Cost of EU Opposition To Genetically Modified Wheat In Terms of Global Food Security

A Thesis Submitted to the College of
Graduate Studies and Research
in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy
in the Department of Agricultural Economics
University of Saskatchewan
Saskatoon

By
Faycal Haggui

PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a Postgraduate degree from the University of Saskatchewan, I agree that the Libraries of this University may make it freely available for inspection. I further agree that permission for copying of this thesis in any manner, in whole or in part, for scholarly purposes may be granted by the professor or professors who supervised my thesis work or, in their absence, by the Head of the Department or the Dean of the College in which my thesis work was done. It is understood that any copying or publication or use of this thesis or parts thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and to the University of Saskatchewan in any scholarly use which may be made of any material in my thesis.

Requests for permission to copy or to make other use of material in this thesis in whole or part should be addressed to:

Head of the Department of Agricultural Economics

University of Saskatchewan,

51 Campus Drive

Saskatoon, Saskatchewan

S7N5A8

ABSTRACT

Crop Biotechnology could help achieve a more food-secure world. However, the strong opposition to GM food, particularly in Europe, will undoubtedly affect the diffusion of GM crops worldwide, delaying or preventing the world from realizing the potential benefits of GM crops in terms of food security. This “braking effect” could deprive the world of a potential tool to increase or stabilize the future worldwide availability of food under a changing or more volatile climate. It is therefore essential to understand how the opposition to GM food has and will affect the diffusion of biotechnological innovations worldwide in order to estimate the effect of this opposition on global food security.

The main objective of the thesis is to estimate the loss in global food security if the EU does not relax their opposition to GM food. To meet this objective a market model is combined with a GM diffusion model to create a global food security (GFS) model. The focus of the model is GM wheat, due to the vital importance of conventional wheat to global food security. This approach allows us to evaluate dynamic economic responses to food production shocks, such as climate change. The GFS model is calibrated using production, consumption and price data for wheat. A number of scenarios are analyzed to consider the range of potential effects of the EU opposition on global food security. The results of the analyses will better inform the ongoing GM policy debates, which often ignore food security impacts.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my supervisor Dr. Richard Gray, for his valuable guidance and assistance in all aspects of the research process.

Thank you to Dr. Peter Phillips, member of my advisory committee, for contributing by his time and expertise to the completion of this thesis.

Thank you to Dr. Ken Belcher, member of my advisory committee, for his helpful comments and advice on developing and reporting this research.

Thank you to Dr. Joel Bruneau, member of my advisory committee, for his valuable suggestions, especially in the later stages of this thesis.

Thank you to Dr. Hartley Furtan for his advice on the modeling component of the thesis and for his friendship.

I would like to thank my external examiner Dr. Terry Veeman, for the time he dedicated to my thesis, for his contributions to the final product and for making my thesis defense a challenging experience.

I also thank the entire faculty, staff (especially Deborah), and students for making the Agricultural Economics department an enjoyable place to work.

I thank my friends and family, for their encouragement over the past years. I would like to express my utmost gratitude and appreciation to my girlfriend, Jean, for being patient and supportive during the completion of this thesis.

Finally, I am grateful for the financial support provided by the Department of Agricultural Economics, University of Saskatchewan.

This thesis is dedicated in memory of my father, Taeïb Haggui, my first and best teacher.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1 : INTRODUCTION

1.0 Background

After rice, wheat is the most important food staple; it is widely produced, consumed and traded worldwide (Antle and Smith, 1999). The rate of growth of wheat yields is decelerating at an increasing rate in developing and developed countries alike[1]. This deceleration is occurring despite the continued development of high-yielding varieties. This trend reinforces a predominant fear that we may be reaching a yield plateau in the case of wheat (Pingali, and Heisey, 2001), and that future global supply may be inadequate to meet the future demands of an increasing world population.

Over the past decades a large body of research has highlighted the severity of the food inadequacy for a significant portion of the rapidly expanding global population and that future global food demands might outstrip global food production (Kendall and Pimentel, 1994; Ehrlich and Ehrlich, 1990; Brown and Kane, 1994). Although the world has achieved a substantial increase in per capita food supplies globally over the last decades, 842 million people, most in developing countries, remain chronically undernourished (FAO, 2003). Lack of food security and widespread under-nutrition are likely to persist and remain unsolved problems for a significant numbers of people in the

---

[1] This is demonstrated in the next chapter.

world in the coming decades (Chrispeels, 2000). It has been estimated that average cereal yields must increase by 80% over the 1990 level in order to meet food demands in 2025 (Serageldin, 1999).

Ensuring food security for the global population will be more challenging if climate change occurs. In the face of climate change food production has to double in the next 35 years to meet future needs (Watson, 2001). There is a high degree of uncertainty associated with estimating climate change and climate change impacts (Parry *et al*, 1999; Wilson, 2001). Although some researchers predict that the overall effect of climate change on food supply will be negligible on a global scale (Adams and Hurd, 1999), there will be large regional variations. Climate change will have adverse effects on poor people in the tropics and subtropics, where agriculture is the main industry (IPCC, 2001). Those affected people are the already food-poor people. In Africa, climate change is expected to depress cereal production by as much as 3% by 2030, exposing 10 million more people to the risk of hunger (FAO, 2002a). Agricultural production will have to adapt quickly to this more volatile climate if a stable food supply is to be maintained.

The combination of agricultural biotechnology[2] (GM wheat in this case) and conventional plant breeding might lead to very encouraging results in plant improvement (Jauhar and Khush, 2001) leading to more abundant food. Agricultural biotechnology can be a tool in the fight against hunger under more volatile climate (FAO, 2000), because it permits the development of new crop varieties with higher productivity, higher nutrition and better adaptation in difficult growing conditions (Pierce, 1999).

GM food faces considerable opposition, especially from consumers in Europe and Japan. This aversion to GM food is based on concerns over potential health risk, environmental effects, ethical concerns, and lack of consumer benefits from first generation of GM crops (Noussair *et al*, 2004). This aversion is magnified by consumer mistrust in the ability of government regulatory systems to ensure a safe food supply. In response to the opposition to GM food by consumers and lobby groups, the EU has enacted legislation that requires labeling for all GM foods leading to trade restriction of GM food products.

The EU intolerance to GM food in general (including GM wheat) is sending a signal to other countries (importers as well as exporters) that the debate over GM foods is still on and that the market may not yet be ready for new GM products. Consumer and environmental concerns in the EU could spill over into developing countries regardless of whether they are importers or exporters of agricultural products (Nielsen *et al*., 2001) making them more resistant to the import as well as the adoption of GM crops (Diaz-Bonilla and Robinson, 2003; Paarlberg, 2001; and Qaim and Virchow, 2000)**.** For example, in 2002, Zambia decided to reject food aid of American corn due to concerns over the presence of GM seeds, which if planted could 'contaminate' their crops and jeopardize the country's exports to countries that accept only GM-free foods (Washington Post, 3 August 2002). In the case of GM wheat, several importers have already stated that they would not import GM wheat or even conventional wheat from the US and Canada if GM wheat is commercialized (Canadian Wheat Board, 2003; and US Wheat Associates, 2002).

---

[2] In this thesis the term biotechnology is restricted to genetic modification technique (See Persley and Doyle, 2001) for

For wheat exporters such as Canada and the USA, the fact that the EU is a wheat exporter and does not tolerate GM wheat is a threat to some of their export markets, as the EU may be able to guarantee competitively priced GM-free exports. Both Canada and the USA have lost a significant share of their export to the EU to their competitors due to the introduction of GM traits into some crops other than wheat (Phillips, 2003a). The probability of occurrence of this phenomenon in the case of wheat is high, since major wheat exporting countries such as Australia have already asserted that they can supply GM free wheat for the international markets (GENET-news, 2000). Therefore it is highly possible that potential adopters of GM wheat such as USA and Canada will hesitate to adopt this technology – at varying degrees– depending on the degree of opposition toward GM wheat induced by the EU worldwide. The reduction in the adoption of new GM crops such as GM wheat due to this opposition may reduce the benefits (in terms of food security) that this technology may offer.

1.1 Problem statement

There is an ongoing fear that the world's food supply cannot meet the demands of the growing world population. Many countries and many people continue to see food insecurity as a threat to their futures and even the future of humankind. Countries that are heavily dependent on imports, including Japan and Korea, continue to support domestic agricultural research and production, based mainly on food security concerns. For many less-developed countries, such as India and China, food security continues to be an issue of national priority. For the poorest countries, food security is a very real day-to-day problem for many of their citizens (Pinstrup-Andersen, 2001a).

---

more details.

GM technology may help the world to reduce food insecurity through increasing food availability assuring a greater food supply, food stock, and lower, more stable world prices. This technology, however, is under pressure from consumers in developed countries (especially in the EU) due to health, environmental and other concerns. This opposition toward GM products may spill over into developing countries making them more hesitant to import or adopt GM crops. This opposition might further discourage the adoption of new GM crops by potential adopters, reducing the benefits (in terms of food security) that this technology may offer. However, it is unknown what the impact that opposition to GM crops will have on global food security.

