by lower farm-level yields and relatively higher farm-level yield variability than for other regions.

Table 3.8 Comparison of mean maize yields (t/ha), standard deviations, and 90% confidence intervals (CI) of historical and simulated yield distributions

	Maize yield, t/ha									
	Kilifi (LT)		**Makueni (DM)**		**Machakos (DT)**		**Bungoma (MT)**		**Kisumu (MM)**	
	S	H	S	H	S	H	S	H	S	H
Upper bound (90% CI)	1.578	0.966	1.208	0.585	1.856	0.999	4.280	2.492	2.692	1.876
Mean	0.904	0.903	0.485	0.484	0.846	0.846	2.300	2.307	1.780	1.783
SD	0.414	0.219	0.400	0.247	0.584	0.535	1.200	0.647	0.563	0.327
Lower bound (90% CI)	0.200	0.841	0.000	0.383	0.000	0.693	0.240	2.122	0.847	1.689

Note: S – simulated, H – historical
LT – Lowland Tropics, DM – Dry Mid-altitude, DT – Dry Transitional, MT – Moist Transitional, MM – Moist Mid-altitude.

Source: CIMMYT yield data, Maize Storage Household Survey in Kenya (2010), and own calculations

3.5.3 Maize price regression

To predict future maize prices that will be used in calculating revenues of the representative farms over a number of years, a projected maize price equation is estimated. Since smallholder farmers use a considerable portion of their maize harvest for self-consumption and to remove the pattern of seasonality, the fair market value of maize is represented in the model by the annual average of the monthly maize prices. Another reason to use annual averages is that the simulation cash flow model is designed to produce annual projected cash flows. As a basis to project maize prices in the simulation model, annual averages for the available series of monthly prices of maize are calculated forming a 15-year time series[46].

A test for non-stationarity of the maize price series is performed. Stationarity refers to a stochastic process in a time series data whereby the means, variances and covariances of the data distribution do not change over time (Verbeek, 2004). The augmented Dickey Fuller and Philips-Perron standard tests are used to check for non-stationarity of price data (see table 3.9). In all tests the T-statistics are significant. Therefore, the null hypothesis that there is a non-stationary process in the series of annual average maize prices is rejected. Annually, maize prices are assumed to be stationary and it is possible to proceed with estimation of a stationary price model.

Table 3.9 Testing for non-stationarity of maize prices

	Augmented Dickey Fuller test		**Phillips-Perron test**	
	T-stat/no trend	**T-stat/trend**	**T-stat/no trend**	**T-stat/trend**
Annual averages of maize monthly prices[a]	-4.12*	-3.80*	-4.29*	-3.84*
Critical value (10%)	-2.57	-3.13	-2.57	-3.13
Note: * - significant at 10% (default) [a] - 15-year time series				

The price regression requires inclusion of the appropriate number or lagged price variables as explanatory variables of the current prices. To determine the number of price lags the Akaike Information Criterion (AIC) and Schwartz Information Criterion (SIC) for the maize price series are calculated. Four lags were created in total (see table 3.10). The lowest value of AIC and SIC determines the optimal number of lags for maize price equation. The optimal number of annual lags is determined to be three.

[46] Other series of maize prices were created and tested (e.g, prices in July of every year, and semi-annual prices). However, the time series of annual average prices of maize, when used in maize price regression analysis, had the highest explanatory power, and was chosen to be used in the analysis.

Table 3.10 AIC and SIC values for maize price equation lag tests

Lag	AIC	SIC
1	8.3112	8.4025
2	8.4637	8.5941
3	**7.7326**	**7.8943**
4	7.7509	7.9318
Note: AIC – Akaike Information Criterion, SIC – Schwartz Information Criterion The lowest values of the AIC and SIC are in bold font		

Based on the determined number of lags, the following price model was estimated using Ordinary Least Squares (OLS) regression:

$$P_t = \beta_0^1 + \beta_1^1 P_{t-1}^1 + \beta_2^1 P_{t-2}^1 + \beta_3^1 P_{t-3}^1 + \varepsilon_t^1 \quad (3.3)$$

where, P_{t-n} is the maize price lagged n periods from the period t, β-s are parameters of the regressions, and ε-s are error terms. OLS regression results are presented in table 3.11.

Table 3.11 Results of the OLS maize price regression

Variable	**Price regression**	
	Coef	**SE**
1 Lag	0.1686	0.2130
2 Lags	-0.5747**	0.2473
3 Lags	0.4854**	0.1531
Constant	292.58***	70.51
SE	41.92	-
R^2	0.63	-
Note: *** - significant at 1%, ** - at 5% Dependent variable is CPI adjusted average annual maize price (Nairobi), $US/t (see table C.7 of appendix C)		

3.5.4 Validation of the price model

The price model is used to simulate maize prices for the period from 2008 to 2038 (30 years) using the @Risk© Excel add-in simulation software. Since the maize price model is a function of lagged maize prices, the initial prices for P_{t-1} to P_{t-3} are specified as a mean of historical maize prices for the most recent 10 years that price data were available (2002 – 2011). Errors in maize price estimates for each year are drawn from the normal probability distribution ~N(1,0) and corrected by multiplying each value of the draw by the standard error of the regression.

To validate whether the chosen price model produces accurate price forecasts, the historical mean of maize prices (2002 – 2011) is compared with the mean of the simulated price in year 30[47]. The simulated price mean of the individual year 2038 is equal to US$ 319.34. The historical mean is equal to US$ 319.98, which is very close to the simulated value of the maize long run mean. Thus we conclude that the price model produces reasonable results and we use this in the subsequent broader simulation analysis.

3.5.5 Modeling yield advantage of transgenic DT maize under drought

The yield advantage of transgenic DT maize is modelled relative to the maize yield in the base case simulation model. In the base case model, maize yield is determined based on the yield equation (see formula 3.2), where temperature and precipitation levels are drawn from the probability distributions specified in table 3.6. The simulated long run mean[48] of maize yield in a specific ACZ serves as a benchmark between a year with and without drought. If the maize yield in the base case simulation model in any given year is higher than or equal to the long run mean yield, it is assumed that no drought happens in that year. If the maize yield in the base case simulation model in any given year is lower than the long run mean yield, some level of drought is assumed to be present in that year. Once it is established that the drought is present in a particular year, the yield advantage of transgenic DT maize is drawn from the appropriate probability distribution (see table 3.12) to determine the percentage increase from the base case yield if the new transgenic DT maize variety is adopted.

Hybrid non-DT maize varieties that were available in local markets in 2008 are assumed to be the maize varieties of the base case simulation model. The WEMA project is developing transgenic DT maize to outperform these maize hybrid varieties by 20-35% under moderate drought conditions. Moderate drought conditions are defined as droughts that result in 30-60% loss of maize yield. Yield

[47] Simulations include 5000 iterations.
[48] Long run mean refers to the mean maize yield of the base case simulation model in year 30.

losses that are below and above this range fall into the definitions of minor drought and severe drought respectively (Vanessa Cook, WEMA project lead, Monsanto, personal communication, January 22, 2012). Based on these assumptions the following four scenarios are developed.

Scenario 1 (*Uniform*). In this scenario it is assumed that under no drought, minor drought or moderate drought, transgenic DT maize will perform uniformly better by 20-35% than the varieties in the base case scenario regardless of the level of drought except for severe drought. This assumption is based on the opinion of Monsanto experts that even under no drought or any level of drought, DT maize varieties are expected to perform better than the base case varieties. However, the exact outcome is not known (Vanessa Cook, WEMA project lead, Monsanto, personal communication, January 22, 2012). Under severe drought conditions when yield losses of the base case scenario comprise over 60% of the mean yield, transgenic DT maize is expected to yield 0-20% more compared to base case maize varieties. The yield advantage of transgenic DT maize is assumed to be stochastic. In the simulation model this is drawn from a uniform probability distribution[49].

Scenario 2 (*Best case*). In this scenario a different approach to modeling yield advantages of transgenic DT maize is employed. It is assumed that with increasing severity of drought, the yield advantage of transgenic DT maize varieties gradually decreases. Under no drought the yield advantage is assumed to be 35%, which is the maximum advantage that is expected by Monsanto. Under minor drought conditions, the yield advantage is only 30%. Under moderate drought this decreases to 25%, and under severe drought a 20% yield advantage is assumed relative to base case maize varieties. This scenario is intended to be a best case scenario and assumes a certain yield advantage for each level of drought. In this particular scenario, yield improvements are deterministic.

[49] In all scenarios the draws from triangular distributions were performed, however, the results match very closely with the results when the draws were from uniform probability distributions. A uniform distribution of the likelihood of yield advantage is applied in all scenarios.

Scenario 3 (*Expectation*). In this scenario it is assumed that transgenic DT maize varieties are performing better under the specific level of drought than the breeding program targeted. Specifically, under a moderate level of drought, transgenic DT maize varieties are expected to produce 20-35% higher yields than the base case varieties (Vanessa Cook, WEMA project lead, Monsanto, personal communication, January 22, 2012). Under no drought, minor drought and severe drought, yields are assumed to perform 0-20% better, since transgenic DT maize varieties are expected to perform better under no drought or any level of drought, including extreme drought. In this scenario, at each level of drought, the yield advantage is drawn from the uniform distribution.

Scenario 4 (*Worst case*). This is designed as a worst case scenario, where under both no drought and under severe drought, transgenic DT maize varieties will not outperform the base case varieties. Therefore, under minor drought on average these varieties are assumed to yield 0-10% better than the base case varieties. Under moderate drought the transgenic DT maize varieties will yield 10-20% more on average. The highest assumed yield advantage of 20% in this case is the lowest level of the anticipated 20-35% range. In this scenario, at each level of drought, the yield advantage is drawn from the uniform distribution. A summary of all the scenarios is provided in table 3.12.

The presence of potential yield advantages of the transgenic DT maize relative to the existing maize hybrids result in higher mean yields of the transgenic DT maize in each scenario. The variance of transgenic DT maize yield also changes since the level of yield in this case is impacted not only by the draws from the distribution of weather variables, but also by the draws from distribution of yield advantages. The level of this change differs across ACZs and scenarios. Generally, in scenarios 1 and 2, the yield variance of transgenic DT maize increased by not more than 0.23 t/ha, in scenario 3 by not more than 0.11 t/ha, and in the scenario 4 the yield variance decreased by approximately 0.01-0.04 t/ha.

The increase or decrease of maize yield variances may be regarded as the increase or decrease in risk associated with adopting transgenic DT maize. The risk associated with growing transgenic DT maize is not the subject of this study; especially since the exact levels of yield advantage of transgenic DT maize are not yet known. However, the presence of some degree of risk when adopting these maize varieties is noted.

Table 3.12 Scenarios for yield advantage of transgenic DT maize

<table>
<tr><th rowspan="2">Yield level[a]</th><th rowspan="2">Drought assumption</th><th colspan="4">Yield advantage of transgenic DT maize, %</th></tr>
<tr><th>Scenario 1 Uniform</th><th>Scenario 2 Best case</th><th>Scenario 3 Expectation</th><th>Scenario 4 Worst case</th></tr>
<tr><td>$y \geq \bar{y}$</td><td>No drought, yield is higher or equal to mean yield</td><td rowspan="3">20-35%[b]</td><td>35%</td><td rowspan="2">0-20%[c]</td><td>0%</td></tr>
<tr><td>$\bar{y} > y \geq 0.7\bar{y}$</td><td>Minor drought, yield loss is less than 30% of mean yield</td><td>30%</td><td>0-10%[d]</td></tr>
<tr><td>$0.7\bar{y} > y \geq 0.4\bar{y}$</td><td>Moderate drought, yield loss is in the range of 30-60% of mean yield</td><td>25%</td><td>20-35%[b]</td><td>10-20%[e]</td></tr>
<tr><td>$y < 0.4\bar{y}$</td><td>Severe drought, yield loss is over 60% of mean yield</td><td>0-20%[c]</td><td>20%</td><td>0-20%[c]</td><td>0%</td></tr>
<tr><td colspan="6">[a] – $\bar{y}$ denotes mean yield of the base case simulation model, y denotes yield of the base case simulation model in a specific year
[b] – number randomly drawn from a uniform distribution with min=20%, max=35%
[c] – number randomly drawn from a uniform distribution with min=0%, max=20%
[d] – number randomly drawn from a uniform distribution with min=0%, max=10%
[e] – number randomly drawn from a uniform distribution with min=10%, max=20%</td></tr>
</table>

In all scenarios presented above a simulated long run mean maize yield is modeled as a cut-off point between no drought and minor drought. Therefore, even small deviation from the mean (e.g., actual yield is 2% lower than a long run mean yield) in the model is considered to happen because of the drought. In reality this small yield loss may be caused by factors other than drought (e.g., pests, weeds, hail etc.) and may not lead to adoption of transgenic DT maize varieties right away. Taking this into account, the speed of adoption of transgenic DT maize may be slightly overestimated. The speed of adoption impacts magnitude of NPV estimates, i.e., the faster the technology is adopted, the higher are the benefits. This is not expected to impact results to a great extent as sensitivity analyses of different levels of adoption are performed and ranges of outcomes are reported later in the paper.

3.5.6 Modeling adoption of transgenic DT maize by the farmers

Adoption of transgenic DT maize is modelled for each category of adopter according to Rogers (2003) (see section 3.3.3.4). The occurrence of drought in each specific year is tracked in the model based on the maize yield (see the first two columns of table 3.12). In the case of drought (minor, moderate or major), the cell will produce a value of one, and in case of no drought, the cell will produce a value of zero. The adoption of transgenic DT maize is modelled based on the occurrence of the drought based on the following assumptions:

1) Innovators adopt right away in 2017, when the new transgenic DT maize varieties are available on the market;
2) Early adopters adopt immediately after they experience one drought after year 2017;
3) The Early majority group adopt in the year following the Early adopters;
4) The Late majority adopt when they experience two droughts after year 2017;
5) Laggards adopt when they experience three droughts after year 2017.

Adoption is tracked by recording in the model ones and zeros, with "one" meaning "adoption" and "zero" meaning "no adoption". The ones and zeros that occur in specific years are multiplied by either cash flows from the base case or cash flows generated from growing transgenic DT maize. The model is set up in such a way that if the new transgenic DT maize varieties have not been adopted in any specific year (i.e., adoption = 0), the difference in the discounted net cash flow from the base case is equal to zero for that year; consequently there is no advantage compared to the base case model. If the transgenic DT maize variety is adopted (i.e., adoption = 1), the difference in discounted net cash flow from the base case has a value.

3.5.7 Choosing the discount rate

3.5.7.1 Private discount rate

One way of looking at the private discount rate is that this is an interest rate that a bank charges the borrower that receives a loan. This loan is used to finance specific projects of the borrower. The private discount rate is essentially an opportunity cost of an investment in the context of absence of a market failure or imperfection. In a perfect market context, money not used for a social project, could be deposited to a bank to receive interest. The private discount rate is a measure of the riskiness of a private investment. Riskier investments would generally be charged higher interest.