1.2 Objectives

The goal of this thesis is to evaluate the impact of consumer opposition to the adoption of GM wheat, with particular focus on European opposition and to the realization of its benefits in terms of global food security. A number of scenarios are analyzed to consider the range of potential effects for the European opposition on global food security. The specific objectives of the thesis are to:

- Illustrate the gravity of the food security problem globally, examine the role of new technology including biotechnology, to help solve this problem and explain the relationship between biotechnology and food security;
- Derive a GM adoption model enabling the estimation of impact of GM market acceptance on GM adoption rates
- Develop a long run stochastic model of the world wheat market.

- Develop a global food security model that incorporates the dynamic economic responses to opposition to GM food by integrating the adoption model and the market model
- Estimate the impacts of the EU policy on global adoption of GM wheat and on global food security under a number of opposition and climate change scenarios.

Achieving these objectives should provide an objective assessment of the relationship between the consumer acceptance of biotech and global food security. It may also uncover important aspects of the relationship ignored or under-emphasized due to the ongoing debate over agricultural biotechnology.

1.3 Methodology

First, I identify the scale of the global food security problem and demonstrate the role for a technology such as GM wheat to produce higher and more stable yields helping to achieve a more food secure world. However consumer opposition might affect the adoption and the diffusion of this technology and diffusion of this technology, reducing its potential benefits in terms of food security. Therefore, I developed from the literature a GM adoption model based on GM corn that incorporates consumer response into the adoption decision of GM product. This adoption model is combined with a market model (developed as well from the literature) to compute a global food security model that allows dynamic economic responses to opposition to GM food as well as to production shocks, such as climate change. The global food security model is calibrated using production, consumption and price data for wheat.

The model is used to examine global food security in several opposition scenarios under two climate change assumptions. The comparison between scenarios leads to estimates of the impacts of the EU policy on food security. In all scenarios, it will be assumed that agricultural biotechnology will be able to develop GM wheat with new multiple traits (e.g., pest resistance and tolerance to abiotic stresses), which could increase the yield growth rate.

CHAPTER 2 : FOOD SECURITY, ENVIRONMENT AND AGRICULTURAL BIOTECHNOLOGY

2.0. Introduction

This chapter aims to clarify the connection between food security, the environment, technical change (GM crops), and consumer opposition to new technology. While global food security may be worsening due to several environmental effects, GM crops may have the potential to produce higher and more stable yields achieving a more food secure world. However, consumer opposition to GM crops may affect the adoption and diffusion of this technology, preventing the harvest of potential benefits in terms of food security.

Wheat is chosen as a case study because it is the second most important food staple after rice and is widely produced, consumed and traded worldwide (Antle and Smith, 1999). Whatever the result of the debate over GM wheat, it will shape the future of GM technology and the future of our food.

Past trends of wheat yield growth signal the existence of a decelerating effect in most regions in the world. Along with the decrease in average wheat yield growth, the wheat yields are increasingly variable in many regions. These two factors pose major problems for both global and local food security. This raises the fear that future wheat supply will fall short of future wheat demands. By 2020, wheat demand worldwide is expected to increase by 40% from its level in 1997 (Rosegrant *et al*. 1997) and less-developed countries will double their grain imports, including wheat, by 2020 (Pinstrup-Andersen *et al*., 1999b).

Pinstrup-Andersen and Schioler (2001) argue that conventional technologies might contribute about 70% of the technological advances needed to meet the world food program targets. Biotechnology offers one way to make up the shortfall. Better understanding of the wheat gene map, use of molecular markers to accelerate the development of better wheat varieties and transgenic modifications to incorporate new traits could help to reverse or slow these worrying trends. However, the opposition facing the introduction of GM wheat may affect its worldwide adoption and prevent the realization of such benefits.

2.1. Food security problems

2.1.1. Global food insecurity problems

The world has made significant progress over the last decade in decreasing the incidence of undernourishment in the developing world, most recently lowering the rate to 17% in 1997-1999 from 20% in 1990-1992 (See Table 2.1).

Table 2.1 – Incidence of undernourishment, developing countries

	Million people		% of total population	
	1990-92	1997-99	1990-92	1997-99
Developing Countries	815	776	20%	17%
Sub-Saharan Africa	168	194	35%	34%
Near East and North Africa	25	32	8%	9%
Latin America and Caribbean	59	54	13%	11%
South Asia	289	303	26%	24%
East Asia	275	193	16%	11%

Source: FAO (2002a)

However, as noted in the latest issue of the State of Food Insecurity in the World

(2002a), 840 million people remain chronically undernourished despite the substantial increase in per capita food supplies globally. Over 95% of undernourished people are in developing countries, while 3.6% are in countries that are in transition, and 1.3% are in industrialized countries.

In 1990-92, as well as in 1997-99, Sub-Saharan Africa was the region with the highest incidence of undernourishment. In both periods, over one third of the total population of Sub-Saharan Africa was undernourished. South Asia and East Asia also have high rates of undernourishment at 26% and 16% respectively. South Asia had the highest absolute number of undernourished people (39% of all undernourished people in the world), followed by Sub-Saharan Africa with 25% (Table 2.1).

Although most developing countries have achieved a proportional decrease in undernourishment since 1990 (see Table 2.1), the absolute number of undernourished people continues to rise in some regions because of rapid population growth. In Sub-Saharan Africa, for example, despite the 1% decrease in the percentage of the undernourished population between 1990-92 and 1997-1999, the absolute number of undernourished people has jumped by over 15% from 168 million to 194 million. The total number of undernourished people in developing countries has decreased by 4.8% between 1990-92 and 1997-99 from 815 million to 776 million. This represents a decrease by 39 million since 1990-1992 (the benchmark period of the World Food Summit in 1996 (FAO, 1996a), corresponding with an average decline of six million per year. To achieve the World Food Summit 1996 goal to halve the number of hungry people by 2015, the annual rate of decrease of undernourished people should be 24 million, or over four times the current pace (FAO, 2002b)

In 2002, 34 countries needed emergency food aid, compared to 21 countries in 2001. The most food-insecure countries are on the African continent, (east, south, and central) mostly due to bad weather, political conflicts, and the impact of HIV/AIDS. The food crises in countries such as Zimbabwe, where half of the population needs emergency food aid, pose a special challenge (FAO, 2002c)

Food assistance is also needed in many Asian regions, such as North Korea and Mongolia, often because of floods and droughts. In Afghanistan, a large percentage of the population depends on food assistance due to the instability caused by recent wars and droughts. In the West Bank and Gaza Strip, military operations limit the movements of families and cause severe food crises. In Iraq, the recent war has worsened the already fragile food security caused by the economic sanctions imposed by the UN (FAO 2002a).

In Latin America the food situation is still critical, especially in El Salvador and Guatemala. Food insecurity is also affecting several countries from the Former Soviet Union (Georgia and Tajikistan), the Federal Republic of Yugoslavia, and Chechnya.

2.1.2.The concept of food security

Food security has been defined in several ways. The FAO (1985) states that "the ultimate objective of food security is to ensure all people, at all times, are in the position to produce or procure the basic food they need and that it should be an integral objective of economic and social plans".

More recently food security has been defined as a state of affairs where all people at all times have access to enough safe and nutritious food to maintain a healthy and active life (World Bank, 1986; FAO, 1996).

The factors that determine the degree of food security in any region or zone are food availability, access to food by all people in that region, and nutritional adequacy (Lacy and Busch, 1986; FAO, 1998). The ‘availability’ of food is viewed as sufficient supply of food with appropriate quality to cover the requirements of a population in both the short and the long term. Availability also implies that the food supply is stable in the face of environmental changes and other social or climatic disturbances. Food availability is directly dependent on the productivity of grains, roots and the tubers, and stability of their yields (Izquierdo, 2000). Food availability depends not only on the ability of a country to produce but also on its ability to import food to meet the local food demand.

Food availability is not a sufficient condition for achieving food security (Smith, 1998). Poverty and food access are recognized as the major causes of people’s food insecurity (Maxwell, 1996; Seragildin, 1995; Alexandratos, 1995; Smith *et al*, 2000). The emphasis on access to food is identified with the influential study by Amartya Sen, 1981 who introduced “entitlements” approach to food security. The dimension of ‘accessibility’ encompasses the ability of consumers to purchase or obtain the food they need. Accessibility is directly related to the price of food as well as the purchasing power of consumers, and can be greatly affected by political and economic stability.

The third essential element of food security is ‘adequacy’. Adequacy means that consumers should have access to a sufficient and sustainable food to maintain a healthy and active life, in the short as well as in the long term (D. Maxwell, 1996).

Poverty, insecurity, instability and distribution are in most cases the main causes of food security problems (UK Institute of Food Science & Technology 1999, Lappe *et al*, 1998). Therefore, it is an oversimplification to consider food insecurity as simply a lack of food availability. Furthermore, the increase of food availability to meet the food requirements of developing countries with surpluses from developed countries could be difficult logistically, and may not insure a solution to the food security problems (McCalla, 1994). Most countries are food insecure because they are unable to import food due to lack of foreign exchange. To be effective, the increase of food availability may need to mainly come from a decrease in the food deficit of the countries themselves (Brown, 1995).