Private discount rates in rural areas of Kenya can be very high. The interest rate charged within communities by savings and loan associations can be as high as 10% per month. This partly reflects high fluctuations in food prices (Hugo De Groote, CIMMYT, personal communication, September 11, 2012) and is common in rural communities in many developing nations where there are few lenders and borrowers have limited resources. As of September 2012 the business (i.e., secured) loan interest rate for banks in Kenya was around 15-20% per year (Barclays, 2012; Central Bank of Kenya, 2012). These rates were even higher prior to summer 2012 when they were reported at 30% (Xinhua, 2012). For the purpose of this study a private discount rate is selected at the level of 20%. The sensitivity of this private rate of return estimate to the rate assumption is assessed by performing these calculations at interest rate levels of 15% and 30% as well as 20%.

3.5.7.2 Social discount rate

Choosing the discount rate in a CBA has always been a somewhat contentious issue. A social discount rate values costs and benefits through time from society's point of view. This is based not only on the concept of a private opportunity cost of forgone investment, but also on the social time preference for consumption. People generally prefer to receive benefits of consumption today and make payments sometime in the future. In Canada, 3% is recommended as the social time preference rate for public investments (Treasury Board of Canada, 2007). In the United Kingdom the Social Time Preference Rate (STPR) is indicated as 3.5% for a public investment with a time horizon up to 30 years (HM Treasury, 2003).

The Environmental Protection Agency (EPA) of the United States recommends using a consumption rate of interest[50] to calculate NPV for environmental projects. This rate is based on the rate of return to Government-backed securities and is close to 3% whereas the private discount rate is based on opportunity cost of capital and was estimated at 7% (EPA, 2010).

There are several CBA studies for environmental and health related projects in Kenya. In Goodman et al. (2006) the costs associated with improvement of malaria management practices in rural Kenya are discounted at 3% over a period of 8 years. Mireri et al. (2008) use a rate of 15% to discount the cost of the sugar project in the Tana river delta, presumably reflecting the commercial focus of sugar production. Mungai et al. (2011) apply discount rates of 7% and 5% in CBA assessments of a conservation area fencing project.

Based on the available literature, a 3% discount rate is chosen as a social discount rate for this study. Sensitivity analyses are performed for the discount rates of 5%, and the maximum of 7%.

[50] Consumption rate of interest is the individual's marginal rate of time preference or the post-tax rate of interest (EPA, 2010).

3.5.8 WEMA project investment costs and aggregation of costs and benefits to a national level

The WEMA project secured funding from the Bill & Melinda Gates Foundation for the period of five years[51] from 2008 to conduct research on developing transgenic DT maize varieties for five WEMA project countries[52]. The year 2008 is assumed to be year zero in the social CBA[53].

Based on the confidentiality agreement between CIMMYT, AATF, Monsanto, and the University of Alberta, the budget of WEMA project was obtained and included in modeling to assess and model costs of the project. The WEMA budget contains actual expenditure figures for the years 2008 to 2009, and budget for projections for the years 2010 to 2012. Each annual budget is subdivided into general expenditures of CIMMYT, AATF, and Monsanto, and the project expenditures that are specific to the NARS of each participating country. This is a common practice given the scope of the project. Exploratory and basic research had to be conducted, and infrastructure and capacity had to be established centrally before the project could be initiated and continued in each participating country. Thus, the general expenditures of AATF, CIMMYT, and Monsanto are divided by five as the centralized research is assumed to benefit all participating countries equally. We add the expenditure/budget figures for the Kenya NARS that are related to WEMA project in Kenya to the Kenya's share of the general expenditures of AATF, CIMMYT, and Monsanto. This final figure, adjusted for inflation, is used in modeling the WEMA investment cost in Kenya. When discounted using a 3% social discount rate to the year 2008, this investment cost is equal to $7.20 million. Due to project confidentiality, original budget data are not presented here.

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[51] In 2013 the funding of WEMA project was extended for five more years.

[52] WEMA project countries include Kenya, Mozambique, Republic of South Africa, Tanzania, and Uganda.

[53] Another important reason to use 2008 as the starting point of the modeling is that the performance of the future transgenic DT maize varieties in terms of yield will be compared in this study to the performance of the common hybrid maize varieties that were available in markets in 2008.

WEMA investment costs cannot be attributed to a specific representative farm because the project is aimed at improving maize varieties for the whole country. These investment costs are included in calculation of the social CBA only. Once the results of the social CBA are aggregated to the national level, WEMA investment costs are included in a NPV analysis as a discounted cash outflow. A summary of the essential differences between these social and private cost benefit analyses is provided in table 3.13 and figure 3.4.

Table 3.13 Summary of the differences between the private and social Cost-Benefit Analysis applied in this study

Action	**Cost-Benefit Analysis**	
	Private	**Social**
Calculating NPV of the cash flows of the representative farms by ACZ	Yes	Yes
Discount rates used	20%	3%
Sensitivity to discount rates	15% and 30%	5% and 7%
Reporting NPV of the cash flows per hectare	Yes	No
Aggregating NPV of the cash flows per hectare to a national level	No	Yes
Subtracting discounted WEMA investment costs from the aggregated level of benefits	No	Yes
Reporting NPV for the total maize area in Kenya where transgenic DT maize is adopted	No	Yes
Adoption over time	Yes	Yes

Private NPV estimates (private CBA). Differences in discounted net cash flows from the base case per ha are summed from 2017 to 2038 to calculate the differences in private NPV estimates from the base case. Discounting is performed using an assumed 20% private discount rate. The differences in private NPV estimates from the base case per ha are reported for each of the five adopter categories, for each of the four scenarios, and for each of the five representative farms in five ACZs. For the sake of simplification the expression “differences in private NPV estimates from the base case NPV” will be referred to as “private NPV estimates” in all the discussions that follow. Private NPV estimates are reported in year 2017 as this is the first year when, according to the projections of Monsanto, the transgenic DT maize varieties will be commercially available to farmers.

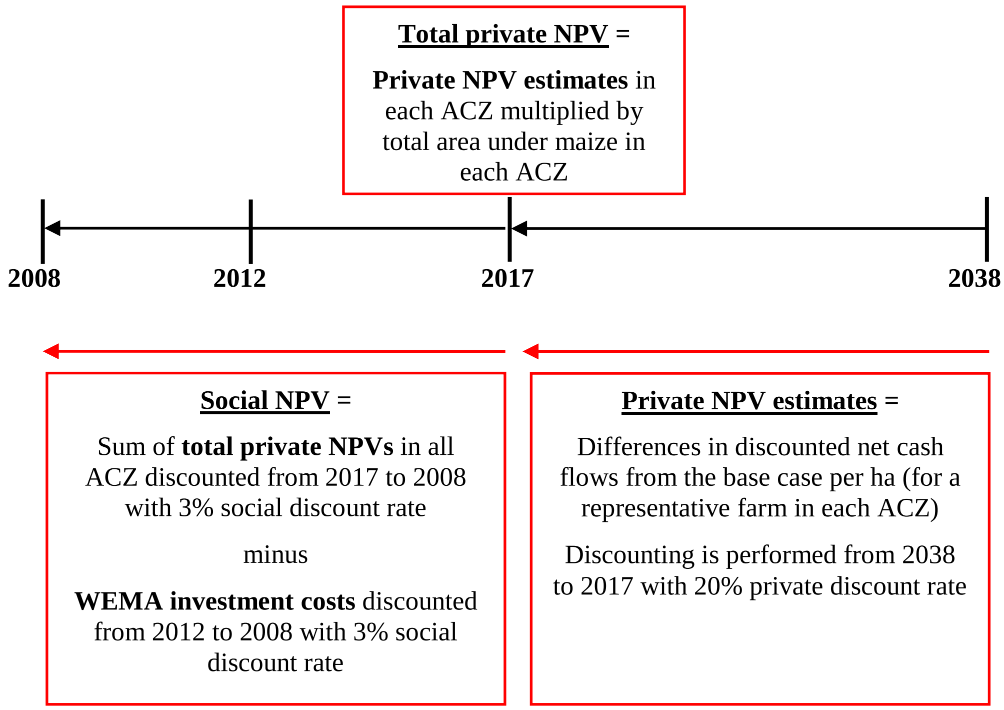

Figure 3.4 Graphical representation of the private and social CBA

Total private NPV. Here and thereafter the expression "total private NPV" is used to denote private benefits of smallholder farmers aggregated to a level of each ACZ. More specifically, the total private NPV is differences in private NPV estimates from the base case discounted with an assumed 20% private discount rate from 2038 to 2017 and aggregated to an ACZ level. Total private NPV is reported for each of the four scenarios and each of the five ACZs in 2017. This is calculated using the following formula:

$$TNPV_{ACZ} = A_{ACZ}(0.025NPV_I + 0.135NPV_{EA} + 0.34NPV_{EM} + 0.34NPV_{LM} + 0.16NPV_L) \quad (3.5)$$

where $TNPV_{ACZ}$ is a total private NPV in each ACZ; A_{ACZ} is an area in hectares planted to maize in each ACZ[54]; NPV_I to NPV_L are private NPV estimates per hectare for each of the adopter categories (i.e., Innovators to Laggards); and the

[54] Since only 1.8% of total crop land in Kenya is irrigated (Karina and Mwaniki, 2011), it is reasonable to assume that the available maize planting area in our study is rainfed. Therefore, transgenic DT maize varieties may potentially be adopted on all available maize planting area.

numerical parameters correspond to the fractions of each adopter category in the total population (see section 3.3.3.4). The total area planted to maize in each ACZ is obtained from De Groote (2002):

- Lowland Tropics (LT) – 33,000 ha;
- Dry Mid-altitude (DM) – 118,000 ha;
- Dry Transitional (DT) – 37,000 ha;
- Moist Transitional (MT) – 424,000 ha;
- Moist Mid-altitude (MM) – 118,000 ha.

Social NPV (social CBA). In the social CBA total private NPV in 2017 summed across all ACZs is treated as a benefit on the national level, and the WEMA investment costs are treated as costs on the national level. Social NPV is total private NPV in 2017 discounted with 3% social discount rate to 2008 minus sum of WEMA investment costs discounted with 3% social discount rate from 2012 to 2008. Here and thereafter the expression “social NPV” is used to denote social benefits from introducing transgenic DT maize in Kenya.

3.6 Results and discussion

3.6.1 Private CBA

The base case scenario of the simulation model assumes no transgenic DT maize varieties are introduced to the market. The simulation model generates annual maize yields for the period from 2017 to 2038. Based on the simulated yields and prices, revenues from maize production (consumption plus sales) are calculated and, after accounting for maize input costs, are discounted to the year 2017. Table 3.14 summarizes mean, standard deviation, minimum, maximum, 5th and 95th percentile (i.e., 90% confidence interval) of NPV of the base case scenario by ACZ.

Table 3.14 Simulation summary statistics of NPV of the Base Case scenario for adoption of transgenic DT maize by Agroclimatic zone ($/ha)

ACZ	Mean	SD	Min	Max	5th percentile	95th percentile
LT	355.32	256.67	-500.06	1,369.38	-50.00	789.00
DM	-294.70	240.69	-986.20	607.24	-667.00	130.00
DT	68.55	354.44	-1,010.70	1,351.14	-487.00	689.00
MT	1,155.50	735.89	-1,265.71	3,927.18	-9.00	2,409.00
MM	1,630.03	365.75	448.89	3,103.46	1,048.00	2,250.00
Note: LT – Lowland Tropics, DM – Dry Mid-altitude, DT – Dry Transitional, MT – Moist Transitional, MM – Moist Mid-altitude						

The figures for the first three ACZs in table 3.14 show lower mean of NPV values than those for the last two ACZs. This is consistent with De Groote et al. (2003) regarding the relative importance of the different ACZs in maize production in Kenya. As the first three zones have relatively low yields, estimates of NPVs are also lower. The Dry Mid-altitudes has a negative NPV estimate, suggesting that it may not make economic sense to grow maize in this particular region since the reported costs exceed benefits. However, interpretation of the negative NPV result should be treated with caution. Choosing a specific district to be representative of this ACZ based on data availability and geographic considerations may have led to some biases. All ACZs except the Moist Mid-altitude have a negative minimum NPV estimate, indicating that the Moist Mid-altitude zone is more suitable and relatively more profitable for growing maize than the other zones.

A summary of the results of estimating a private CBA by scenario and adopter category for each ACZ is provided in table 3.15. The base case NPV numbers reported in the second column of the table are the means taken from table 3.14. The differences, from the base case, in the NPV estimates (or "private NPV estimates") by the categories of adopters indicate how much more, per hectare, the representative farm for each category of adopters would receive above the base case NPV per hectare had they adopted transgenic DT maize on their farm. For example, had the transgenic DT maize been adopted in the Lowland Tropics zone according to scenario 1, the Innovator category of adopters would receive $457.65/ha benefits in net present value above the base case of $355.32/ha, which is $812.97/ha, as viewed from the perspective of private benefits and costs. The Laggards category, however, would receive only $162.88/ha above the base case NPV, which is $518.20/ha.

Table 3.15 displays means of the private NPV estimates by adopter category and ACZ as of 2017. A more detailed summary of the descriptive statistic of these estimates include means, standard deviations, minimums, maximums, and 5th and 95th percentiles. These are provided in tables E.1 to E.4 of appendix E. Discussions of the scenarios are based on the mean values of the private NPV estimates.

The results in table 3.15 indicate that the private NPV estimates are positive for all ACZs, adopter categories, and scenarios. Thus introduction of transgenic DT maize by Kenya is expected to be justified economically, resulting in the positive economic returns to smallholders. Such results are not unexpected. Since transgenic DT maize is assumed to exhibit yield advantages over existing maize hybrids in Kenya and the seeds of transgenic DT maize are to be transferred to smallholder farmers at the same cost as existing maize hybrids, there will always be some private benefits, even in the worst case scenario. The discussion below revolves around the question why there are differences in the results presented in table 3.15 for different adopter categories, ACZs, and scenarios.

Table 3.15 Summary results of the private NPV estimates in 2017 by adopter category of transgenic DT maize, scenario, and Agroclimatic zone ($/ha)

Scenarios by ACZ	Base case mean NPV	Private NPV estimates in 2017*				
		Innovators	**Early adopters**	**Early majority**	**Late adopters**	**Laggards**
Lowland Tropics (LT)						
1	355.32	457.65	325.32	270.01	230.20	162.88
2		551.94	392.05	325.19	277.18	196.16
3		196.21	139.36	115.83	98.74	69.67
4		40.89	28.91	23.96	20.50	14.44
Dry Mid-altitude (DM)						
1	-294.70	243.74	176.37	146.77	128.09	92.11
2		301.33	218.03	181.25	158.11	113.64
3		100.42	72.46	60.34	52.64	37.90
4		13.34	9.56	7.87	6.92	5.01
Dry Transitional (DT)						
1	68.55	424.45	304.56	253.17	218.36	156.20
2		520.82	373.58	310.27	267.51	191.36
3		178.41	127.77	106.22	91.49	65.44
4		28.29	20.18	16.62	14.44	10.30
Moist Transitional (MT)						
1	1,155.50	1,161.42	826.41	685.99	586.67	416.22
2		1,407.88	1,000.82	830.45	709.88	503.79
3		497.28	353.18	293.55	251.27	177.90
4		97.04	68.77	56.78	48.90	34.62
Moist Mid-altitude (MM)						
1	1630.03	911.87	645.48	535.41	455.59	321.87
2		1,087.56	769.51	638.01	542.72	383.53
3		382.16	270.18	224.52	190.96	134.54
4		88.84	62.75	51.87	44.19	31.11

Note: Scenario 1 (Uniform): 20-35% yield advantage (with uniform distribution) under no drought to moderate drought, and 0-20% yield advantage (with uniform distribution) under severe drought.
Scenario 2 (Best case): yield advantage of 35% under no drought, 30% under minor drought, 25% under moderate drought, and 20% under severe drought.
Scenario 3 (Expectation): 0-20% yield advantage (with uniform distribution) under no drought to minor drought, 20-35% yield advantage (with uniform distribution) under moderate drought, and 0-20% yield advantage (with uniform distribution) under severe drought.
Scenario 4 (Worst case): 0% yield advantage under no drought or severe drought, 0-10% yield advantage (with uniform distribution) under minor drought, and 10-20% yield advantage (with uniform distribution) under moderate drought.
*-"NPV estimates" should be understood as "mean values of the differences in NPV estimates from the base case NPV".

Differences in the results by adopter categories. The private NPV estimates decrease the longer adopters of transgenic DT maize wait to adopt. Innovators receive the highest private NPV estimates per ha, followed by Early adopters, then Early majority, then Late adopters and Laggards. This holds true for each scenario and each ACZ. Innovators receive the highest private NPV estimates, because they adopt in the year when the seed of transgenic DT maize is first available. Since there is no penalty in terms of higher seed costs for transgenic DT maize, the Innovators' benefits are higher than for the other categories of adopters. When drought hits, the other categories of adopters are still experiencing higher maize yield losses compared to Innovators.

Differences in the results by ACZs. When looking at the results of different ACZs, the Dry Mid-altitude zone has the lowest positive benefit compared to all other zones. This is consistent with the feature that the Dry Mid-altitude zone is the only zone that has a negative mean NPV of future cash flows for production of maize in the base case model. Historically this zone has low maize mean yields (less than 0.5 t/ha) because of its relatively dryer climate than in the other zones.

The highest positive benefits occur in the Moist Transitional zone, followed by Moist Mid-altitude zone. This is consistent with the fact that in these zones the historical level of maize mean yields is relatively higher (2.3 and 1.8 t/ha respectively), reflecting relatively more abundant moisture than in other maize growing areas. Relatively higher benefits in the zones with higher maize mean yields also occur because of an implicit assumption of the same percentage of yield advantage of transgenic DT maize over existing hybrids across all ACZs. For example, in two zones with mean maize yields of 1 t/ha and 2 t/ha, transgenic DT maize varieties are assumed to perform 20-35% relative to those respective mean maize yield levels. While realistically it may not be reasonable to expect, better information regarding prospective yield advantage in different ACZs does not exist. However, WEMA project partners are trying to develop different transgenic DT maize varieties for each of these ACZs, adapted to specific weather conditions and yield levels. If in reality transgenic DT varieties will perform differently in different ACZ, the estimation of benefits from adoption of these varieties may be biased. Before results from the transgenic DT maize trials are available, it is not possible to know, what actual yield advantage outcomes exist.

The Lowland Tropics and Dry Transitional zones receive positive benefits of comparable magnitude. However, the Dry Transitional zone has a lower base case NPV since it is a drier zone compared to the Lowland Tropics zone.

Differences in the results by scenarios. Looking at all four scenarios, private NPV estimates exhibit similar patterns across ACZs and adopter categories. However, the results of the Best case scenario are very different from the results of the Worst case scenario. For example, The Best case scenario produced the highest positive private NPV estimates compared to the other scenarios as it was expected. The second highest positive private NPV estimates are obtained in the Uniform scenario (scenario 1). The private NPV estimates in the Expectation scenario are lower compared to the Best case and Uniform scenarios. This most closely reflects the expectations of Monsanto regarding transgenic DT maize varieties compared to the other scenarios. The Worst case scenario has the lowest private NPV estimates when compared to the rest of the scenarios.

Overall, private NPV estimates range from as high as $1,407.88 per ha for the Innovator category in the Best case scenario, in Moist Transitional zone to as low as $5.01 per ha for the Laggards category in the Worst case scenario, in Dry Mid-altitude zone (see table 3.15). Average size of a smallholder farm in Kenya is approximately 1 ha across different ACZs (see table 3.4), and the period of adoption considered is 2017-2038 (i.e., 21 years). Therefore, these private NPV estimates translate into as high as $67 to as low as $0.24 of benefits on average per year per farm. In the 2010 Maize Storage Household Survey an average annual smallholder income from all sources (i.e., farm and off-farm) in Kenya is reported to be $US 1,460, while annual median income is $US 850. Thus, the benefits of transgenic DT maize to smallholder farmers are quite substantial for their livelihoods.

The model allows calculation of the probabilities of drought occurrence[55] in each ACZ. Table 3.16 summarizes average probabilities of drought occurrence in each ACZ of Kenya for the years from 2017 to 2038. The Dry Mid-altitude zone has the lowest probability of no drought and the highest probability of severe drought. This explains why the simulation model produced the lowest positive benefit to smallholder farmers in this zone. The Moist Mid-altitude zone has the lowest probability of severe drought and the highest probability of no drought and minor drought. The other zones range between these two in terms of probability of drought. Generally, the magnitude of the private NPV estimates, displayed in table 3.15, corresponds to the probability of drought in each ACZ. The higher is the probability of drought, the lower are private NPV estimates.

Table 3.16 Probability of drought by ACZ in Kenya, 2017-2038

ACZ	**Probability of**			
	No drought	**Minor drought**	**Moderate drought**	**Severe drought**
Lowland Tropics(LT)	0.49	0.24	0.16	0.10
Dry Mid-altitude (DM)	0.46	0.12	0.11	0.30
Dry Transitional (DT)	0.48	0.15	0.14	0.23
Moist Transitional (MT)	0.49	0.21	0.16	0.14
Moist Mid-altitude (MM)	0.50	0.33	0.14	0.03

Note: No drought - yield is higher or equal to mean yield
Minor drought - yield loss is less than 30% of mean yield
Moderate drought - yield loss is in the range of 30-60% of mean yield
Severe drought, yield loss is over 60% of mean yield

The average number of years to complete adoption of the transgenic DT maize differs by adopter category (section 3.5.6 describes how adoption is modeled for each adopter category). On average, the Early Adopters adopt transgenic DT maize within the first 3 years (with a standard deviation of 1.3-1.4 years) from the time DT maize seeds are available to the farmers. The Early Majority adopt within 4 years (with a standard deviation of 1.3-1.4 years), the Late Majority adopt within 5 years (with a standard deviation of 2 years), and the Laggards

[55] Calculation of the probability of drought occurrence in each ACZ is based on the assumptions of drought described in table 3.12.

adopt within 7 years (with a standard deviation of 2.2-2.4 years). The Innovators category is modeled to completely adopt transgenic DT maize in the year 1.

3.6.2 Social CBA

The aggregate "total private NPV" in 2017 for each ACZ is calculated first, and the social NPV is estimated (see section 3.5.8 for detailed description of estimation and calculations). The total private NPV in each ACZ and the social NPV are reported in table 3.17 for each scenario.

Table 3.17 Summary of results of the total private NPV in 2017 and the social NPV in 2008 for adoption of transgenic DT maize by scenario and Agroclimatic zone (1,000 $US)

Scenarios	**Total private NPV by ACZ (2017)**					**Social NPV (2008)**
	LT	**DM**	**DT**	**MT**	**MM**	
1	8,274	16,248	8,806	271,317	59,077	271,558
2	9,963	20,069	10,790	328,441	70,389	329,752
3	3,546	6,679	3,695	116,098	24,750	111,411
4	738	880	579	22,548	5,762	16,175

Note: Definitions of the scenarios are provided in the table 3.15 or section 3.5.5
LT – Lowland Tropics, DM – Dry Mid-altitude, DT – Dry Transitional, MT – Moist Transitional, MM – Moist Mid-altitude.

Since all the private NPV estimates of the representative farms reported in table 3.15 are positive, the total private NPV in each ACZ is positive in all scenarios (see table 3.17). Considering the different scenarios, the magnitude of the total private NPV for each ACZ follows the same pattern as do the private NPV estimates per ha at the levels of representative farms. For example, in the Lowland Tropics, in the Best Case scenario (scenario 2), the total private NPV is higher than for all other scenarios and is equal to $9,963,000. In the Uniform scenario (scenario 1) the total private NPV in the Lowland Tropics is lower than in the Best Case scenario and is equal to $8,274,000. In the Expectation scenario (scenario 3) the total private NPV is reduced to $3,546,000, and in the Worst Case scenario (scenario 4) this is only $738,000.

The overall social NPV for Kenya from introduction of the transgenic DT maize in 2008 ranges from $329,752,000 (Best Case scenario) to $16,175,000 (Worst Case scenario). Average size of a smallholder farm in Kenya is approximately 1 ha across different ACZs (see table 3.4), and the total area under maize in Kenya is approximately equal to 730,000 ha (see section 3.5.8). Therefore, social NPV per farm in Kenya ranges from $452 (Best Case scenario) to $22 (Worst case scenario). Average social NPV per farm and per year (when considering the period of 2008-2038) ranges from $15 (Best Case scenario) to $0.74 (Worst case scenario). This indicates that even with the minimal yield advantage, the introduction of the transgenic DT maize varieties in Kenya results in small albeit positive economic returns to the smallholder farmers.

In our study consumer benefits are not explicitly modelled. This can be considered a limitation of the study, as the cash flow maize production simulation model captures only producer benefits. Annual consumer benefits from introduction of the transgenic maize varieties in Kenya that are estimated in the other studies are as follow: $6.4-16.8 million by Andreu et al. (2006), $11.4 million by Kostandini et al. (2009), and $12.5 million by Kostandini et al. (2011). Based on the results of these similar studies, it can be speculated that consumer benefits from the introduction of transgenic DT maize in Kenya could range from $6 million to $17 million annually. Since smallholder maize producers in Kenya are believed to consume some share of their own produced maize, consumer benefits in our study could have been partially captured by producer benefits of the subsistence smallholders.

3.6.3 Sensitivity analysis

The sensitivity of the private NPV estimates, total private NPV by ACZ, and social NPV relative to changes in selected parameters in the simulation model is examined in this section. These parameters are the private and social discount rates, price of maize, input cost levels, and adoption levels of the transgenic DT maize.

3.6.3.1 Private and social discount rates

The sensitivity of the private NPV estimates to a private discount rate is performed for discount rates of 15% and 30%. The results are presented in table 3.18 for the Lowland Tropics[56] along with the results from use of the initial 20% private discount rate.

Table 3.18 Sensitivity of the private NPV estimates in 2017 to the private discount rate changes by adopter category of transgenic DT maize and scenario for the Lowland Tropics ($/ha)

Scenarios	Discount rate, %		Base case mean NPV	Private NPV estimates in 2017*				
				Innovators	Early adopters	Early majority	Late adopters	Laggards
1	15	value	440.66	568.09	431.65	372.11	325.96	245.52
		% Δ	24	24	33	38	42	51
	20		355.32	457.65	325.32	270.01	230.20	162.88
	30	value	261.08	335.58	209.96	161.52	131.03	82.01
		% Δ	-27	-27	-35	-40	-43	-50
2	15	value	440.66	684.99	520.13	448.17	392.51	295.70
		% Δ	24	24	33	38	42	51
	20		355.32	551.94	392.05	325.19	277.18	196.16
	30	value	261.08	404.87	253.07	194.52	157.75	98.75
		% Δ	-27	-27	-35	-40	-43	-50
3	15	value	440.66	243.47	184.85	159.53	139.73	105.02
		% Δ	24	24	33	38	42	51
	20		355.32	196.21	139.36	115.83	98.74	69.67
	30	value	261.08	143.93	89.98	69.36	56.25	35.07
		% Δ	-27	-27	-35	-40	-43	-50
4	15	value	440.66	50.71	38.36	33.03	29.02	21.78
		% Δ	24	24	33	38	42	51
	20		355.32	40.89	28.91	23.96	20.50	14.44
	30	value	261.08	30.03	18.66	14.33	11.67	7.27
		% Δ	-27	-27	-35	-40	-43	-50

Note: Definitions of the scenarios are provided in table 3.15 or section 3.5.5
% Δ is a percentage change of the NPV with 15% and 30% private discount rate from the NPV with 20% private discount rate
* - "NPV estimates" should be understood as "mean values of the differences in NPV estimates from the base case NPV".

[56] The sensitivity to private discount rates analysis is performed for the other ACZs. The percent changes in NPV differences from the base case are the same as in the Lowland Tropics. For this reason, only the results of Lowland Tropics are reported and interpreted as an example.

Table 3.18 shows that the sensitivity to private discount rates of the NPV estimates is higher for the adopter categories that are less likely to quickly adopt transgenic DT maize varieties (e.g., Laggards, Late adopters) compared to the adopter categories that are more likely to adopt (e.g., Innovators). For example, in scenario 1 the Innovators' private NPV estimates increase by 24% when the private discount rate is lowered from 20% to 15%. The Laggards' private NPV estimates from increase by 51% in the same scenario. Laggards adopt transgenic DT maize varieties later than Innovators. Benefits that occur later in time, but are discounted with a lower private discount rate, have a relatively higher value today. The opposite is true when the private discount rate is increased from 20 to 30%. In scenario 1, those who are in the Innovators category will receive 27% lower private NPV estimates whereas Laggards will receive 50% lower private NPV estimates. In this case benefits that occur later in time, but are discounted with a higher private discount rate, have a relatively lower value today

Overall, the private NPV estimates are highly sensitive to the private discount rates for all adopter categories and across all scenarios. Changes in the private discount rate (i.e., from 20% to 15%) lead to considerable changes in the values of NPV estimates.

The magnitude of the total private NPV in each ACZ and the social NPV also changes, depending on the level of private discount rate used in the model. Table 3.19 displays the results of this sensitivity when private discount rate assumed is changed from 20% to 15% and 30%. In these assessments the social discount rate is held at 3% level.

As in the case of private NPV estimates, aggregate total private NPV by ACZ as well as social NPV is sensitive to the level of private discount rate. When the private discount rate decreases from 20% to 15%, the total private NPV values increase from 37% to 41% in the various ACZs and scenarios. When the private discount rate is increased from 20% to 30%, the total private NPV values decline by -40% to -43% in the various ACZs and scenarios.