2.1.3. Wheat and global food security

Wheat is one of the world's major cereal crops, accounting for over 20% of global consumed calories in 1997 (Pardey *et al*, 2000). The dependence of the world population on wheat as a source of calories remains high over time (See Appendix A for more details on this topic). People in different regions of the world still depend on wheat as one of the most important staple crops. Since 1961, wheat has remained a major source of food supply for an increasing population in both the developing and developed world. Wheat still offers over 30% of the quantity of food supplied (in terms of weight) for individuals in the developed world, and over 20% of the quantity of food supplied for individuals in the developing world (Figure 2.1).

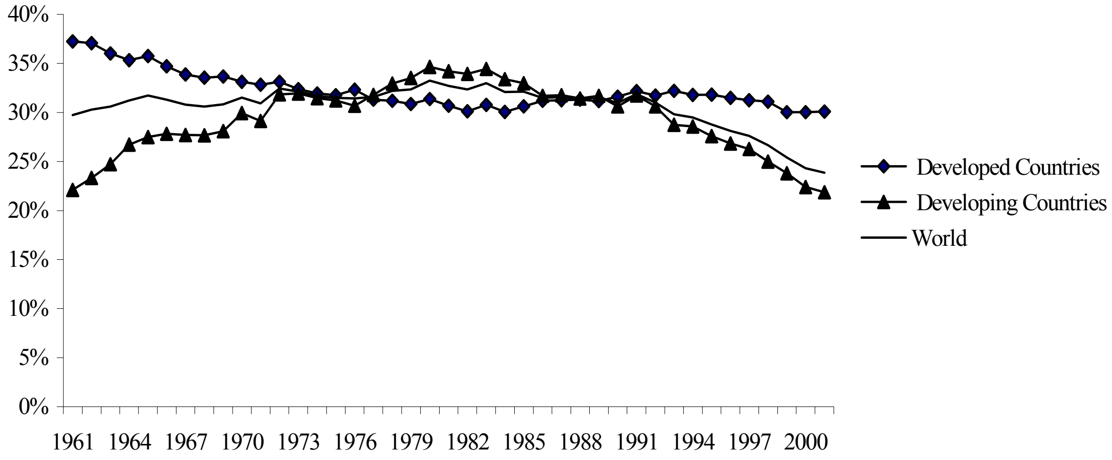


Figure 2.1 – Wheat contribution to total food supply.
Data from FAO.

Data for world wheat production, consumption, trade and stocks for the period 1960-2000 are taken from the USDA (details are presented in Appendix A). As shown in Figure 2.2, world wheat production has exceeded the world wheat consumption with the exception of periods at the beginning of the 1960s, the mid-1980s and the mid-1990s. Most of the increase in world wheat production between 1960 and 2000 has been the result of a significant increase in yields.

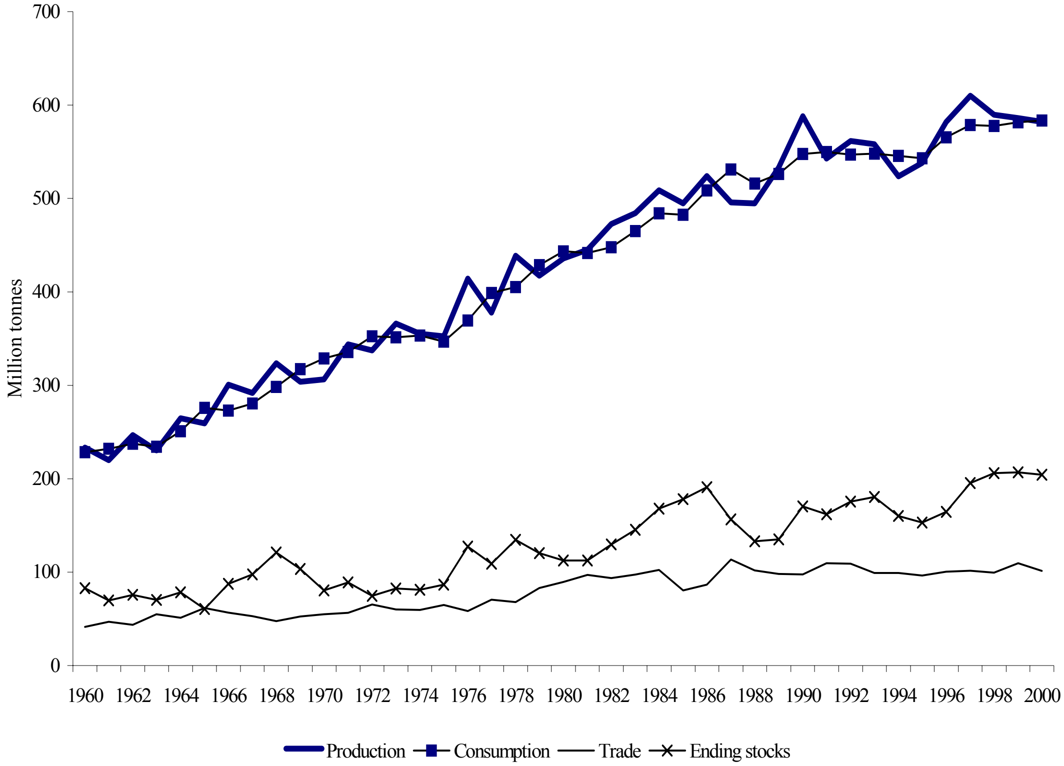


Figure 2.2 – World wheat production, consumption, trade and ending stocks, 1960-2000 (in million tonnes).

World wheat trade did not fluctuate much over the period 1960-2000, staying approximately at 18% of world production. World wheat stocks, however, fluctuated between 1960 and 2000, rising to 35% of world consumption in 2000, reaching levels not seen since 1960. World wheat consumption has increased by 1.5 times during 1960-2000. Wheat production has increased by a similar magnitude between 1960 and 2000 (Figure 2.2).

The increase in wheat production occurred despite the downtrend of wheat acreage worldwide (Figure 2.3). The downtrend of wheat acres is due mainly to the significant decline in wheat acreage in China, the biggest producer in the world. The increase in global wheat production between 1960 and 2000 was due to the steady yield growth, which accounted for 86% for the increase in food production in the world (Evenson and Gollin, 2003) .The yield growth is attributed largely to the development of high yielding varieties and input intensification (Pingali and Heisey, 2001). However the yield growth in many regions of the world is declining at an increasing rate (Figure 2.3). Another cause of concern is the fact that wheat production leveled off during the 1990s (Figure 2.2). In fact, since 1997/1998, world wheat production has been decreasing and was below consumption in 2000/2001.

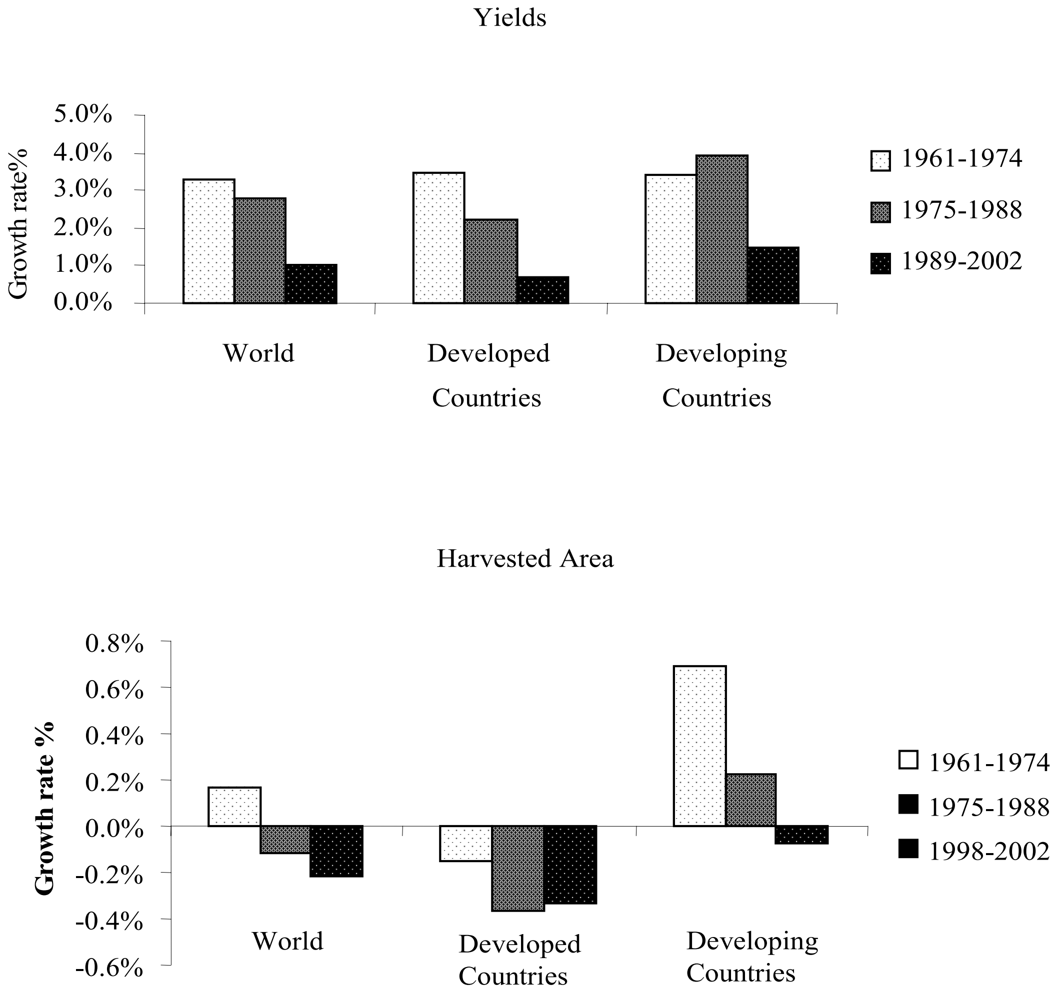


Figure 2.3 – Annual growth rate of wheat yields and harvested area, 1961-2002. (Calculated using Data from FAO)

As world wheat production, consumption, and trade change, wheat prices have varied as well. Real wheat prices are presented in Figure 2.4. The world wheat price is estimated by the average of US dollar-denominated free on board (f.o.b) Gulf of Mexico export price for US Hard Red Spring No2 (Antle and Smith, 1999). The prices have been converted to inflation-adjusted terms using the US GDP price deflator index of 2000. In real terms, wheat prices have declined by more than 80% between 1980 and 1999, but have fluctuated over the years.