Table 3.19 Sensitivity of the total private NPV in 2017 and the social NPV in 2008 for adoption of transgenic DT maize to the private discount rate changes by scenario and Agroclimatic zone (1,000 $US)

Scenarios	**Discount rate, %**		**Total private NPV by ACZ (2017)**					**Social NPV (2008)**
			LT	**DM**	**DT**	**MT**	**MM**	
1	15	value	11,520	22,527	12,149	376,518	81,683	380,181
		% Δ	39	39	38	39	38	40
	20		8,274	16,248	8,806	271,317	59,077	271,558
	30	value	4,928	9,743	5,226	161,164	34,882	157,504
		% Δ	-40	-40	-41	-41	-41	-42
2	15	value	13,876	27,815	14,889	455,772	97,338	461,653
		% Δ	39	39	38	39	38	40
	20		9,963	20,069	10,790	328,441	70,389	329,752
	30	value	5,935	12,034	6,406	195,113	41,566	191,256
		% Δ	-40	-40	-41	-41	-41	-42
3	15	value	4,937	9,260	5,093	161,031	34,205	157,090
		% Δ	39	39	38	39	38	41
	20		3,546	6,679	3,695	116,098	24,750	111,411
	30	value	2,114	4,005	2,192	69,009	14,629	63,504
		% Δ	-40	-40	-41	-41	-41	-43
4	15	value	1,024	1,218	802	31,303	7,913	22,160
		% Δ	39	38	39	39	37	37
	20		738	880	579	22,548	5,762	16,175
	30	value	438	524	344	13,384	3,389	9,543
		% Δ	-41	-40	-41	-41	-41	-41

Note: Definitions of the scenarios are provided in table 3.15 or section 3.5.5
LT – Lowland Tropics, DM – Dry Mid-altitude, DT – Dry Transitional, MT – Moist Transitional, MM – Moist Mid-altitude
% Δ is a percentage change of the NPV with 15% and 30% private discount rate from the NPV with 20% private discount rate

The sensitivity of the social NPV to the social discount rate is assessed for discount rates of 7% and 15%. These results are presented in table 3.20 along with the results when the initial 3% social discount rate is used. The private discount rate is held at the 20% level.

The social NPV estimated at the national level is fairly sensitive to changes in the social discount rate. With a 5% discount rate the values of social NPV decrease by 16% to 17% across the scenarios compared to the values of social NPV when a 3% social discount rate is utilized. When the social discount rate is further increased to the level of 7%, the decrease in the social NPV values across the scenarios is equal to -30%, compared to the baseline scenario of a 3% social discount rate. Even so, the social NPV remains positive with the highest social discount rate of 7% and under the Worst Case scenario (scenario 4), and is equal to $11,323,000.

Table 3.20 Sensitivity of the social NPV in 2008 for adoption of transgenic DT maize to the social discount rate changes by scenario (1,000 $US)

Discount rate, %		**Scenarios**			
		1	**2**	**3**	**4**
3		271,558	329,752	111,411	16,175
5	value	227,558	276,503	92,863	13,426
	% Δ	-16	-16	-17	-17
7	value	191,222	232,523	77,564	11,323
	% Δ	-30	-29	-30	-30

Note: Definitions of the scenarios are provided in table 3.15 or section 3.5.5
% Δ is a percentage change of the NPV with 7% and 15% social discount rate from the NPV with 3% social discount rate

3.6.3.2 Price levels of maize

The sensitivity of the private NPV estimates to changes in the level of maize prices is checked by increasing and decreasing the value of the intercept of the price regression model by 25% respectively. This results in a 25% upward or downward shift of the simulated maize price mean. Table 3.21 displays the impact of an upward and downward change in maize prices on the private NPV estimates by adopter category and by different scenarios for the Lowland Tropics[57] region.

The private NPV estimates increase by 25% for all adopter categories and scenarios when the price of maize increases by 25%. Likewise, the private NPV estimates decrease by 25% for all adopter categories and scenarios when the price of maize decreases by 25%. When the maize price increases or decreases by 25%, the base case NPV increases or decreases by 117% respectively. The conclusion is that the base case NPV is highly sensitive to the maize price level, whereas the private NPV estimates change by the same proportion as does the price level.

[57] The analysis of sensitivity to changes in maize price levels is assessed for the other ACZs. The percentage changes in NPV estimates are the same as in the Lowland Tropics. For this reason, as an example, only the results of the Lowland Tropics are reported and interpreted.

Table 3.21 Sensitivity of the private NPV estimates in 2017 to the changes in the price of maize by adopter category of transgenic DT maize and scenario for the Lowland Tropics ($/ha)

Scenarios	Price	Base Case mean NPV	Private NPV estimates in 2017*				
			Innovators	Early adopters	Early majority	Late adopters	Laggards
1	+25%	769.69	570.08	406.25	337.73	287.72	203.37
	no change	355.32	457.65	325.32	270.01	230.20	162.88
	-25%	-58.85	345.29	244.46	202.35	172.73	122.41
2	+25%	769.69	687.54	489.57	406.75	346.45	244.93
	no change	355.32	551.94	392.05	325.19	277.18	196.16
	-25%	-58.85	416.42	294.60	243.71	207.98	147.42
3	+25%	769.69	244.40	174.00	144.88	123.41	87.01
	no change	355.32	196.21	139.36	115.83	98.74	69.67
	-25%	-58.85	148.03	104.73	86.80	74.08	52.35
4	+25%	769.69	50.92	36.09	29.97	25.63	18.04
	no change	355.32	40.89	28.91	23.96	20.50	14.44
	-25%	-58.85	30.85	21.73	17.95	15.38	10.84

Note: Definitions of the scenarios are provided in table 3.15 or section 3.5.5
When the price of maize increases by 25%, base case NPV increases by 117%, and all private NPV estimates increase by 25%
When the price of maize decreases by 25%, base case NPV decreases by 117%, and all private NPV estimates decrease by 25%
* - "NPV estimates" should be understood as "mean values of the differences in NPV estimates from the base case NPV".

Table 3.22 presents results of assessing the sensitivity of the social NPV to changes in the maize price. When the maize price increases by 25%, in scenario 1 the social NPV increases by 26%; by 25% in scenario 2; and by 27% in scenarios 3 and 4. Similar percentage changes in the social NPV (i.e., same magnitude of changes, but in negative values) occur when the maize price decreases by 25%. Changes in estimates of the social NPV are directly proportional to the assumed changes in maize prices.

Table 3.22 Sensitivity of the social NPV in 2008 for adoption of transgenic DT maize to the changes in the price of maize by scenario (1,000 $US)

Price		**Scenarios**			
		1	**2**	**3**	**4**
+25%	value	342,163	412,190	141,492	20,542
	% Δ	26	25	27	27
no change		271,558	329,752	111,411	16,175
-25%	value	200,953	244,016	81,330	11,808
	% Δ	-26	-26	-27	-27

Note: Definitions of the scenarios are provided in table 3.15 or section 3.5.5
% Δ is a percentage change of the social NPV when the maize price is 25% higher or 25% lower relative to than the baseline price of maize.

3.6.3.3 Input costs of the representative farms

Analysis of sensitivity to changes in the level of input costs at the level of the representative farm is performed. Assumed input costs were increased and decreased by 25%. As a result of this, the private NPV estimates remained at the same level as in the situation in which initial input cost values were used. The base case NPV values changed. That is, varying the levels of input costs does not make any impact on the CBA in this study, since the results are reported as differences from the base case. However, the level of input costs has an impact on the ability, overall, of the smallholder farmers to be involved in growing maize. The higher are their input costs, the lower are their profits from selling maize. It should be also noted that although seed of transgenic DT maize varieties will be sublicensed to approved seed companies in Kenya, this does not guarantee the distribution of seeds to smallholders without a price premium. Seed companies can potentially sell transgenic DT maize seeds at a higher price without authorization. This would increase input costs of smallholders to buying these seeds, therefore lowering their benefits from growing transgenic DT maize in the long run. The likelihood of this situation to take place is expected to be very low as WEMA partner will be distributing transgenic DT maize seeds only through approved seed companies.

3.6.3.4 Level of adoption of transgenic DT maize

Different levels of adoption of transgenic DT maize have been considered (see table 3.15) in terms of assessing the impact of adoption behavior of various categories of adopters. In this section it is assumed that all smallholders adopt transgenic DT maize once this is available in local markets. In other words, we assume here that the adoption behavior of smallholder farmers corresponds to that of the Innovators. Table 3.23 summarizes the results of the sensitivity analysis of the total private NPV to changes in adoption that range from 100% adoption to 10% adoption of transgenic DT maize. The results are reported by scenarios considered for the Lowland Tropics[58] region.

The total private NPV increases with the increasing area on which transgenic DT maize is adopted. The estimated total private NPV values range from $18,214,000 with 100% adoption in the Best Case scenario (scenario 2) to $135,000 with 10% adoption in the Worst Case scenario (scenario 4).

Table 3.23 Sensitivity of the total private NPV in 2017 to changes in the adoption level of transgenic DT maize by scenario for the Lowland Tropics (1,000 $US)

Scenario	**Adoption level, % of the maize planting area in the Lowland Tropics zone**									
	100%	**90%**	**80%**	**70%**	**60%**	**50%**	**40%**	**30%**	**20%**	**10%**
1	15,102	13,592	12,082	10,572	9,061	7,551	6,041	4,531	3,020	1,510
2	18,214	16,393	14,571	12,750	10,928	9,107	7,286	5,464	3,643	1,821
3	6,474	5,827	5,180	4,532	3,885	3,237	2,590	1,942	1,295	647
4	1,349	1,214	1,079	944	810	675	540	405	270	135

Note: Definitions of the scenarios are provided in table 3.15 or section 3.5.5

Table 3.24 provides a summary of the sensitivity of the social NPV at the national level to changes in the adoption levels of transgenic DT maize. If transgenic DT maize is adopted on all maize planting areas in year 2017, the social NPV in 2008 is equal to $604.6 million in the Best Case scenario (scenario 2). It is seen that estimated social NPV decreases with decreases in the area of adoption. In all

[58] The results of the sensitivity analysis of the total private NPV to the adoption level of transgenic DT maize are provided in the table F.1 to F.4 of appendix F.

scenarios and under all levels of adoption, the social NPV is positive, except in scenario 4 in the case of a 10% adoption level. In the Best case scenario and under 100% adoption, the social NPV is equal to \$604.6 million (or \$27.6 on average per farm per year). In the Worst Case scenario, the social NPV is equal to \$-2.9 million (or \$-0.26 on average per farm per year) if transgenic DT maize is adopted on only 10% of the Kenya's maize planting area. It is concluded that social NPV will be negative only under very low levels of adoption (i.e., lower than 20% of Kenya's total maize planting area) and in the case of a very low yield advantages of transgenic DT maize.

Table 3.24 Sensitivity of the social NPV in 2008 to changes in the adoption levels of transgenic DT maize by scenario (1,000,000 \$US)

Scenario	**Adoption level, % of the maize planting area in Kenya**									
	100%	**90%**	**80%**	**70%**	**60%**	**50%**	**40%**	**30%**	**20%**	**10%**
1	498.3	447.8	397.2	346.7	296.1	245.6	195.0	144.5	93.9	43.4
2	604.6	543.5	482.3	421.1	359.9	298.7	237.5	176.3	115.2	54.0
3	208.1	186.6	165.0	143.5	122.0	100.4	78.9	57.4	35.8	14.3
4	35.4	31.1	26.9	22.6	18.4	14.1	9.8	5.6	1.3	-2.9
Note: Definitions of the scenarios are provided in the table 3.15 or section 3.5.5										

The occurrence of negative social NPV could reflect a real life situation should disadoption of the transgenic DT maize varieties take place. Another reason could be if the transgenic DT maize varieties were to be adopted on only a limited maize planting area (i.e., WEMA project investment cost would be higher than the private benefits realized on a very small area planted to transgenic DT maize). Possible disadoption is not a subject of this study; however, the possibility of disadoption is noted. Low levels of adoption could occur in several situations, as when there is:

1) Low awareness of smallholder farmers about the availability of the transgenic DT maize varieties;
2) The transgenic DT maize varieties are not accessible to the smallholder farmers from remote areas;

3) The confidence of smallholder farmers about the benefits of the transgenic DT maize varieties is low;
4) Reluctance of the smallholder famers to plant transgenic maize;
5) Varieties prove inferior in actual farm use.

The solution to the first two issues is to provide comprehensive extension by the WEMA project partners and to make sure that the seeds of the transgenic DT maize varieties are available at reasonable prices in the remote areas. The confidence of the smallholder farmers can also be boosted via extension work and when they see positive results on neighbor's fields. The recognition of adopter categories should help to understand the process of adoption of technologies. The reluctance of farmers to adopt transgenic maize may be an issue; however, this is not studied here. It can be speculated that such reluctance will be very low if the transgenic DT maize has high yield advantages compared to the hybrids available in local markets and there are no concerns about the quality or costs of the new seeds. Negative social NPV resulting from disadoption is unavoidable if transgenic DT maize varieties prove inferior and do not perform as expected in farmers' fields.

3.7 Conclusions

In this paper the private and social cost and benefits of the introduction of transgenic DT maize in Kenya for smallholder farmers under humanitarian license are analysed. A cash flow simulation model is developed to estimate differences in private NPV per hectare from the base case scenario incurred by smallholder farmers, as projected over the years from 2017 to 2038. Then private NPV estimates per hectare are aggregated to the Agroclimatic zone level (i.e., total private NPV for each ACZ), and then to the national level (social NPV). The total private NPV summed across all ACZs along with WEMA project investment costs is used in social cost and benefit analyses to estimate social NPV in 2008. The following conclusions have been drawn based on the research results presented in section 3.6.

1. Introduction of transgenic DT maize in Kenya under humanitarian license produces positive private NPV estimates for smallholder farmers

The estimated NPV differences from the base case NPV estimates (denoted in the text as "private NPV estimates") are positive for all ACZs, adopter categories, and scenarios, including a Worst Case scenario. Thus introduction of transgenic DT maize in Kenya is economically justified as this results in positive economic returns. Assessing the results of estimates for different ACZs, the Dry Mid-altitude zone has the lowest positive benefit compared to all other zones. The highest positive benefits occur in the Moist Transitional zone, followed by the Moist Mid-altitude zone. The Lowland Tropics and the Dry Transitional zones receive positive benefits of comparable magnitude. These results closely correspond to the importance of each of these ACZs for growing maize in Kenya as discussed in De Groote et al. (2003).

2. Private NPV estimates for smallholder farmers decrease the longer they wait to adopt transgenic DT maize

The private NPV estimates decrease the longer adopters of transgenic DT maize wait to adopt. Innovators receive the highest private NPV estimates per ha, followed by the Early adopters, then Early majority, then Late adopters and Laggards. This holds true for each scenario and each ACZ. Since there is no penalty in terms of higher seed costs for transgenic DT maize, but there is yield advantage even under no drought, those who adopt earlier obtain higher benefits compared to those who adopt later.

3. Introduction of transgenic DT maize in Kenya under humanitarian license produces positive social NPV on the national level

Since all the private NPV estimates per hectare of the representative farms are positive, the overall social NPV for Kenya is positive in all scenarios as well. The social NPV for Kenya in 2008 ranges from $329,752,000 (or $452 on average per farm in Best Case scenario) to $16,175,000 (or $22 on average per farm in Worst Case scenario). This indicates that even with a minimal yield advantage (as in the Worst Case scenario) the introduction of the transgenic DT maize varieties in Kenya results in positive economic returns to the smallholder farmers.

4. Private NPV estimates for smallholder farmers and social NPV at the national level are highly sensitive to changes in private discount rates

Private NPV estimates are highly sensitive to variation in private discount rates for all adopter categories and across all scenarios. For example, a change of the private discount rate from 5% to 10% leads to considerable changes in the values of private NPV estimates. As in the case of private NPV estimates, the social NPV is sensitive to changes in the levels of private discount rates. If the private discount rate decreases from 20% to 15%, the estimated value of the social NPV increases by 37% to 43%, depending on the scenario. As the private discount rate increases from 20% to 30%, the social NPV value changes by -41% to -43%, depending on the scenario. Estimations based on private discount rates should be undertaken with care as to the assumed rate and assessed as precisely as possible for a specific country and period of time.