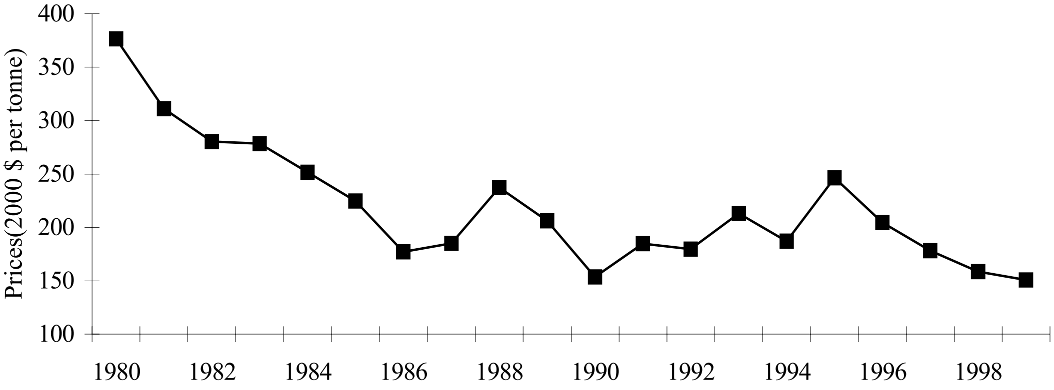


Figure 2.4 – Real world wheat prices, 1980-1999.

2.2. Environment

2.2.1. Climate change influence on food / wheat

There is a high degree of uncertainty associated with estimating climate change and climate change impacts on food (Parry *et al*, 1999; Wilson, 2001). Although the overall effect of climate change on food supply is expected to be small on a global scale (Adams and Hurd, 1999), there will be large regional variations. Climate change might decrease the world food supply, exposing more people to the risk of hunger (Parry *et al*, 1999). Climate change will have adverse effects on poor people in the tropics and subtropics, where agriculture is the main industry (IPCC, 2001). Those affected people are the already food-poor people. In Africa, climate change is expected to depress cereal production by as much as 3% by 2030 exposing 10 million more people to the risk of hunger (FAO, 2002b). Agricultural production will have to adapt quickly to this more volatile climate if a stable food supply is to be maintained.

2.2.2. Concerns over future wheat yield variability

The yield variability for wheat has decreased globally from 1961 to 2002, both for developed and developing countries (Table 2.2). Globally the average percent deviation has decreased significantly from 4.1% to 2.6%. Although yield variability has declined for developing countries between the 1961-74 and 1989-2002 periods, there was a significant rise in variability in the 1975-1988 period. This pattern is similar to that of Asia developing and Africa developing regions. Both regions have observed a significant drop in variability between the later two periods (Table 2.2).

Table 2.2 – Yield variability coefficients, 1961-2002.

	Average percent deviation from trend[a]			Tests of significance between periods[b]		
Region	Period 1 1961-1974	Period 2 1975-1988	Period 3 1989-2002	1 and 2 F1,2	1 and 3 F1,3	2 and 3 F2,3
World	4.1%	4.1%	2.6%	1.34	8.54**	6.40**
Developed Countries	5.6%	5.1%	3.9%	2.22	11.03**	4.96**
Developing Countries	3.5%	5.0%	2.8%	0.73	4.63**	6.38**
European Union (15)	5.4%	6.1%	4.0%	0.99	6.89**	6.94**
Transition Markets	11.7%	11.0%	12.0%	2.72*	3.83*	1.41
North America	8.7%	6.6%	8.0%	3.60*	2.54	0.70
Canada	20.8%	14.8%	11.6%	2.40	4.42**	1.84
U.S.A	6.9%	6.1%	7.7%	1.62	1.79	1.11
Central America	9.6%	5.6%	6.2%	5.49**	4.19**	0.76
South America	11.6%	9.8%	6.8%	1.60	1.41	3.48*
Africa Developed1	16.5%	19.7%	13.7%	0.95	0.54	0.57
Africa Developing	10.4%	10.5%	8.2%	0.43	1.71	4.01**
Asia Developed2	22.1%	7.1%	8.1%	2.97*	7.23**	2.43
Asia Developing	4.2%	5.0%	2.9%	1.08	6.32**	5.86**
Oceania	17.7%	23.6%	22.0%	0.54	0.65	1.21

[a]Standard error from regression: lnYield = a + bt . [b]Significance is tested using F-Test Two-Sample for Variances. **Significant at 1%. * Significant at 5%. Source: Author's calculation from FAO data.

Other regions, such as Central America, and even North America, have observed an increase in yield variability between the 1975-88 and 1989-2002 periods. Although this increase was not significant, it is somewhat alarming as North America is among the biggest exporters in the world. Many Former Soviet Union states are also traditional large wheat producers. A small increase in yield variability in such key regions may lead to a significant decline in food availability and a spike in wheat prices, worsening already fragile global food security.

Due to climate change and the possibility of reaching a yield plateau with conventional varieties, it is possible that the pattern of increased variability for wheat will be more common worldwide and more significant in the future. Climate change may already be having an effect. In 2002/2003, Australia and Canada were devastated by drought, while East Europe (especially Romania and Hungary) were hard hit by a heat wave. Adverse weather also affected USA wheat in 2002/2003. Some researchers link these events to climate change. Adverse weather may not only reduce wheat yields but also wheat acreage because bad weather could discourage farmers from continuing to farm.

The decrease of global acreage, decelerating yield growth and the potential increased yield variance in several wheat producing countries might imply that future wheat supplies will be less stable and may not meet the demand of the increasing global population. There are several approaches to address decreased food security including soil and water conservation practices, modified crop rotations, and agronomic innovations such as developing new crops with higher yields. Pinstrup-Andersen and Schioler (2001a) argue that conventional technologies might contribute about 70% of the technological advances needed to meet the world food program targets. Biotechnology offers one way to make up the shortfall. Better understanding of the wheat gene map and the use of molecular markers to accelerate the development of better wheat varieties could help to reverse these trends.

2.3. Technical change

2.3.1. Past trends in wheat yields

Yield per hectare is the most commonly used indicator in measuring cereal crop productivity and potential for future growth in developing countries (Pingali and Heisey, 2001). This section assesses the growth and variability of wheat yields at the global level, since in addition to the reason mentioned above, yield is a major explanatory factor for production variability and directly reflects the effect of climate and technological changes (Naylor *et al*, 1997).[3] Acreage increase, yield gains, multiple cropping, and substituting lower yielding crops with higher yielding crops are the four main avenues to increase crop production (Evan, 1993).

Time series data (1961-002) of wheat yield for the world and different region were taken from the FAO. The period 1961-2002 is divided into three equal periods, period 1─ 1961-1974, period 2 ─ 1975-1988, period 3 ─ 1989-2002. In each period the natural logarithm of yield for each region is regressed against time. The slope coefficient b is the annual yield growth. As revealed in Table 2.3, almost all regions have experienced a significant increase in wheat yield. The global yield almost doubled between period 1 and 2. Global yields rose annually by around 2.3% between 1961 and 2002. In the first period, the yield growth rate in developing countries was slightly

---

[3] To understand the relation between grain yield instability and production variability see: Hazell 1985,

smaller than that of developed countries. However, yield growth of developing countries was 2.25 times that of developed countries in the final period.

2.3.2. Concerns about future wheat yields

Global wheat yield growth is decreasing at an increasing rate, including developing and developed countries, as well most geographical regions (Table 2.4). Worldwide, yield growth has decreased by 15% between periods 1 and 2, while it has decreased by 64% between the second and third periods (see Table 2.4). The same trend is observed for the EU, Transition Markets, and developing Asia. Central America, North America, Canada and developed Africa (e.g. South Africa) experienced an increase in yield growth rate between period 2 and period 3. The rest of the regions (including developing Africa) experienced an obvious decrease in yield growth between period 2 and period 3. The yield growth deceleration in developing Africa is due to the limited use of modern inputs and diminishing return due to continuous cropping (World Bank, 1992).

1989, Singh and Byerlee 1990; and Anderson et al. 1988.