5. Estimated social NPV at the national level is sensitive to the levels of social discount rates adopted

The estimated social NPV values at the national level are fairly sensitive to the changes in the social discount rate. With a 7% discount rate the values of social NPV decline by -30% for the different scenarios, relative to the values of social NPV when a 3% social discount is utilized. When the social discount rate is increased to a level of 5%, the decrease in social NPV values ranges from -16% to -17% for the different scenarios relative to the baseline scenario applying a 3% social discount rate. However, the estimated social NPV remains positive even with the highest social discount rate of 7% and under the Worst case scenario, when this is equal to $11,323,000.

6. Private NPV estimates for smallholder farmers and social NPV at the national level increase and decrease proportionally to the respective decrease and increase in maize prices

The private NPV estimates increase by 25% for all adopter categories and scenarios when the price of maize increases by 25%. Likewise, the private NPV estimates decrease by 25% for all adopter categories and scenarios when the price of maize decreases by 25%. The values of social NPV increase or decrease by 25% to 27% as the price of maize goes up or down by 25% respectively.

7. Social NPV at the national level increase when the planted area of transgenic DT maize increases

If transgenic maize was to be adopted on all the maize planting area of Kenya starting from 2017, the social NPV in 2008 would be equal to $604.6 million in the Best Case scenario. Estimated social NPV decreases with decreases in the area of adoption. In all the scenarios and for all levels of adoption the social NPV is positive, except in scenario 4 with only 10% adoption. In this Worst case scenario, the social NPV equals the loss of $2.9 million should transgenic DT maize only be adopted on 10% of Kenya's maize planting area.

It is concluded that the introduction of transgenic DT maize for smallholder farmers in Kenya is beneficial from both private and social points of view. Transgenic DT maize varieties are not expected to have a yield penalty compared to the currently available maize hybrids even when there is no drought. The seed will be available royalty free to smallholder farmers, so there will not be extra seed costs, as compared to currently available maize hybrids. Negative benefits to society may only occur under very low levels of adoption of the transgenic DT maize (i.e., under 20% of Kenya's total maize planting area), and if the yield advantage of the transgenic DT maize is very low. However, under the assumptions of the study, private benefits to the smallholder farmers are always positive and range from $67 to $0.24 on average per farm per year.

Overall, the results of this study are consistent with those of previous comparable studies that measure producer and consumer benefits from introducing transgenic maize in Kenya. For example Andreu et al. (2006) assessed ex-ante economic impacts of transgenic maize tolerant to streak virus. Estimated producer surplus one year after adopting these maize varieties ranged from $0.6 to $14.2 million depending on farm size. In our study the social NPV estimated for Kenya in 2008 ranges from $16.2 to $329.8 million depending on the scenario. Social NPV can be regarded as total producer benefit in our study, as consumer benefits to other than to smallholders is not considered. Divided by 22 years over which these benefits were estimated, the annual aggregate average smallholder benefits in Kenya would range from $0.7 to $15 million.

Kostandini et al. (2009) report aggregate estimates of $6.7 million in benefits accruing annually to those Kenyan producers that would adopt transgenic DT maize. This is a smaller value than in our study since the maximum adoption rate of transgenic DT maize is assumed to be 50% of total maize planting area in Kenya, whereas our model allows adoption to increase up to 100%. In Kostandini et al. (2011) the estimated total annual benefit to producers generated by transgenic DT maize research in Kenya ranges between $3 and $20 million. These numbers are close to the estimates in our study.

The assumption of humanitarian license in this study equates the seed cost of transgenic DT maize with the seed cost of existing hybrid maize varieties. It is of interest to assess how the benefits to smallholder farmers would be impacted if they had to pay technology fee for DT maize seed varieties. In their study Kostandini et al. (2011) apply marginal cost of $35/ha for transgenic DT maize seeds in Kenya. Incorporating this additional seed cost into our model, social NPV values are reduced from $329.8 to $214 million (Best Case scenario) and from $16.2 to -$96.1 million (Worst Case scenario). It is concluded that the humanitarian license is very important when introducing transgenic DT maize into Kenya. The absence of such a license would greatly reduce the benefits of smallholder farmers. Moreover, if these transgenic DT varieties did not perform as expected (e.g., Worst Case scenario), all smallholder farmers would incur losses.

Losses of smallholder farmers in developing countries very often lead to malnutrition and poverty. This is different from the situation in the developed world, where losses in agricultural business may lead to bankruptcy, but not necessarily to extreme poverty and food insecurity. The cash flow model applied to a representative smallholder farm in Kenya does not capture the huge importance of additional income that can be received following adoption of transgenic DT maize. Neither does it capture the value of such externalities as improved health as a result of better nutrition and possibly reduced inequality. In terms of importance of food security for smallholder farmers in Kenya, the magnitude of benefits of transgenic DT maize generated in our model may not be fully captured.

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Appendix C. Historical weather data, maize yields and prices in Kenya

Table C.1 Historical weather data for the representative district Kilifi (Lowland Tropics) in Kenya

Year	Monthly average of average daily temperatures, ^{0}C					Monthly precipitation, mm				
	Mar	**Apr**	**May**	**Jun**	**Jul**	**Mar**	**Apr**	**May**	**Jun**	**Jul**
1975	28.12	27.08	26.00	24.73	23.88	15	134	209	96	97
1976	27.33	27.03	25.90	24.92	23.83	20	104	185	81	90
1977	27.27	27.26	25.93	24.25	24.32	29	122	74	89	37
1978	27.22	26.48	25.02	24.82	23.50	138	189	229	75	42
1979	27.70	26.78	25.10	23.80	23.30	74	141	319	131	94
1980	28.12	28.20	26.90	24.78	24.10	17	79	56	43	67
1981	27.64	26.48	24.82	24.54	23.62	161	93	140	60	58
1982	27.63	26.36	25.10	24.18	23.32	75	155	415	109	114
1983	28.12	28.32	26.08	25.80	24.72	22	87	382	116	90
1984	27.80	27.54	25.92	24.06	23.62	19	209	154	161	95
1985	26.98	26.98	25.54	24.43	23.68	26	171	169	32	66
1986	27.82	26.86	25.27	24.72	23.68	29	209	299	23	23
1987	28.34	28.00	26.23	24.83	23.93	2	147	247	46	87
1988	28.58	27.50	26.30	25.12	24.57	54	171	52	136	33
1989	27.60	26.36	25.20	24.28	23.98	48	151	125	81	64
1990	27.40	26.62	26.00	24.45	23.83	152	133	106	46	25
1991	27.90	27.60	26.00	24.95	24.10	44	79	341	88	96
1992	28.20	27.65	26.18	25.34	23.86	16	108	173	71	97
1993	27.77	27.68	26.68	24.84	23.68	24	92	135	125	36
1994	28.28	27.53	25.88	24.84	24.02	31	201	291	54	119
1995	27.90	27.48	25.90	24.96	24.58	40	120	175	5	66
1996	27.88	27.42	25.72	25.13	24.08	128	116	301	28	60
1997	27.98	26.68	25.72	24.84	24.32	11	212	228	122	121
1998	28.54	27.73	26.18	25.48	24.16	42	339	199	212	43
1999	28.32	26.95	25.80	24.58	23.92	44	230	186	92	80
2000	27.92	27.24	25.68	24.33	24.90	147	39	191	118	46
2001	28.92	27.00	26.08	24.68	24.10	86	103	172	56	74
2002	28.33	27.78	26.42	25.48	24.30	126	118	117	32	87
2003	28.68	28.42	27.08	25.60	24.28	16	88	228	90	68
2004	28.50	27.53	26.58	24.93	24.54	61	153	144	93	49
2005	28.50	27.63	26.10	25.33	24.08	60	109	200	93	68
2006	28.70	26.97	25.77	24.83	23.63	39	237	156	131	65
2007	27.78	27.25	26.20	24.94	24.32	82	120	183	76	42
2008	27.70	26.80	25.52	24.36	23.90	98	132	171	72	52
2009	28.44	28.03	26.42	25.63	24.46	34	142	72	118	49

Source: East Anglia Climate Research Unit obtained in a compiled form from CIMMYT (Kai Sonder, CIMMYT, personal communication, August 29, 2011) and own calculations for specific districts of Kenya.

Table C.2 Historical weather data for the representative district Makueni (Dry Mid-altitude) in Kenya

Year	Monthly average of average daily temperatures, ^{0}C					Monthly precipitation, mm				
	Mar	**Apr**	**May**	**Jun**	**Jul**	**Mar**	**Apr**	**May**	**Jun**	**Jul**
1975	25.24	24.10	22.69	21.33	20.83	15	110	32	7	6
1976	24.77	23.96	22.91	21.66	20.66	20	132	24	5	3
1977	24.76	24.16	23.00	20.88	20.58	62	194	44	11	4
1978	23.50	23.63	21.88	21.23	20.29	170	142	14	5	4
1979	23.63	23.96	22.71	21.03	20.38	62	203	81	13	6
1980	25.04	24.83	23.45	20.94	20.26	45	91	38	3	3
1981	24.91	23.44	22.28	21.24	19.76	144	211	66	7	3
1982	25.00	23.83	22.61	21.60	20.84	38	139	61	13	6
1983	25.27	24.89	23.09	22.28	21.23	25	78	23	9	6
1984	24.79	23.06	23.10	21.33	20.45	14	94	6	11	7
1985	24.24	23.74	22.39	20.84	20.39	50	138	41	2	3
1986	24.63	23.93	22.44	20.95	20.09	50	164	50	7	2
1987	25.89	25.50	23.36	21.63	20.86	22	108	44	6	4
1988	25.69	24.39	23.11	22.59	21.09	144	164	15	14	3
1989	24.71	23.29	22.39	21.05	20.49	73	214	47	1	4
1990	24.47	23.81	23.14	21.13	20.50	177	219	31	5	3
1991	25.21	24.34	23.08	21.99	20.61	78	85	60	9	4
1992	25.39	24.53	22.94	22.01	20.63	17	180	45	7	4
1993	24.37	24.59	23.64	21.85	20.29	24	27	9	15	2
1994	23.53	24.03	22.95	21.63	20.98	73	101	43	4	4
1995	24.66	24.41	23.08	22.14	20.98	70	197	16	1	6
1996	25.30	24.44	23.13	21.93	20.83	82	71	43	9	5
1997	24.36	24.13	23.13	21.94	21.13	25	209	57	9	8
1998	25.49	23.93	22.34	22.08	21.06	75	196	97	25	4
1999	25.39	24.74	22.85	22.69	20.94	118	127	14	11	4
2000	25.67	25.44	24.15	21.40	22.11	89	55	17	15	4
2001	26.31	23.81	22.88	21.45	20.49	157	75	22	6	6
2002	26.03	25.20	23.85	22.46	21.23	130	121	47	2	5
2003	25.77	25.35	24.15	22.73	21.16	26	121	74	7	5
2004	25.57	24.43	23.71	21.86	21.33	80	171	33	13	5
2005	25.81	25.03	23.06	22.18	20.75	80	97	42	13	5
2006	25.73	24.34	23.88	21.46	21.34	108	211	37	8	5
2007	25.03	24.46	23.50	21.55	20.63	68	104	40	12	4
2008	24.70	24.36	22.84	21.24	20.81	189	97	27	9	4
2009	25.77	25.26	23.40	22.45	21.24	37	163	21	11	5

Source: East Anglia Climate Research Unit obtained in a compiled form from CIMMYT (Kai Sonder, CIMMYT, personal communication, August 29, 2011) and own calculations for specific districts of Kenya.

Table C.3 Historical weather data for the representative district Machakos (Dry Transitional) in Kenya

Year	Monthly average of average daily temperatures, ^0C					Monthly precipitation, mm				
	Mar	**Apr**	**May**	**Jun**	**Jul**	**Mar**	**Apr**	**May**	**Jun**	**Jul**
1975	22.88	22.10	20.75	19.40	19.00	42	163	76	13	16
1976	22.71	21.81	21.08	19.85	18.88	22	151	37	20	8
1977	22.65	21.98	21.18	19.16	18.80	95	297	116	18	14
1978	20.89	21.51	19.95	19.29	18.51	162	202	38	11	13
1979	20.93	21.88	20.95	19.37	18.58	110	276	128	24	13
1980	22.64	22.69	21.49	19.00	18.47	46	116	135	9	4
1981	22.71	21.29	20.53	19.44	18.01	122	238	122	12	7
1982	22.91	21.79	20.88	20.03	19.13	48	157	113	12	15
1983	22.81	22.74	21.28	20.25	19.38	29	160	35	21	11
1984	22.43	20.69	21.34	19.79	18.66	18	100	12	6	16
1985	22.03	21.50	20.43	18.88	18.49	113	208	69	7	11
1986	22.20	21.84	20.54	18.95	18.18	57	233	122	17	5
1987	23.70	23.45	21.46	19.75	19.18	23	153	82	32	10
1988	23.30	22.16	21.19	20.91	19.11	119	304	69	25	11
1989	22.36	21.05	20.54	19.23	18.54	90	217	98	8	14
1990	22.05	21.64	21.31	19.23	18.60	177	217	105	10	9
1991	22.99	22.06	21.25	20.40	18.64	50	110	147	10	12
1992	23.19	22.43	20.98	20.13	18.76	14	251	110	10	17
1993	21.83	22.55	21.78	20.29	18.44	41	70	58	23	13
1994	20.51	21.74	21.14	19.79	19.16	56	148	65	11	16
1995	22.16	22.30	21.30	20.69	18.98	118	239	66	13	16
1996	23.18	22.34	21.40	20.09	19.00	97	62	70	21	16
1997	21.80	22.05	21.41	20.34	19.30	40	280	129	10	17
1998	23.08	21.46	20.19	20.11	19.23	87	159	249	38	17
1999	23.33	22.90	20.89	21.26	19.21	139	129	28	16	6
2000	23.66	23.89	22.71	19.89	20.51	35	83	27	20	10
2001	24.10	21.63	20.88	19.54	18.69	181	87	40	11	20
2002	24.04	23.31	22.20	20.74	19.41	113	179	129	1	11
2003	23.63	23.33	22.33	21.07	19.40	33	218	184	7	13
2004	23.33	22.28	21.93	20.15	19.54	84	209	80	20	13
2005	23.70	23.15	21.16	20.54	18.84	85	103	94	20	13
2006	23.31	22.41	22.44	19.66	19.81	135	260	89	5	11
2007	22.85	22.60	21.80	19.65	18.81	76	154	90	20	13
2008	22.26	22.38	21.11	19.51	19.00	221	108	46	17	11
2009	23.54	23.21	21.59	20.58	19.43	34	230	57	15	13

Source: East Anglia Climate Research Unit obtained in a compiled form from CIMMYT (Kai Sonder, CIMMYT, personal communication, August 29, 2011) and own calculations for specific districts of Kenya.