Table 2.3 – Annual growth rates and annual average of wheat yield, 1961-2002

		Periods					Periods	
		1	2	3		1	2	3
Regions	1961-2002	1961-1974	1975-1988	1989-2002	1961-2002	1961-1974	1975-1988	1989-2002
	Annual average yields(hg/kg)				Annual growth rate of yields			
World	19,956	13,945	19,980	25,943	2.26**	3.29**	2.81**	1.01**
Developed Countries	21,298	15,980	21,403	26,509	1.87**	3.49**	2.21**	0.66*
Developing Countries	17,960	10,616	17,990	25,272	3.11**	3.40**	3.95**	1.49**
European Union (15)	40,428	26,184	40,351	54,750	2.69**	3.64**	3.60**	1.15**
Transition Markets	17,169	13,324	17,670	20,514	1.67**	4.66**	2.07*	-0.15
North America	21,340	17,863	21,662	24,494	1.16**	2.41**	0.67	0.7
Canada	18,682	15,578	18,585	21,884	1.19**	2.89*	-1.18	-0.01
U.S.A	22,629	18,932	23,178	25,776	1.16**	2.17**	1.59**	0.96
Central America	35,818	25,590	38,685	43,180	2.00**	4.38**	1.65**	1.93**
South America	16,376	12,762	15,329	21,036	1.78**	-0.11	3.54**	1.62**
Africa Developed1	12,760	7,120	11,718	19,442	3.64**	3.87**	3.23*	6.66**
Africa Developing	13,094	9,238	12,171	17,872	2.30**	1.21	3.31**	0.81
Asia Developed2	27,466	23,659	28,130	30,609	0.98**	1.13	2.53**	-0.51
Asia Developing	18,340	10,317	18,530	26,174	3.36**	4.21**	4.00**	1.59**
Oceania	14,437	12,330	13,756	17,224	1.08**	-0.19	1.18	-0.05

[1] South Africa, [2] Japan and Israel. ** Significant at 1%, * Significant at 5%.

Source: Authors' calculation from FAO data.

Table 2.4 – Decelerating rate of wheat yield growth, 1961-2002.

	Coefficients of the regressions		
Regions	a	b	c
World	9.2752**	0.0366**	-0.0007**
Developed Countries	9.4257**	0.0338**	-0.0007**
Developing Countries	8.9336**	0.0481**	-0.0008**
European Union (15)	9.8590**	0.0430**	-0.0007**
Transition Markets	9.1811**	0.0417**	-0.0012**
North America Developed	9.6181**	0.0237**	-0.0006**
Canada	9.4482**	0.0267**	-0.0007*
United States of America	9.6844**	0.0226**	-0.0005**
Central America	9.8263**	0.0468**	-0.0012**
South America	9.3997**	0.0030	0.0007**
Developed Africa	8.6417**	0.0251**	0.0005
Developing Africa	8.9855**	0.0169**	0.0003
Developed Asia	9.9142**	0.0207**	-0.0005
Developing Asia	8.8461**	0.0566**	-0.0011**
Oceania	9.3724**	0.0033	0.0003

** Significant at 1%, * Significant at 10%. The coefficients (a, b, and c) are taken directly from regression $\mathrm{Ln(yield)} = a + b\,t + c(1/2\,t^2)$ for each region. Source: Authors' calculation from FAO data.

The coefficient c is a measure of the speed of change in yield growth with time. If this coefficient is positive, there is an acceleration effect meaning that yield growth is increasing with time. However, if this coefficient is negative, there is a deceleration effect meaning that yield growth is declining with time. Many attribute he significant decline of yield growth (the coefficient c) to resource degradation due to intensive cropping systems (Cassman *et al*., 1995; and Huang *et al*., 1995)

In developing countries, the percentage of the area planted with modern high yielding wheat varieties increased significantly, reaching 82% (of the area planted to wheat) in 1997 (see table 2.5). In the 1990s, the adoption rates of these modern varieties were highest in Latin America and Asia (more than 80%) and lowest in Sub-Saharan Africa (around 40%) (Evenson and Gollin, 2003). These modern varieties have played a major role in increasing wheat productivity. However, the decelerating effect of the yield growth has happened despite the high adoption rates and continued development of newer generations of high-yielding varieties (Sayre 1996).

Table 2.5 – Percentage cultivated area planted to modern varieties of Wheat [a] in developing countries, 1970-1997

	1970	1977	1983	1990	1994	1997
All developing countries	20[b]	41 [b]	59 [b]	70	78	82

Source: Byerlee and Moya (1993); CIMMYT (1996); CIMMYT wheat impacts database.
a Excludes tall varieties released since 1965. If these varieties are included, the area under modern varieties increases. b Excludes China.

2.3.3. Agricultural biotechnology: a part of the solution

Biotechnology is "any technique that uses living organisms, or substances from those organisms, to make or modify a product, to improve plants or animals, or to develop microorganisms for specific uses" (OTA, 1989). Agricultural biotechnology uses a wide range of processes such as genetic manipulation technology and recombinant DNA technology to exploit the biological potential of plants. Biotechnology facilitates the development of desired characteristics that are otherwise difficult or impossible to achieve through traditional plant breeding techniques. This is achieved by implanting foreign gene segments into the genetic structure of an organism or by modifying its existing genetic sequence in order to manipulate target characteristics (Persley, 1992; Roller and Harlander, 1998). In this thesis, the focus is on the use of modern biotechnology (specifically genetic engineering) in crop breeding.[4]

While genetic engineering may play a major role in solving the global food security problem, this technique has attracted a great deal of concern and criticism. This

---

[4] See Wolpers (1996) for more details about this technique.

section outlines concerns and risks that GM food may cause, and the potential it may offer to food-insecure people. Developing countries are desperate for whatever tools are available in the pursuit of food security. Consumers in developing countries have an urgent need for more food, and the priority for many is on how to obtain more food for these numerous hungry and food-deficient people.

There is general agreement that agricultural research and development has contributed very substantially to past agricultural productivity and have improved global food security (Alston, 2000). However, whether or not biotechnology will be allowed to play a role in achieving a food-secure world is still debatable. Pro-biotechnology groups often claim that GM crops have the potential to feed the poor, protect the environment, and reduce poverty in developing countries. Agricultural technology (biotechnology specifically) may affect global food security through several mechanisms. The four most important mechanisms are:

a) Increasing the availability of food through higher productivity and total food production.
b) Improving the access to food through more affordable food, which would help to increase and possibly stabilize food consumption.
c) Stabilizing food supply by helping crops adapt to exogenous shocks such as weather variability and possible climate change.
d) Developing food that is more nutritious.[5]

Agricultural biotechnology has enormous potential human and environmental benefits. The application of biotechnology could develop crops with improved resistance

---

[5] See Pinstrup-Andersen-Andersen (1984),; Pinstup-Andersen et al (1976) and Perrin and Scobie (1981) for example.

to insect and plant pathogen attacks, and crops with higher yields (Kendall and Pimentel 1994). This could improve agricultural performance (yields) with reduced use of pesticides, which would otherwise have a harmful impact on the environment and human health (Huang *et al* 2001). Along with permitting higher yields biotechnology might reduce farming costs as well (Traxler *et al*. 2003; and Ismael *et al*. 2001). Biotechnology may also offer farmers a greater ability to grow crops in inhospitable environments through increased ability of the plants to grow in conditions of drought, salinity and extremes of temperature and in the face of other consequences of global warming (Genome Prairie 2001). This can help food production to keep pace with the needs of growing populations, especially in developing countries. Biotechnology could also enhance taste and nutritional levels of staple crops, such as rice, which could then help combat widespread nutritional problems among the poor in developing countries (Pinstrup-Andersen *et al*, 1999b; CBAC 2001).

The above claims about the potential effects of agricultural biotechnology on food security in developing countries are viewed skeptically by many. The previously stated claims can be seen as extremely biased for several reasons. For example, developed countries remain dominant in the innovation and the use of biotechnology, as well as the opposition to GM food (see James, 2003)**.** Agricultural biotechnology efforts and applications have been mostly limited to solving problems facing farmers in developed countries (Pinstrup-Andersen *et al*, 1999b; Herdt, 1999). It is therefore most likely that the benefits of biotechnology will work to the advantage of the countries conducting the research rather than to poor countries, since the research will focus on improving crops of importance to those countries rather than to developing countries.

Technological effects as well as technology transfer are very slow processes, while food security is an urgent problem. At the present time most biotechnology innovations are profit-driven rather than need-driven (Altieri and Rosset, 1999, Phillips and Khachatourians, 2002), which could limit the benefit to poor countries from agricultural biotechnology research. It is also doubtful that significant discoveries made by private biotechnology companies will be made available quickly and inexpensively to poor countries (Byerlee and Fischer, 2000).

Despite the debate presented above it is possible under a favorable environment for agricultural research and adoption of its innovations (e.g. stable and good governance, availability of proper institutions and investment in infrastructure, research and rural infrastructure), that agricultural biotechnology may contribute to the improvement of global food security. This will happen if biotechnology focuses on solving the problems of small farmers and is committed to developing seeds that are affordable to farmers in developing countries (Pinstrup-Andersen, 2001b). Success ultimately could lead to both higher incomes for small farmers and lower food prices for poor consumers.

2.3.4. GM wheat research

Monsanto is a key company working on herbicide tolerant wheat and has undertaken more than 76% of total wheat field trials in the USA. Monsanto Company has conducted several research and development trials with GM wheat in selected Canadian Prairie Provinces and in several states since 1994. Until May 2004, Canada and the US were considering the approval of a Roundup Ready GM wheat variety; on May 10 Monsanto announced it was not proceeding with its new product. Monsanto's

GM wheat is produced through the insertion of a Roundup resistant gene (a gene from a soil micro-organism) into a hard red spring variety. This transformation makes wheat tolerant to glyphosate herbicide (Roundup). This wheat was expected to be available to farmers as early as 2005, but is now indefinitely postponed.

Herbicide tolerant wheat is attracting a lot of debate because it is undergoing review in the approval process in both Canada and USA. It is likely that other traits will have similar attention once they are close to the release stage. Syngenta Company in 2002 indicated that a fungal resistance variety may be released around 2007.

Global GM wheat research started around 1993 and its trends have been closely related to the degree of acceptance to the GM food technology. For the purpose of understanding this relationship, GM wheat field trial data was collected from several web sites.[6] Almost all field trials have been undertaken in wheat exporting countries. Canada and the USA dominate the GM trait research by being the location of over 45% of research in GM wheat traits each (Figure 2.5).

---

[6] Argentine data: http://www.sagpya.mecon.gov.ar/0-/index/programas/conabia/index_conabia.htm.
Australia data: http://www.health.gov.au/ogtr/index.htm, and www.oecd.org/ehs/biobin.
EU data: http://biotech.jrc.it/deliberate/gmo.asp;
USA data: http://www.isb.vt.edu/cfdocs/fieldtests1.cfm
Canadian data: http://www.inspection.gc.ca/english/plaveg/bio/triesse.shtml

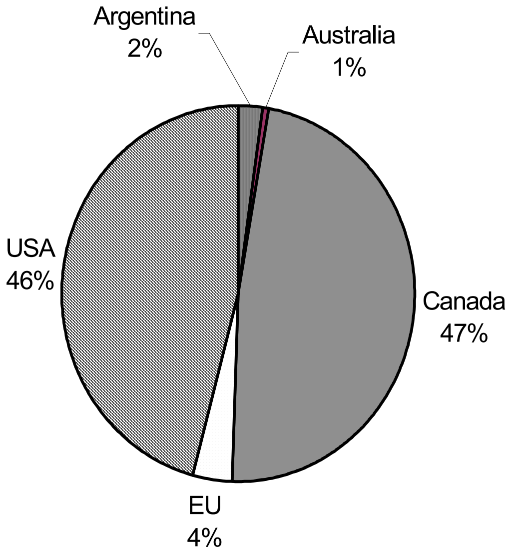


Figure 2.5 – Share of World GM Wheat Field Trials, 1993-2002
Source: please see footnote 6.

The number of GM wheat field trials in the world quadrupled from 1998 to 1999. This enormous increase is due to the significant increase of wheat field trials in North America, and especially Canada. In Canada wheat field trials increased over 9 times between 1998 and 1999, while in the USA the number doubled (see Figure 2.6). After 1999 the number of field trials decreased steadily to reach a level of around 100 in 2002. This decline may be related to the ban on approvals of genetically modified foods and crops by the EU since October 1998. However, it may simply be because the discovery work was done and researchers focused their limited investments on their candidate variety.

Figure 2.6 – Number of GM wheat field trials (1993-2002)
Source: please see footnote 6.

Herbicide tolerance (glyphosate tolerance) is not the only trait developed in the 1994-2002 period in the USA, this trait occupied over 65% of field trials. The herbicide tolerance trait is followed by fusarium (fungus which causes loss in crop yields and grain quality) resistance, virus resistance, agronomic prototype, product quality (improved digestibility, increased yield, storage protein altered), marker genes and others (see Figure 2.7).

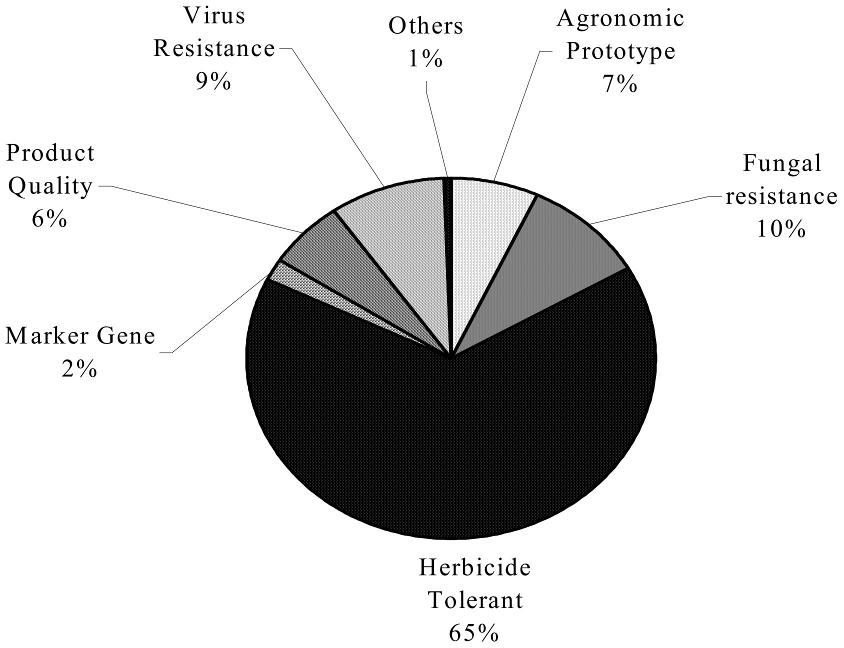


Figure 2.7 – Share of the USA GM wheat field trials by trait, 1994-2002
Source: please see footnote 6.

2.4. Adoption of GM crops and consumer opposition

The global adoption of GM crops has grown dramatically since 1996. In 2003, the global area of GM crops was 67.7 million hectares, a 40 fold increase in the global area of GM crops since 1996. In 2003, 7 million farmers in 18 countries grew GM crops. The number of acres planted with GM crops increased 11% between 1999 and 2000 and 15% between 2002 and 2003 (James, 2003). In 2003, the adoption of biotechnology remains geographically concentrated, with 94% of the global transgenic crop produced by four principal countries. The USA grew 63% of the global total, followed by Argentina (21%), Canada (6%) and China (4%). Globally, GM soybean occupies 61% of the total GM area, followed by GM corn at 23% (James, 2003).

The development and proliferation of GM crops was faced by some skepticism. Several studies indicate that the adoption of present GM crops has only modest benefits for farmers. A study done by the OECD (2001) indicates that gains from GM adoption in terms of yield increase are small. Furthermore, Malla, Gray, and Phillips (2004) concluded that marginal returns to research in biotechnology are relatively small due to large gestation periods and short periods of adoption. Moreover, consumer perceptions about acceptability of GM food has led to lower demand in some regions, particularly the EU (Evenson, Santaniello, and Zilberman, 2002; Gaskel, Bauer, and Durant, 1998; Kalaitzandonakes, 2000). This opposition to GM penetration in some markets along with expected small gains might have slowed the diffusion of GM crops in GM producer countries as well as in consuming countries.

2.4.1. Reasons for consumer opposition

GM crops developed so far, known as first generation traits, are perceived to have no benefit to the end-consumer. This negative perception is one of the major reasons for the strong opposition to GM food available to date (Moschini, Lapan and Sobelevsky 2000, Phillips 2003b, Gray *et al* 2001a). In addition, GM food has precipitated health concerns, generated debate about possible environmental damages that could threaten the sustainability of agriculture (CBAC 2001, Gray *et al* 2001a) and brought forward significant ethical unease (Thompson 2000). There is also concern that biotechnology could reduce agricultural diversity by promoting extensive mono-culture, which could make our food supply even more vulnerable to climate change (Altieri 1995).

The nature of regulatory oversight for GM wheat may be another reason for consumer rejection of new products. Foreign consumers do not appear to trust the regulatory systems in governments such as the USA and Canada, since those governments are perceived to be promoters of biotechnology and partners with biotech companies.

Another major reason for consumers to oppose GM food is the widespread perception that a few large corporations will be the primary beneficiaries of agricultural biotechnology (Phillips, 2003b and Gray *et al*, 2001a), and that those biotech companies have a supply-push strategy for the introduction or commercialization of their products. For example, biotechnology companies such as Monsanto have insisted on the continuation of the licensing process of GM wheat despite widespread concerns of consumers and farmers about the impacts of GM wheat. This accentuates the suspicion that the priority of biotechnology companies is commercial interests, regardless of farmers' opinions or interests, and that they will try to force GM wheat on the market.

Regardless of whether those concerns have a scientific base or not, they pose a serious obstacle to the introduction, commercialization, and diffusion of the new GM wheat technology. Consumers have the power to influence the decision of governments to import GM wheat or not. If a government does ignore the opposition of their consumers to GM wheat and approves import, consumers may simply use their purchasing power to express their rejection.

It is important to mention that the weights given to the different concerns as well as benefits associated with GM food depends on the level of wealth of those doing the weighting (NFSD, 2001). In other words, what an individual thinks about biotechnology is quite personal and depends on whether the individual needs this tool (biotechnology) or not. For people in developed countries, biotechnology may be a luxury, but for people in poor countries biotechnology may be an important component of a food security strategy.