Table C.4 Historical weather data for the representative district Bungoma (Moist Transitional) in Kenya

Year	Monthly average of average daily temperatures, ^{0}C					Monthly precipitation, mm				
	Mar	**Apr**	**May**	**Jun**	**Jul**	**Mar**	**Apr**	**May**	**Jun**	**Jul**
1975	21.40	20.83	19.80	19.00	19.15	112	128	169	169	176
1976	21.15	20.48	19.78	19.40	19.00	54	146	301	131	154
1977	21.30	20.65	20.18	18.85	18.75	109	244	244	153	123
1978	19.33	20.95	19.50	19.15	18.80	148	181	152	134	122
1979	19.80	20.90	20.08	19.13	19.05	95	149	203	162	83
1980	21.60	21.50	20.08	18.80	18.88	59	172	223	119	94
1981	21.35	20.73	20.03	19.55	18.35	223	252	177	71	124
1982	21.90	21.13	20.20	19.83	19.68	54	202	229	113	115
1983	22.08	21.60	20.80	20.20	19.83	60	196	205	133	95
1984	21.65	19.75	20.55	19.70	19.10	29	190	159	136	132
1985	20.80	19.95	19.65	18.85	18.88	172	237	233	111	176
1986	20.78	20.85	20.13	18.78	18.65	112	258	156	90	163
1987	22.35	22.38	20.43	19.78	20.10	126	169	304	97	72
1988	22.20	21.23	20.38	20.70	19.33	117	296	156	116	183
1989	20.98	19.93	19.70	18.90	19.20	115	158	217	86	115
1990	20.98	21.10	20.73	19.88	19.30	150	211	150	49	73
1991	21.55	21.00	20.13	20.15	19.05	140	152	252	127	122
1992	21.68	21.30	19.88	19.80	19.15	37	227	139	205	127
1993	20.60	21.10	20.23	20.15	19.30	72	100	241	135	68
1994	19.68	20.53	20.30	19.55	19.35	185	189	229	139	168
1995	20.98	22.00	20.48	20.50	19.35	146	209	125	121	112
1996	21.60	21.10	20.45	19.88	19.48	185	161	177	138	133
1997	21.38	21.10	20.78	20.05	19.75	92	354	58	175	129
1998	21.98	20.60	19.53	19.90	19.65	74	140	193	195	209
1999	21.65	21.80	19.78	20.95	19.55	258	191	108	89	138
2000	22.28	22.70	22.40	19.95	20.45	27	84	227	87	104
2001	22.95	21.65	20.88	19.80	19.55	107	195	122	155	110
2002	22.95	22.65	21.98	21.08	20.80	90	137	274	51	77
2003	22.95	22.50	21.73	20.75	20.13	89	327	257	110	132
2004	22.28	20.85	21.45	20.43	20.45	99	213	139	128	130
2005	22.90	22.73	20.33	20.48	19.25	109	97	201	123	130
2006	22.33	21.98	20.73	19.45	20.70	159	151	135	72	96
2007	23.03	22.20	21.83	19.05	18.10	92	217	195	127	181
2008	22.03	21.75	20.90	19.83	19.55	93	104	114	118	115
2009	22.68	22.15	20.88	20.33	19.90	39	285	165	42	129

Source: East Anglia Climate Research Unit obtained in a compiled form from CIMMYT (Kai Sonder, CIMMYT, personal communication, August 29, 2011) and own calculations for specific districts of Kenya.

Table C.5 Historical weather data for the representative district Kisumu (Moist Mid-altitude) in Kenya

Year	Monthly average of average daily temperatures, ^{0}C					Monthly precipitation, mm				
	Mar	**Apr**	**May**	**Jun**	**Jul**	**Mar**	**Apr**	**May**	**Jun**	**Jul**
1975	22.55	21.73	20.98	20.40	20.53	205	178	180	113	137
1976	22.33	21.43	21.08	20.73	20.35	80	201	238	103	106
1977	22.38	21.68	21.40	20.15	20.08	159	275	257	141	116
1978	20.63	21.68	20.60	20.40	20.15	259	250	234	130	73
1979	20.78	21.68	21.25	20.43	20.35	159	157	199	127	81
1980	22.23	22.35	20.93	19.98	20.00	122	175	214	121	75
1981	22.10	21.40	21.05	20.65	19.53	273	216	172	75	132
1982	22.83	21.90	21.28	21.08	20.93	70	158	272	135	120
1983	22.93	22.35	21.40	21.30	21.05	79	214	179	132	99
1984	22.50	20.50	21.58	20.90	20.30	49	232	157	104	122
1985	21.50	21.00	20.75	20.05	20.18	206	253	200	91	157
1986	21.88	21.68	21.15	20.03	19.88	145	243	191	92	103
1987	23.10	23.28	21.63	21.03	21.13	169	172	241	109	85
1988	22.83	22.00	21.45	22.00	20.65	173	334	174	125	153
1989	21.77	20.88	20.85	20.23	20.38	207	167	208	79	71
1990	22.05	21.85	21.75	20.88	20.48	213	214	141	57	49
1991	22.73	21.90	21.40	21.43	20.35	166	165	308	117	76
1992	22.83	22.15	21.03	21.10	20.45	66	217	170	227	116
1993	21.68	21.90	21.17	21.43	20.48	103	130	251	172	71
1994	20.53	21.45	21.48	20.83	20.65	251	211	190	124	147
1995	22.05	22.83	21.27	21.65	20.58	198	228	157	133	89
1996	22.40	22.03	21.27	21.13	20.80	222	175	215	104	91
1997	22.13	22.03	21.93	21.33	21.05	131	422	81	147	105
1998	23.00	21.38	20.55	21.23	20.95	96	164	237	186	165
1999	22.40	22.73	21.00	22.40	20.85	352	196	86	71	107
2000	23.03	23.55	23.17	20.98	21.40	37	82	202	79	82
2001	24.00	22.45	21.78	21.05	20.80	155	183	112	126	92
2002	23.98	23.50	23.05	22.25	22.05	132	168	294	34	64
2003	23.98	23.35	22.83	22.05	21.33	121	354	270	88	104
2004	23.35	21.73	22.23	21.60	21.73	131	222	140	120	103
2005	23.90	23.50	21.53	21.75	20.55	154	114	204	115	103
2006	23.28	22.78	22.00	20.65	21.85	222	164	161	61	80
2007	24.13	23.10	22.93	20.28	19.58	135	245	196	119	137
2008	22.90	22.55	22.05	21.05	20.78	162	117	113	103	82
2009	23.20	22.98	21.98	21.58	21.15	60	316	165	39	103

Source: East Anglia Climate Research Unit obtained in a compiled form from CIMMYT (Kai Sonder, CIMMYT, personal communication, August 29, 2011) and own calculations for specific districts of Kenya.

Table C.6 Historical maize yield data for the representative districts in Kenya

Year	Mean maize yield, t/ha				
	Kilifi (LT)	Makueni (DM)	Machakos (DT)	Bungoma (MT)	Kisumu (MM)
1975	0.97	n/a	0.98	1.65	1.71
1976	0.99	n/a	0.21	1.75	1.72
1977	0.96	n/a	1.04	1.77	1.72
1978	0.93	n/a	1.11	1.81	1.74
1979	0.98	n/a	1.13	1.85	1.76
1980	1.03	n/a	1.17	1.89	1.78
1981	1.00	n/a	0.90	0.39	1.75
1982	0.90	n/a	1.17	0.39	1.72
1983	0.90	n/a	0.90	2.10	1.68
1984	1.03	n/a	1.85	1.84	1.62
1985	1.00	n/a	0.36	2.70	1.62
1986	1.20	n/a	0.76	2.70	1.80
1987	0.67	n/a	1.02	2.00	1.70
1988	0.60	n/a	1.86	2.25	1.98
1989	1.53	n/a	1.32	2.25	1.98
1990	1.45	n/a	0.99	2.30	1.98
1991	0.80	n/a	1.35	2.59	1.41
1992	1.03	0.72	0.83	2.36	1.41
1993	1.00	1.10	0.90	2.50	1.35
1994	0.95	0.55	0.25	2.70	2.52
1995	0.67	0.34	0.54	2.70	1.80
1996	0.60	0.19	0.21	2.70	2.25
1997	0.52	0.89	0.50	2.70	1.67
1998	0.69	0.27	0.18	2.64	2.31
1999	0.67	0.37	2.68	2.44	2.66
2000	0.99	0.64	0.45	2.66	1.10
2001	0.99	0.55	0.48	2.61	1.35
2002	0.81	0.52	0.77	2.10	1.35
2003	0.85	0.28	0.41	2.57	1.60
2004	0.99	0.40	0.26	2.79	1.59
2005	0.66	0.13	0.25	2.83	2.07
2006	0.99	0.31	0.63	2.97	2.09
2007	0.60	0.62	0.71	3.74	2.01
2008	0.82	0.41	0.68	2.74	1.81
2009	0.84	0.42	0.73	2.75	1.76

Note: LT – Lowland Tropics, DM – Dry Mid-altitude, DT – Dry Transitional, MT – Moist Transitional, MM – Moist Mid-altitude

Source: Annual reports of the Kenyan Ministry of Agriculture obtained in a compiled form from CIMMYT (Kai Sonder, CIMMYT, personal communication, March 30, 2011).

Table C.7 Historical maize price data in Kenya

Year	Average annual maize price (Nairobi), $US/t	Consumer Price Index (CPI)	CPI adjusted average annual maize price (Nairobi), $US/t
1997	270.58	40.21	715.05
1998	197.17	42.85	488.94
1999	211.42	45.37	495.15
2000	220.58	49.89	469.82
2001	152.92	52.75	308.04
2002	156.92	53.79	309.98
2003	198.36	59.06	356.89
2004	216.92	66.03	349.08
2005	207.92	72.57	304.44
2006	224.92	76.95	310.59
2007	202.42	80.24	268.06
2008	309.33	92.36	355.89
2009	376.50	102.09	391.88
2010	251.17	106.26	251.17
2011	361.27	127.20	301.80
Note: CPI base is February 2009 = 100. The CPI adjusted prices are in 2010 real value.			

Source: RATIN (2012), KNBS (2012) and own calculations

Appendix D. Distribution fit statistics for temperature and precipitation variables

Table D.1 Kolmogorov-Smirnov distribution fit statistics for temperature and precipitation variables

Variable	Kolmogorov-Smirnov test statistics					
	Kilifi (Lowland Tropics)		**Makueni (Dry Mid-altitude)**		**Machakos (Dry Transitional)**	
	Triangular	**Weibull**	**Triangular**	**Weibull**	**Triangular**	**Weibull**
T3	0.0869	0.1018	0.0799	0.0831	0.1117	0.0553
T4	0.1711	0.1109	0.1010	0.0899	0.0727	0.0751
T5	0.0952	0.1042	0.1516	0.1588	0.1365	0.1064
T6	0.1245	0.1282	0.1247	0.0996	0.0831	0.0735
T7	0.0663	0.0730	0.0808	0.1606	0.1813	0.0879
R3	0.1856	0.0921	0.1397	n/a	0.1178	0.1058
R4	0.1955	0.0996	0.1832	0.1196	0.1242	0.1097
R5	0.0910	0.1456	0.1081	0.0987	0.1905	0.0808
R6	0.1412	0.0870	0.1746	0.1098	0.1461	0.0843
R7	0.1060	0.1143	0.0784	0.0947	0.0845	0.1300

Variable	**Bungoma (Moist Transitional)**		**Kisumu (Moist Mid-altitude)**	
	Triangular	**Weibull**	**Triangular**	**Weibull**
T3	0.1329	0.0968	0.0861	0.1040
T4	0.0963	0.1174	0.1112	0.1221
T5	0.0918	0.1604	0.1296	0.0741
T6	0.2070	0.1310	0.0834	0.1731
T7	0.1008	0.0957	0.0876	0.0863
R3	0.1248	0.1506	0.0891	0.1758
R4	0.0994	0.0665	0.1981	0.1402
R5	0.0711	0.0811	0.0757	0.0806
R6	0.1468	0.1147	0.2135	0.1243
R7	0.1751	0.1331	0.1054	0.0970

Note: T – average monthly temperature in ^{0}C, R – monthly precipitation in mm, numbers 3 to 7 denote months of March through July respectively.

Table D.2 Chi-Squared distribution fit statistics for temperature and precipitation variables

Variable	Chi-Squared test statistics					
	Kilifi (Lowland Tropics)		Makueni (Dry Mid-altitude)		Machakos (Dry Transitional)	
	Triangular	Weibull	Triangular	Weibull	Triangular	Weibull
T3	2.0	6.0	1.6	4.0	3.2	2.8
T4	8.8	2.4	3.6	1.6	2.4	2.8
T5	4.4	5.6	9.6	11.6	3.2	7.6
T6	1.2	3.6	2.6	1.6	0.8	0.8
T7	1.6	4.0	4.4	8.8	6.4	4.8
R3	6.8	6.4	9.8	n/a	3.0	5.6
R4	7.2	4.0	7.6	6.8	6.0	5.6
R5	2.8	12.0	9.4	5.6	7.6	4.0
R6	5.2	3.6	7.2	2.8	7.6	6.4
R7	7.6	9.6	3.2	6.4	1.2	2.4
Variable	**Bungoma (Moist Transitional)**		**Kisumu (Moist Mid-altitude)**			
	Triangular	**Weibull**	**Triangular**	**Weibull**		
T3	6.4	0.8	2.8	4.4		
T4	3.6	8.8	8.0	3.6		
T5	1.6	9.4	3.6	1.2		
T6	7.4	3.2	2.0	4.6		
T7	2.4	4.0	2.8	2.8		
R3	2.8	13.0	4.0	7.4		
R4	2.4	0.8	5.6	7.6		
R5	3.2	3.6	2.0	2.0		
R6	2.8	7.2	9.2	8.0		
R7	14.0	4.8	2.4	4.8		

Note: T – average monthly temperature in ^{0}C, R – monthly precipitation in mm, numbers 3 to 7 denote months of March through July respectively.

Table D.3 Anderson-Darling distribution fit statistics for temperature and precipitation variables

Variable	Anderson-Darling test statistics					
	Kilifi (Lowland Tropics)		**Makueni (Dry Mid-altitude)**		**Machakos (Dry Transitional)**	
	Triangular	**Weibull**	**Triangular**	**Weibull**	**Triangular**	**Weibull**
T3	0.3726	0.2117	0.3694	0.2263	0.5233	0.1566
T4	Infinity	0.3021	0.3438	0.2715	0.2003	0.1850
T5	0.4322	0.3712	0.4607	0.4043	0.5041	0.3758
T6	0.3427	0.3393	+Infinity	0.2980	0.1890	0.1461
T7	0.1950	0.1871	0.9699	0.3194	1.1326	0.3205
R3	1.4975	0.4344	+Infinity	n/a	+Infinity	0.3424
R4	1.7674	0.4546	+Infinity	0.5548	0.4936	0.3920
R5	0.6556	0.3998	+Infinity	0.2585	1.1966	0.2433
R6	0.6811	0.2425	+Infinity	0.3994	0.8245	0.3229
R7	0.3955	0.3088	0.2631	0.2701	0.5081	0.2504

Variable	**Bungoma (Moist Transitional)**		**Kisumu (Moist Mid-altitude)**	
	Triangular	**Weibull**	**Triangular**	**Weibull**
T3	+Infinity	0.3232	0.5276	0.3623
T4	0.4135	0.3780	0.4802	0.4305
T5	+Infinity	0.2665	0.7584	0.3296
T6	+Infinity	0.5664	+Infinity	0.2921
T7	0.3967	0.3405	0.3350	0.2585
R3	+Infinity	0.2926	+Infinity	0.2468
R4	0.3441	0.1952	1.4104	0.5992
R5	0.2786	0.1981	0.2135	0.1878
R6	0.4813	0.3873	1.4013	0.6041
R7	0.6136	0.5226	0.3125	0.2777

Note: T – average monthly temperature in ^{0}C, R – monthly precipitation in mm, numbers 3 to 7 denote months of March through July respectively.