2.4.2. EU effect on international perceptions of GM food

GM food faces considerable opposition, especially from consumers in Europe and Japan. This aversion to GM food is based on concerns over potential health risks, environmental effects, ethical concerns, and lack of consumer benefits from first generation of GM crops (Noussair *et al*, 2004). This aversion is magnified by the consumer mistrust in the ability of government regulatory system to ensure a safe food supply. In response to the opposition to GM food by consumers and lobby groups, the EU has enacted legislation that requires labeling for all GM foods leading to trade restriction of GM- food products.

The EU intolerance to GM food in general is sending a signal to import and export countries that the debate over GM foods is still on and that the market may not yet be ready for new GM products such as GM wheat. Consumer and environmental concerns in the EU could spill over into developing countries regardless of whether they are importers or exporters of agricultural products (Nielsen *et al*., 2001) making them more resistant to the import as well as the adoption of GM crops (Diaz-Bonilla and Robinson, 2003; Paarlberg, 2001; and Qaim and Virchow, 2000)**.** The EU's opposition to GM products may affect many countries stance regarding GM food through several mechanisms. The EU may demand food exporters to the EU to label their products or otherwise they may stop imports. This connection between the requirement of labeling and the continuation of exports to the EU has already affected Pakistan. There are reports that the EU threatened to stop importing agriculture products from Pakistan and other countries if these countries don’t implement labeling rules on feed and food exported to the EU (Daily Times, August 25, 2003).

Most developing countries have no technological ability to distinguish between GM-free and GM-based food. Under this condition many countries may be particularly cautious about importing or adopting any GM food, because they cannot deal with a dual system and cannot prove that their food is GM free once the system is ‘contaminated’ with GM food. Several countries may break from adopting or importing GM food due to fear that this may contaminate their production system and may jeopardize some of their exports to the EU. The EU has already warned Thai rice exporters that the EU may reject Thai rice if any GM organisms are found in it (Pinstrup-Andersen, 1999a).

The opposition to GM food has spread to some unlikely consumers. In summer 2002, Zambia and Zimbabwe rejected food aid despite the widespread famine in those countries. The Zambian decision to reject food aid for three million people was based on concerns over human health and the economic implications of GM food (BBC News, 17 August 2002). The Zimbabwe government has also rejected food aid of American corn due to concerns over the presence of GM seeds, which if planted could ‘contaminate’ their crops and jeopardize the country’s exports to countries that accept only GM-free foods (Washington Post, 3 August 2002). In another example from Africa, Uganda refused to grow a disease-resistant type of banana, fearing it would cost them exports to Europe (Angelo, 2003). India also rejected a large shipment of corn-soya blended food-aid from the US in January 2003 because it contained genetically modified food (Luce, 2003).

Furthermore, most developing countries do not have the ability to test for themselves whether GM food is safe or not, therefore they will have to defer to others. It is likely that many countries will follow the EU lead, rather than accept the US judgment, given that the US is perceived as gaining a direct advantage from promoting GM food. The EU stance vis-à-vis GM wheat will be taken as a message that GM food is not safe, which might lead many importing countries to import more expensive GM free foods to avoid the perceived risk of GM food.

2.4.3. Effect of opposition on the adoption and diffusion of GM crops

Many food-exporting countries are conscious and hesitant to adopt GM crops due to the experience of North American farmers losing some EU markets because of the adoption of GM crops. Following the introduction of GM soy, corn and canola in North America, these product exports have faced resistance, especially in the EU. This appears to be seriously altering the trade of these three crops[7]. Market resistance to GM food caused key GM adopters such as Canada and the USA to abandon or divert their exports to new markets (Phillips, 2003a) causing the two countries a great deal of economic losses. The U.S has lost 70% of exports of corn to the EU, and 48% of its exports of soybeans to the EU. In Canada the introduction of GM canola had cost the country 96% of its canola export to the EU. At the same time the EU has developed new GM-free markets, such as Brazil for soybeans and Australia for canola (Phillips, 2003a).

A GM Herbicide Tolerant flax variety developed in early 1990s was the first GM flax crop to receive regulatory approval in Canada (McHughen 2000), but industry fears of losing the EU market, which represented 90% of the export market, caused the GM flax to never be commercialized.

---

[7] For examples see Sustainability Council, February 2003. Market Rejection of GM Foods: the US experience. www.sustainabilitynz.org.

The discovery of StarLink[8] in 2001 in U.S. corn has led to a significant decline in Japan's corn imports from the United States. Meanwhile a dramatic increase in imports from China and South Africa took place. The StarLink case also caused a movement to zero tolerance against the imports of unapproved GM products in Japan. The StarLink incident helped strengthen the opposition of Japanese consumers to future imports of GM wheat (GENET-news, 2001).

2.5. GM wheat and international trade

2.5.1. Major exporters

Relatively few nations account for most of the wheat exports. Argentina, Australia, Canada, the EU, and the USA are the five key wheat exporters in the world. These countries account for 37.6% of total production and 85% of trade (see Table 2.6). As shown in Table 2.6, Australia, Canada and Argentina have a small share of global wheat production, but their low local consumption permits them to be large net exporters. EU and USA are net exporters despite large local consumption because they have a significant share of global production.

Table 2.6 – Key exporting countries for wheat (ten year average from 1991-2000, thousands of tonnes)

Key Exporting Countries	Ten Year Average Production	Share from Total Production	Ten Year Average Export	Share from Total Export
Argentina	12,610	2.2%	7095.24	7.3%
Australia	17,922	3.1%	12874.8	13.2%
Canada	26,861	4.7%	15427.13	15.8%
USA	63,099	11.0%	31259.1	32.0%
EU	94,047	16.5%	16532.3	16.9%
World	571,050	100.0%	97818.4	100.0%

Source: (FAO, Canada Grains Council, 2002; and Author's calculations)

---

[8] StarLink is a genetically altered corn variety, which had not been approved for human consumption.

Many large wheat producers are not net exporters. This is because the largest producers, such as China, India and the Former Soviet Union, are also the largest consumers. For example, China is the largest producer as well as the largest consumer of wheat (1999-2001). Whether or not future wheat production in China exceeds Chinese wheat consumption will have a major effect on world markets and wheat prices, affecting the state of global food security.

2.5.2. Trade linkages to potential "rejecters" countries

While GM wheat was engaged in the approval process (before May 2004), several importers had already expressed to the USA and Canada their refusal to import GM wheat or even conventional wheat if GM wheat is commercialized. The Canadian Wheat Board, which represents 85,000 western Canadian farmers, reports that 82% of its customers have indicated that they will reject the import of Canadian wheat once GM wheat is introduced (Canadian Wheat Board, 2003). The US Wheat Associates conducted a survey of buyers to determine the willingness of buyers to accept GM wheat and they received a similar response (Gillam, 2002). Their Asian wheat market survey indicates that all of the Japanese, Chinese and Korean, 82% of Taiwanese and 78% of the South Asian buyers had indicated they will reject GM wheat. Japanese buyers state they have zero tolerance to trace contamination, regardless of Japanese government regulation, while a third and quarter of Chinese and Korean buyers respectively have expressed limited tolerance to trace contamination. More than 31% of all respondents cited consumer rejection to biotechnology as the reason for their opinion, while 30% of the respondents indicated food safety issues as the reason of their stance regarding GM wheat (Forsythe, 2002). However, some developing Asian markets such as Indonesia indicated they would accept GM wheat, since they expect it to be cheaper than the conventional varieties (Cropchoice, June 17, 2003).

The opposition of foreign consumers to GM wheat ought to be taken as a very serious issue for several reasons. First, there are several exporters that may offer GM-free wheat, which gives no incentive for importers to buy wheat from GM wheat producing countries because their wheat exports may be contaminated. Second, the intolerance to GM food remains high in the EU.

The Eurobarometer survey by the European Commission in 2003 found that more than 68% of consumers in countries that joined the EU in 2004 reject GM food, with more than half believing the GM food to be dangerous (The Economist, 2003).

The Eurobarometer (1998) opinion poll published by the European Commission in December 2001 showed that 94.6 per cent of European citizens want the right to choose and 70.9 per cent simply do not want GM food. Third, wheat is intended mostly for human consumption and it is unlikely that GM wheat products will escape the labeling rules (highly processed GM products from soy, canola and corn often are exempted from labeling because their novel proteins are removed during processing).

Several EU countries allowed the commercialization and importation of GM crops in the 1990s. However, the attitude of those governments has shifted due to growing consumer concerns over GM food. The consumer pressure has led to a 6 year moratorium on approval of any new GM foods. At the end of 2004, the EU may lift this moratorium. However, in exchange, the European Parliament has approved tough traceability and labeling rules. The new rules require traceability of genetically modified organisms at all stage of production, and the labeling of food exceeding 0.9 percent GM content as: "This product is produced from genetically modified organisms".

Once a GM crop is released, GM presence throughout the commercial grain handling system in the USA and Canada may make low levels of purity (below 2%) difficult or impossible to guarantee under any segregation system (Downey and Beckie, 2002). Due to the fear of potential economic losses due to the increased consumer opposition to GM wheat, many wheat producers, farmer organizations, agricultural academics, and other groups are expressing their concerns and opposition to the release of GM wheat.