Appendix E. Simulation summary statistics of the private NPV estimates

Table E.1 Simulation summary statistics of the private NPV estimates for a representative farm by adopter category of transgenic DT maize and ACZ, Scenario 1 ($US)

ACZ	Mean	SD	Min	Max	5th percentile	95th percentile
Lowland Tropics						
Innovators	457.65	77.99	208.38	731.29	333.00	590.00
Early Adopters	325.32	88.41	27.76	640.18	176.00	465.00
Early Majority	270.01	73.63	23.50	531.00	146.00	386.00
Late Majority	230.20	81.89	14.28	510.95	95.77	367.43
Laggards	162.88	68.54	1.86	399.36	54.11	280.51
Dry Mid-altitude						
Innovators	243.74	69.31	59.13	497.74	138.02	366.65
Early Adopters	176.37	61.22	22.69	427.93	82.60	284.28
Early Majority	146.77	51.21	15.25	363.77	69.92	236.56
Late Majority	128.09	52.26	9.06	338.46	50.43	221.94
Laggards	92.11	42.24	1.13	282.60	29.93	168.92
Dry Transitional						
Innovators	424.45	103.46	130.09	787.01	263.00	604.00
Early Adopters	304.56	97.06	25.06	680.14	157.00	469.00
Early Majority	253.17	81.27	21.38	571.40	127.00	392.00
Late Majority	218.36	85.06	11.41	556.50	87.00	367.00
Laggards	156.20	69.09	1.91	449.19	51.67	280.72
Moist Transitional						
Innovators	1161.42	221.05	479.66	1932.96	813.00	1534.00
Early Adopters	826.41	235.08	34.48	1695.57	442.00	1207.00
Early Majority	685.99	196.11	31.94	1406.36	362.00	1002.00
Late Majority	586.67	214.12	31.94	1353.87	236.00	949.00
Laggards	416.22	177.33	4.92	1059.86	138.00	727.00
Moist Mid-altitude						
Innovators	911.87	114.39	517.11	1347.65	730.00	1105.00
Early Adopters	645.48	159.77	33.72	1136.78	363.00	882.00
Early Majority	535.41	133.22	28.04	935.62	298.00	732.00
Late Majority	455.59	154.42	28.04	929.57	191.00	700.00
Laggards	321.87	131.85	3.51	711.32	109.00	544.00

Table E.2 Simulation summary statistics of the private NPV estimates for a representative farm by adopter category of transgenic DT maize and ACZ, Scenario 2 ($US)

ACZ	Mean	SD	Min	Max	5th percentile	95th percentile
Lowland Tropics						
Innovators	551.94	98.15	236.30	925.23	396.00	720.00
Early Adopters	392.05	108.53	34.33	727.58	207.00	566.00
Early Majority	325.19	90.37	29.33	610.38	172.00	468.00
Late Majority	277.18	99.79	16.52	589.33	114.00	443.00
Laggards	196.16	83.32	2.22	514.86	65.00	342.00
Dry Mid-altitude						
Innovators	301.33	86.57	59.08	630.46	169.00	455.00
Early Adopters	218.03	76.19	25.98	497.78	100.98	351.54
Early Majority	181.25	63.63	19.84	424.71	85.47	292.13
Late Majority	158.11	64.80	10.83	401.57	62.12	273.37
Laggards	113.64	52.43	1.35	360.91	37.38	209.54
Dry Transitional						
Innovators	520.82	129.30	138.87	996.67	318.00	749.00
Early Adopters	373.58	120.50	30.79	790.44	183.00	578.00
Early Majority	310.27	100.62	26.47	670.33	154.00	482.00
Late Majority	267.51	104.96	12.90	631.24	106.00	451.00
Laggards	191.36	85.40	2.28	571.25	63.00	344.00
Moist Transitional						
Innovators	1407.88	277.15	547.60	2423.42	966.00	1882.00
Early Adopters	1000.82	289.75	38.99	1930.35	521.00	1470.00
Early Majority	830.45	241.56	36.34	1619.89	430.00	1225.00
Late Majority	709.88	262.01	36.34	1553.98	284.00	1153.00
Laggards	503.79	216.69	5.87	1376.32	166.00	891.00
Moist Mid-altitude						
Innovators	1087.56	146.16	616.21	1640.51	856.00	1336.00
Early Adopters	769.51	194.20	37.62	1296.99	428.00	1057.00
Early Majority	638.01	161.80	32.36	1081.06	349.00	878.00
Late Majority	542.72	186.03	32.26	1064.92	228.00	842.00
Laggards	383.53	158.23	4.19	933.24	127.00	655.00

Table E.3 Simulation summary statistics of the private NPV estimates for a representative farm by adopter category of transgenic DT maize and ACZ, Scenario 3 ($US)

ACZ	Mean	SD	Min	Max	5th percentile	95th percentile
Lowland Tropics						
Innovators	196.21	42.98	63.15	384.28	128.00	271.99
Early Adopters	139.36	43.11	9.39	316.41	70.77	212.06
Early Majority	115.83	35.72	8.86	281.12	59.33	174.37
Late Majority	98.74	37.63	5.49	248.93	39.42	163.30
Laggards	69.67	31.19	0.81	199.35	22.74	125.75
Dry Mid-altitude						
Innovators	100.42	32.37	15.46	260.21	53.40	158.84
Early Adopters	72.46	27.94	7.90	207.88	32.08	122.07
Early Majority	60.34	23.32	2.88	187.14	26.52	102.52
Late Majority	52.64	23.05	2.88	175.05	19.28	94.59
Laggards	37.90	18.48	0.49	139.02	11.87	72.08
Dry Transitional						
Innovators	178.41	49.95	47.19	434.30	103.61	267.17
Early Adopters	127.77	45.25	7.86	327.24	58.54	207.02
Early Majority	106.22	37.71	7.40	292.10	49.43	172.26
Late Majority	91.49	37.98	4.32	283.48	35.88	158.26
Laggards	65.44	30.72	0.83	224.24	20.91	119.80
Moist Transitional						
Innovators	497.28	115.86	148.37	996.98	313.00	701.00
Early Adopters	353.18	112.55	16.36	831.92	177.00	545.00
Early Majority	293.55	93.70	13.83	738.45	147.00	449.00
Late Majority	251.27	97.93	5.35	690.52	98.00	419.00
Laggards	177.90	80.54	1.82	531.29	58.00	323.00
Moist Mid-altitude						
Innovators	382.16	74.62	163.50	719.82	263.00	509.00
Early Adopters	270.18	80.02	16.40	533.23	137.00	400.00
Early Majority	224.52	66.35	10.72	454.53	111.56	331.78
Late Majority	190.96	71.16	6.30	451.20	74.91	309.04
Laggards	134.54	59.53	1.52	362.80	43.20	240.99

Table E.4 Simulation summary statistics of the private NPV estimates for a representative farm by adopter category of transgenic DT maize and ACZ, Scenario 4 ($US)

ACZ	Mean	SD	Min	Max	5th percentile	95th percentile
Lowland Tropics						
Innovators	40.89	19.18	0.31	118.77	12.85	75.85
Early Adopters	28.91	15.17	0.31	102.77	7.91	57.23
Early Majority	23.96	12.51	0.00	81.93	6.23	46.77
Late Majority	20.50	11.76	0.00	81.93	4.82	42.48
Laggards	14.44	9.10	0.00	63.56	2.80	31.57
Dry Mid-altitude						
Innovators	13.34	8.69	0.00	52.12	1.97	29.36
Early Adopters	9.56	6.74	0.00	41.35	1.23	22.81
Early Majority	7.87	5.53	0.00	41.35	0.92	18.23
Late Majority	6.92	5.11	0.00	41.35	0.74	16.87
Laggards	5.01	3.94	0.00	29.18	0.42	12.73
Dry Transitional						
Innovators	28.29	16.25	0.00	101.81	5.81	58.61
Early Adopters	20.18	12.63	0.00	90.39	3.74	44.14
Early Majority	16.62	10.33	0.00	67.41	3.09	35.72
Late Majority	14.44	9.69	0.00	67.41	2.31	33.04
Laggards	10.30	7.44	0.00	52.58	1.36	24.95
Moist Transitional						
Innovators	97.04	48.24	0.64	297.52	27.47	184.09
Early Adopters	68.77	37.59	0.64	256.97	17.20	138.69
Early Majority	56.78	31.16	0.00	227.32	13.76	115.14
Late Majority	48.90	29.28	0.00	227.32	10.38	104.83
Laggards	34.62	22.48	0.00	169.67	6.15	77.81
Moist Mid-altitude						
Innovators	88.84	37.60	6.20	251.64	32.01	155.14
Early Adopters	62.75	30.33	2.08	195.01	19.01	117.65
Early Majority	51.87	25.12	1.24	168.00	16.26	98.01
Late Majority	44.19	24.04	0.45	163.10	11.49	89.36
Laggards	31.11	18.72	0.00	114.80	6.70	66.69

Appendix F. Sensitivity of the total private NPV to the adoption level of transgenic DT maize

Table F.1 Sensitivity of the total private NPV to the adoption level of transgenic DT maize by scenario in Dry Mid-altitude zone in Kenya (1,000 $US)

Scenario	**Adoption level, % of the maize planting area in Dry Mid-altitude zone**									
	100%	**90%**	**80%**	**70%**	**60%**	**50%**	**40%**	**30%**	**20%**	**10%**
1	28,761	25,885	23,009	20,133	17,257	14,381	11,505	8,628	5,752	2,876
2	35,557	32,002	28,446	24,890	21,334	17,779	14,223	10,667	7,111	3,556
3	11,850	10,665	9,480	8,295	7,110	5,925	4,740	3,555	2,370	1,185
4	1,575	1,417	1,260	1,102	945	787	630	472	315	157

Table F.2 Sensitivity of the total private NPV to the adoption level of transgenic DT maize by scenario in Dry Transitional zone in Kenya (1,000 $US)

Scenario	**Adoption level, % of the maize planting area in Dry Transitional zone**									
	100%	**90%**	**80%**	**70%**	**60%**	**50%**	**40%**	**30%**	**20%**	**10%**
1	15,705	14,134	12,564	10,993	9,423	7,852	6,282	4,711	3,141	1,570
2	19,270	17,343	15,416	13,489	11,562	9,635	7,708	5,781	3,854	1,927
3	6,601	5,941	5,281	4,621	3,961	3,301	2,640	1,980	1,320	660
4	1,047	942	837	733	628	523	419	314	209	105

Table F.3 Sensitivity of the total private NPV to the adoption level of transgenic DT maize by scenario in Moist Transitional zone in Kenya (1,000 $US)

Scenario	**Adoption level, % of the maize planting area in Moist Transitional zone**									
	100%	**90%**	**80%**	**70%**	**60%**	**50%**	**40%**	**30%**	**20%**	**10%**
1	492,442	443,198	393,954	344,710	295,465	246,221	196,977	147,733	98,488	49,244
2	596,940	537,246	477,552	417,858	358,164	298,470	238,776	179,082	119,388	59,694
3	210,846	189,761	168,677	147,592	126,508	105,423	84,338	63,254	42,169	21,085
4	41,147	37,032	32,917	28,803	24,688	20,573	16,459	12,344	8,229	4,115

Table F.4 Sensitivity of the total private NPV to the adoption level of transgenic DT maize by scenario in Moist Mid-altitude zone in Kenya (1,000 $US)

Scenario	**Adoption level, % of the maize planting area in Moist Mid-altitude zone**									
	100%	**90%**	**80%**	**70%**	**60%**	**50%**	**40%**	**30%**	**20%**	**10%**
1	107,601	96,841	86,081	75,321	64,561	53,801	43,040	32,280	21,520	10,760
2	128,332	115,499	102,666	89,833	76,999	64,166	51,333	38,500	25,666	12,833
3	45,095	40,585	36,076	31,566	27,057	22,547	18,038	13,528	9,019	4,509
4	10,483	9,435	8,386	7,338	6,290	5,242	4,193	3,145	2,097	1,048

CHAPTER 4. Conclusions

4.1 Summary and considerations of the research conducted

4.1.1 Main conclusions of the research

In the study presented in chapter 2 selected welfare effects from introducing GM DT wheat and MAS DT wheat on the world market are estimated and compared. A partial equilibrium world wheat trade model is developed to estimate these welfare effects. The results of this study contribute to literature by modifying and amending the trade model developed by Sobolevsky et al. (2005) to accommodate specifics of trading GM and MAS wheat tolerant to abiotic stress (i.e., drought). This study is the first attempt to compare welfare effects of trading DT wheat, when DT trait in wheat is achieved by applying GM tools versus MAS/conventional breeding tools.

Under the assumptions of this study it has been found that adoption of GM DT wheat in wheat exporting countries and introduction of this wheat on a world wheat market increases trade welfare[59]. These positive welfare changes are driven by higher non-GM wheat prices relative to GM wheat prices. There are a few reasons for this to happen:

- Some countries (i.e., EU, Japan, and South Korea in this particular model) refuse to import GM DT wheat in favor of importing only non-GM wheat. The existence of two segregated markets for GM DT and non-GM wheat causes wheat price difference on these two markets in favor of a higher price for non-GM wheat.
- When drought causes yield losses of non-GM wheat, this also drives up non-GM wheat prices. As a result, producer surplus in exporting countries increases and overweighs the influence of decreases in consumer surplus from decreased output associated with drought. The analysis also shows

[59] Trade welfare is a sum of producer and consumer welfare in all wheat exporting countries (excluding welfare of domestic consumers) and wheat importing countries (excluding welfare of domestic producers) in the model.

that segregated markets for GM DT and non-GM (conventional) wheat leads to increases in trade welfare even when there is no yield advantage for GM DT wheat relative to conventional wheat (i.e., in the years without droughts).

According to the results of the model, adoption and trade of GM DT wheat may be welfare reducing. This occurs under hypothetical circumstances of no restrictions on GM DT wheat trade (i.e., all importing countries remove barriers against importation of GM DT wheat) and relatively low adoption levels of GM DT wheat in wheat exporting countries. When there are no trade restrictions, the prices of conventional wheat are not inflated by higher levels of demand for conventional wheat. Low adoption and consequent low supplies of GM DT wheat bring GM DT wheat prices closer to the price levels for conventional wheat. This might lead both GM DT and conventional wheat prices to fall below the benchmark price (i.e., price of wheat from a base case "status quo" model, where only non-GM conventional wheat is being traded). This would make it unprofitable for wheat exporters to adopt GM DT wheat.

Generally, results of the GM DT wheat trade model should be interpreted with caution. Positive changes in trade welfare in the GM DT wheat model may only hold true when the segregation system for GM DT and conventional wheat markets is well designed and functions without errors. Without such system there would only be one market of wheat. In this case welfare gains may be nullified.

When DT wheat developed by MAS and conventional breeding tools is introduced on a world wheat market, the trade welfare decreases relative to the level of trade welfare in the base case model. The negative welfare change in the case of MAS DT wheat adoption is driven by additional supply of better performing MAS DT wheat in the drought years. The additional supply of wheat drives wheat prices down. Although this benefits consumers, producer surplus in exporting countries decreases and outweighs the increased consumer surplus.

Drought tolerance in MAS wheat is essentially a technological advancement that allows producing more wheat (i.e., losing less wheat if drought occurs) at a lower price. This result reflects the assumptions of inelastic demand and static demand that does not grow relative to the increases in supply. The analysis shows that even when MAS DT wheat does not exhibit yield advantage relative to conventional wheat in specific years (e.g., in the years without drought), trade welfare change from the base case is nevertheless negative albeit small in magnitude. This is attributed to higher seed costs for MAS DT wheat as compared to seed costs of conventional wheat.

The impact of MAS DT wheat adoption and trade on trade welfare differs from that of GM DT wheat adoption and trade. In GM DT wheat trade model, the price premium paid on non-GM wheat allows wheat exporters to benefit. This occurs if some importing countries reject cheaper GM DT wheat in favor of more expensive conventional wheat. In MAS DT wheat trade model, there is only one price and one market for both conventional (non-DT) and MAS DT wheat. Therefore, if some portion of the wheat planted area is sown to MAS DT wheat, this will produce better yields (i.e., exhibit lower yield losses) than conventional wheat. However, when sold at the same price as conventional wheat, this will be lower than the benchmark price due to the higher levels of wheat supplies.

In the study presented in chapter 3 the private and social cost and benefit analysis of the introduction of transgenic DT maize in Kenya for smallholder farmers under humanitarian license is performed. A cash flow simulation model is built to calculate differences in private NPV estimates from the base case NPV (i.e., private NPV estimates) per hectare incurred by smallholder farmers in the years 2017-2038. Then private NPV estimates per hectare are aggregated to the Agroclimatic zone level to calculate total private NPV, and then to a national level to calculate social NPV (based on the available maize planting area in each zone and country-wide respectively). WEMA project investment cost incurred in 2008-2012 along with the total private NPV by ACZ is used in the social cost and benefit analysis to calculate social NPV in 2008, the year when WEMA project was initiated.

This study is a contribution to the case study literature on the economic impacts of improved crops on the livelihoods of smallholder farmers as individuals and as a society in the developing countries. The unique feature of this study is that the adoption of transgenic DT maize occurs in different times based on adopter categories according to Rogers (2003) and is incorporated in the model as an endogenous stochastic variable. The decision to adopt depends on the number of drought occurrences in the region. Another distinctive feature in this study is incorporation of private benefits of the smallholder farmers into social cost benefit analysis.

The results of the study show that introduction of transgenic DT maize in Kenya under humanitarian license produces positive private benefits to smallholder farmers. The differences in private NPV estimates per ha from the NPV of the base case “status quo” model are positive for all ACZs, adopter categories, and scenarios. Additional gains in terms of private NPV estimates range from as low as $US 5 per ha (in the Worst case scenario in the driest Dry Mid-altitude zone of Kenya) to as high as $US 1,408 per ha (in the Best case scenario Moist transitional zone that is relatively more abundant with precipitations). Such results are expected. Transgenic DT maize is assumed to exhibit yield advantage over existing maize hybrids in Kenya and the seeds of transgenic DT maize are transferred to smallholder farmers at the same cost as existing maize hybrids. In general the magnitude of the private benefits that occur in each ACZ corresponds closely to the importance of each of these ACZs for maize production in Kenya as discussed in De Groote et al. (2003).

Considering results of different ACZs, the Dry Mid-altitude zone has the lowest positive benefit compared to all other zones. The highest positive benefits occur in the Moist Transitional zone, followed by the Moist Mid-altitude zone. Lowland

Tropics and Dry Transitional zones receive positive benefits of comparable magnitude.

According to the results of the simulation cash flow model, private benefits to smallholder farmers decrease the longer they wait to adopt transgenic DT maize. As expected, Innovators receive the highest private NPV estimates per ha, followed by Early adopters, then Early majority, then Late adopters and Laggards. Since there is no penalty in terms of higher seed costs for transgenic DT maize, but there is yield advantage even when there is no drought, those farmers who adopt earlier, obtain higher benefits compared to those who adopt later.

Even though positive private benefits were expected to occur based on the assumptions in the model, it was of great importance to estimate social benefits at the country level. This estimation includes WEMA investment costs to reveal whether implementation of the WEMA project is economically justified. The results show that introduction of transgenic DT maize in Kenya under humanitarian license produces positive social benefits at the national level in the majority of scenarios. The social NPV for Kenya in 2008 ranges from $329,752,000 (Best Case scenario) to $16,175,000 (Worst Case scenario). Social NPV decreases with decreased area of adoption. In the Worst case scenario the social NPV in 2008 would be equal to $-2.9 million if transgenic DT maize were adopted on only 10% of the Kenya's maize planting area. Therefore, under very low adoption levels and if transgenic DT maize does not perform as expected, the cost of the project will exceed the benefit.

Overall, introduction of transgenic DT maize for smallholder farmers in Kenya is beneficial from both private and social point of view. Transgenic DT maize varieties are not expected to have a yield penalty compared to the currently available maize hybrids even when there is no drought. The seed will be available royalty free to smallholder farmers, so there will not be extra seed cost as compared to the currently available maize hybrids.

4.1.2 Additional considerations and links between research papers

Research presented in this thesis is organized in the form of two essays. The main link between these two essays is that both essays are looking at the economic impact of using modern genomic tools such as genetic modification, marker assisted selection or both in developing cereal crop varieties tolerant to drought and their consecutive adoption. However, the research questions that are being answered in each essay are different. First essay looks at the economic welfare implications of trading GM DT and MAS DT wheat on a world market. Results of the study are presented as producer and consumer welfare changes from the base case in wheat exporting and wheat importing counties. Second essay looks at the economic benefits from adoption of transgenic DT maize in a developing country, Kenya. Thus, both studies cover different aspects of adopting DT crop cereal crop varieties to fully capture possible outcomes:

- wheat versus maize;
- GM DT versus MAS DT wheat;
- economic benefits from international trade of DT crops by major and mainly developed countries versus economic benefits of DT crops to smallholder farmers in a developing country;
- when technology fee is charged for the GM DT wheat seed versus transferring transgenic DT maize seed under humanitarian license to smallholder farmers.

As drought tolerance research becomes more important due to potential future impact of climate change, some specifics of this trait should be noted. Drought tolerance is governed by multiple genes in crops. GM and MAS technologies have been used with success to improve traits that are governed by one gene only (Dean Spaner, wheat breeder, University of Alberta, personal communication, June 10, 2010). This means that despite continuous advances in genomics, the desired target levels of drought tolerance in crops may not be easily achieved. Crops that are specifically bred for DT may not always exhibit yield advantage under drought, or may underperform under specific weather and climate conditions. Our study uses assumptions of reasonable yield advantage of DT crops communicated by experts and sensitivity analyses are performed to include very conservative levels of yield advantage.

Another aspect of this research that should be acknowledged is the concept of yield advantage. In reality yield increases in crops can stem from breeding for multiple trait improvements, better crop management, more favorable weather conditions in specific years and regions, higher availability of crop nutrients in the soil, more efficient harvesting techniques, and others. In our study it is assumed that yield increases of DT cereal crops stem from reduced yield losses of these crops alone during drought years. This assumption is introduced to simplify analysis. If this assumption were relaxed, the contribution of DT to the yields increases in cereals would have been overestimated.

One more interesting result of the study requires additional attention. Although our study suggests that the adoption of MAS DT wheat is in most cases welfare decreasing (according to the results of the first essay), this conclusion does not necessarily apply to the situation when DT crop varieties are adopted in a small country (according to the results of the second essay). A small country that experiences increases in wheat supply is unlikely to influence world wheat prices. Results of the second essay show that adoption of transgenic DT maize (which is not segregated from conventional maize hybrid varieties) increases welfare of individual farmers who obtain higher yields in drought years. In these circumstances consumers also benefit from the reduction in yield losses. This is usually the case in developing countries (e.g., Kenya) where smallholder farmers use much of their crop for self-consumption and affordable prices of basic staple foods are important to landless labourers.

It should be noted that price effects are treated differently in both essays. In the first essay, changes in wheat prices impact quantities traded according to the specified demand and supply relationships. In the second essay, it is assumed that there are no price effects based on the quantities of maize produced. Kenya was a net importer of maize since 1980s with the exception of few specific years (FAO, 2013). Kenya is a price taker on a world market. Local increases in maize supply are assumed to have no effect on the price of maize.

4.2 Limitations of the research

4.2.1 Limitations of the research on the economic impact of genetic modification versus marker assisted selection (the case of drought tolerance in wheat)

The partial equilibrium trade model used in this study is a one year static model. This approach is commonly used in estimating ex ante welfare implications of introducing and adopting new crop varieties or technologies in the first year following the adoption (Berwald et al., 2006; Henry de Frahan and Tritten, 2003; Moschini et al. 2000; Qaim and Traxler, 2005; Sobolevsky et al., 2005; Wilson et al., 2008). The dynamic model that includes adoption (or even disadoption) of the GM DT or MAS DT wheat over time could give a better picture of the magnitude of consumer and producer surplus.

The level of investment into developing GM DT or MAS DT varieties were excluded from the model. The reason is that information on the magnitude of such investment is not available. Secondly, these costs are incurred by the breeding companies before the improved varieties reach commercialization stage. Our model covers trade of the improved crops once they are fully commercialized and costs of developing GM DT or MAS DT wheat varieties are assumed to be included into technology fee of GM DT wheat and increased cost of MAS DT wheat in this study. However, if the data on investment costs were available, it would be possible to estimate benefits that accrue to breeding companies.

Another limitation of this study is an assumption that the percentage of consumers that accepts GM DT wheat in each importing country is described by a constant exogenous parameter. This assumption is adopted from Sobolevsky et al. (2005), since the exact behavior of consumers with respect to purchasing GM DT wheat is not available in literature. The sensitivity analysis is not conducted by changing the parameter of consumer acceptance. Changing this parameter would require recalibration of the model (i.e., obtaining new values for the other parameters). Essentially, this would lead to obtaining a "new" model, and results would not be directly comparable.

The assumption of no domestic producers in wheat importing countries and no domestic consumers in wheat exporting countries is a limitation of this study. For example, in the USA a considerable share of wheat is produced for domestic market. In this case exclusion of the U.S. domestic consumers from calculation of total consumer surplus may lead to underestimation of total consumer surplus. In this thesis consumer surplus is related only to import demand consumer surplus, and producer surplus is related only to export supply producer surplus. Overall welfare is, therefore, denoted in this study as "trade welfare" and not "total welfare", as it does not include welfare of domestic consumers in wheat exporting countries and welfare of domestic producers in wheat importing countries.

It should be pointed out that scenarios of this study are constructed based on the assumption that an effective segregation system of non-GM and GM DT wheat is in place and functions without errors. Without perfect segregation welfare gains from introducing GM DT wheat in Canada and USA may be reduced or nullified. Without a perfect segregation system EU, Japanese and S. Korean wheat markets could be lost for Canada and the USA.

4.2.2 Limitations of the research on economic returns from transferring transgenic drought-tolerant maize technology to low income countries under humanitarian license (the case of Kenya)

Transgenic DT maize varieties in Kenya are assumed to be commercially available in 2017. This requires that all biosafety approvals of these varieties are obtained. This assumption may not hold in reality due to a lengthy application and approval process, lack of or insufficient legislation, and consumer aversion to GM crops. The cost of biosafety approval, that will have to be incurred by the WEMA project participant countries, is not estimated in this study. If this cost was accounted for, the total social NPV in Kenya could have been somewhat lower.

Another limitation is that in each ACZ of Kenya drought occurrence is modeled based on the departure of maize yield in a specific year from average historical maize yield. The drought is assumed to occur if the departure is negative. The implication of this, for example, is an assumption of drought occurrence in one ACZ with the actual yield of 1 t/ha versus historical average of 2.5 t/ha. At the same time the assumption of drought absence would hold in another ACZ with the same level of actual maize yield of 1 t/ha versus historical average of 0.5 t/ha.

Since it is difficult to define the level of drought and to predict the frequency of its occurrence, the use of this method is justified. Each ACZ has maize varieties adapted to the specific climate and weather conditions of that zone. The transgenic DT maize varieties are being developed using germplasm of these locally adapted maize varieties. This means that the performance of the transgenic DT maize lines adapted to be grown in different ACZs may vary.

4.3 Potential extensions

4.3.1 Potential extensions of the research on the economic impact of genetic modification versus marker assisted selection (the case of drought tolerance in wheat)

A potential extension of this study would be to construct dynamic world wheat trade model that incorporates changes in welfare of producer and consumer surplus over time. Change in welfare may be induced by the dynamics of adoption of GM DT or MAS DT wheat in exporting countries, changes in world wheat prices, and shifts in the wheat supply curves to adjust for extra supplies of wheat in good years and shortages in drought years. Shifts in the demand curves due to changing consumer preferences for GM DT wheat may also impact economic welfare distribution.

Absence of exogenously determined parameter that describes consumer acceptance of GM DT wheat is stated in the limitations of the research. Further exploration about various consumer acceptance modeling approaches may be a potential extension. Ideally, consumer acceptance of GM crops is supposed to depend not only on whether the price of GM DT wheat is lower than the price of non-GM wheat, but also on the gap between these two prices. Changes in wheat prices can be better tracked when modeling wheat trade over a period of time rather than employing a one year static model. Therefore, improvements in modeling consumer acceptance may be achieved when constructing dynamic wheat trade model.

The question may arise whether drought tolerance is an appropriate trait to look at as means to improve crop yields. Other crop technologies that may be yield-increasing, but not necessarily related to drought tolerance may exist and become a better alternative to drought tolerance. Improving irrigation system efficiency, fertilizer use efficiency, various crop best management practices can be alternatives to drought tolerance. Comparing welfare effects of these different crop technologies with welfare effects of drought tolerance may be a subject of future research.

4.3.2 Potential extensions of the research on economic returns from transferring transgenic drought-tolerant maize technology to low income countries under humanitarian license (the case of Kenya)

This study estimates economic returns from transgenic DT maize in Kenya. There are four other countries[60] that participate in WEMA project. NARS in each of these countries receive their portion of funding to assist in developing transgenic DT maize varieties. Therefore, project investment costs may be different in each of these countries. Based on the methodology developed in our study the estimation of economic benefits in the other WEMA project countries can be conducted. It would be especially important to perform estimation of economic benefits from transferring transgenic DT maize to the Republic of South Africa. It is a large country where other GM crops are already commercialized. Smallholder farmers in the Republic of South Africa are considered to be farmers with less than 3 hectares of land, unlike in all other WEMA countries, where all farmers are considered to be smallholder.

When trial data from several seasons of planting transgenic DT maize are available, the analysis can be improved by setting more realistic levels of yield advantage of the improved varieties. In the long run, after transgenic DT maize varieties are developed and adopted, there may be a need to conduct an ex-post study of economic impacts of these varieties. Our study may provide a starting point to do this.

[60] WEMA project countries are Kenya, Mozambique, Republic of South Africa, Tanzania and Uganda.

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