Wheat farmers in countries considering the approval of GM wheat are nervous about losing their export market, possibly indefinitely. In May 2003, the Canadian Wheat Board asked Monsanto to withdraw its application to the Canadian Food Inspection Agency (CFIA) for environmental safety assessment of Roundup Ready wheat in order to avoid the economic harm that the release of Roundup Ready wheat may cause to the Canadian wheat industry. Monsanto initially refused to comply, insisting that farmers will benefit from GM wheat and that market acceptance will be addressed before the commercialization of Roundup Ready wheat (Network of Concerned Farmers, 2003), However Monsanto Ltd announced that it would cease to develop and commercialize its Roundup Ready variety of GM wheat on May 10, 2004.

The Australian Wheat exporter AWB has also expressed awareness of the anti-GM feeling in the international market. The AWB has asserted that they can supply certified non-GM wheat, and that they will not sell GM wheat in the near future (GENET-news, 2000).

A group of agricultural academics (Fulton, Furtan, Gray, and Khachatourians, 2003) at the University of Saskatchewan, in an editorial, urged the government of Canada to learn its lesson from BSE in licensing and commercialization of GM wheat.

The group of experts suggests that the experience of lost markets for Canadian beef because of one cow infected by BSE might be repeated for the Canadian wheat industry if GM wheat is introduced. The group indicates that licensing GM wheat will jeopardize the export market of Canada to the EU and Japan. The message of the group to Ottawa was very clear: "GM wheat may be great, but our markets don't want it. Listen up, Ottawa: We want those markets".

2.6. Conclusion

Agricultural resources are degrading and an increase in the productivity of those resources is needed to increase food production. Biotechnology may be a powerful tool to achieve a more food secure world. However, consumer concerns have to be taken seriously for those benefits to be achieved. Consumers should be insured against any potential problems that those alternatives could pose (FAO, 1999). Consumer acceptance is necessary for the development and realization of biotechnology benefits in agriculture. If consumer mistrust is not resolved, the benefits that biotechnology may offer will be proven to be empty promises, and categorized as propaganda.

The effects of biotechnology should be analyzed not only from the scientific and economic perspectives, but also from a human perspective. Food security is a humanitarian problem that biotechnology may play a role in solving. Fear of the unknown is a human trait, and GM food raises these fears despite the potential benefits. This study will assess the potential for fears of GM food to deprive the food insecure from a tool that could help them to ease their hunger and end their struggle to get enough food to survive.

The next chapter offers a review of the literature surrounding food security models, effects of technical change, climate change, and adoption model and identifies the gaps in the literature.

CHAPTER 3 : LITERATURE REVIEW

3.0. Introduction

In this thesis, four areas are combined to construct a global food security model that allows dynamic economic responses to opposition to GM food. These areas are: (1) food security; (2) environment effects on food security; (3) technical change or economic effects of GM crops; and (4) opposition to GM crops and the diffusion of this technology. This chapter reviews the literature in these areas, and identifies the limitations of that work. This chapter also highlights the complex nature of the relationship between biotechnology and food security, and shows this relationship depends on many factors external to biotechnology.

3.1. Food security models

The most commonly used food security models are designed to forecast future production, consumption, and prices. These forecast models include short, medium, and long run models. Three short to medium runs models dominate:

- The FAPRI baseline forecast model to the year 2005.[9]
- The OECD AGLINK forecast model to the year 2000.[10]

---

[9] See Antle et al, 1999 for more details about the FAPRI model

[10] See OECD, 1996 for application of the AGLINK model

- The Food Security Assessment Model (FSAM) developed by US Department of Agriculture (USDA).[11]

The International Food Policy Research Institute (IFPRI) operates a longer run model called the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) (Rosegrant *et al*, 1995)[12]. All of these forecast models are multi-commodity, multi-country econometric models, which permit the interaction between agricultural commodity markets and trade links between countries. The complexity of these models depends on the number of countries and commodities included in the analysis. Each of these models provide a system of demand and supply equations to forecast commodity prices.

All of these models make key assumptions, and modifying these key assumptions will result in new scenarios. The key assumptions usually include:

- Agricultural policies: This includes whether the present agricultural policies will change or not, or whether or not trade agreements such as WTO are binding with respect to a specific country or region.
- Global and individual country economic growth, as well as population growth: these assumptions along with endogenous changes in commodity prices determine demand.
- Yield growth and production growth for specific regions: These are used to determine the commodity supply.

---

[11] See Deininger and Shapouri 2003 for application of the FSAM

[12] For more details about this model see also Rosegrant et al 1997; Rosegrant et al 1998, Rosegrant et al 2001.

These models have several drawbacks. The first drawback is that they do not take into account the fact that both crop yield and production have shown a degree of stagnation, partially due to environmental degradation caused by agriculture (Conway, 1997). These models also have ignored environmental factors such as weather fluctuations, which could lead to sizable food production shortfalls and deterioration in food security in many parts of the world (see Pinstrup-Andersen *et al*, 1999b) The last drawback is that the effect of a promising agricultural technology, such as biotechnology, is never quantified in those models.

3.2. Effect of Climate Change

Assessing the effect that climate change may have on global food security is the subject of an abundant literature. Some researchers argue that the overall effect of climate change on food supply is expected to be negligible on a global scale. This argument is based on the assumptions that farmers will take the necessary measures to adapt to climate change, and by the beneficiary effect of the additional CO2 on yields (Adams and Hurd, 1999). However other researchers such as Grechen *et al* (1990) suggested that climate change will have a devastating effect on agriculture and the human population. He predicted that several hundreds of millions to a billion people could die of hunger in future decades because of climate change.

3.3. Effect of technical change

3.3.1. Economic effect of GM crops

The literature offers relatively few quantitative studies on GM crops and their global economic effect (Marra, 2001). This lack of economic research is due mainly to the limited information on the economic benefit of GM crops and the insufficiency of the multidisciplinary approach in the ex ante studies (Fishel, 1987; Havlicek, 1990; Chan-Halbrendt, 1996). Most studies trying to estimate the economic impact of the adoption of GM crops have used some measure of farm level effects. In most models, the study period was a single time period, and there is an assumed degree of GM-induced productivity growth, reduction in overall production costs, or increase in profit for the selected crops in regions included in the studies. Most of those studies calculated the aggregated benefits using the framework offered by Alston, Norton and Pardey (1998) for estimating changes in producer and consumer surplus due to technical change. This approach is inadequate for the study of the impacts of innovations such as agricultural biotechnology since those impacts are dynamic and are not constant over time (Abernathy and Utterback, 1978).

In their study of the global effects of Roundup Ready (RR) soybeans, Moschini *et al* (2000) assumed a US$20 per hectare increase in profit for farmers due the adoption of this technology. Flack-Zepeda *et al* (1999) have assumed supply shifts in the United States and the rest of the world (ROW) due to the adoption of insect tolerant (Bt) cotton and herbicide tolerant soybeans[13]. Nielsen and Anderson (2001) and Anderson *et al* (2001) assumed a 5% productivity growth due to the adoption of GM maize and soybean in different regions. Adoption of those maize and soybean was also estimated to reduce the cost of production by $9.5/acre and $6/acre respectively (Barkley, 2002).

---

[13] A gene of a soil bacterium called Bacillus thuringiensis (Bt) is inserted through biotechnology into the genome of a specific crop to give resistance to a selected variety of crop pests. Cottonne is so far the most widely commercialized Bt crop. Herbicide-tolerant crops are engineered to enable crops to resist doses of herbicides that would otherwise kill them. Roundup Ready crops are manufactured by the multinational company Monsanto, the producer of the herbicide known commercially as Roundup.

3.3.2. Estimated economic effect of GM wheat

3.3.2.1. Farm level impacts

There are several benefits associated with the introduction of GM wheat. According to Monsanto Ltd, Roundup Ready wheat has an 11% to 14% yield advantage over conventional wheat. Blackshaw and Harker (2002) indicated a wider interval of yield advantage ranging from 4% to 16%. Monsanto (2001), suggests that the use of Roundup Ready wheat will improve and simplify weed management resulting in some yield benefit. Roundup Ready wheat provides growers with a much simpler and more efficient weed control system (Monsanto,2001). With Roundup Ready wheat, farmers can control a wide range of weeds with a single active ingredient in comparison to the current practice of 2- 3 active ingredient applications (Ogg and Jackson, 2001).

Holzman (2001) studied the farm level impact of the introduction of Roundup Ready wheat in Western Canadian crop rotations. Under the assumption that Roundup Ready wheat will have a yield advantage of 6% and cost saving of $20.75 per acre, the author found that while farmers will benefit from the adoption of Roundup Ready wheat, those benefits are highly sensitive to management practices of individual farmers. Some researchers (such as Holzman *et al*. 2001) suggest that the engineered herbicide tolerance of Roundup Ready wheat may reduce the level of herbicide injury in wheat. This was supported by the work of Rauch and Thill (2001) that found no injury to the transgenic wheat in any field experiments.

Gianessi *et al* (2002) conducted a study on Herbicide Tolerant wheat in Montana, Minnesota, North Dakota, and South Dakota. They estimated that the adoption rate of the Roundup Ready wheat in those states would be equal to one-third of the spring wheat acres. This level of adoption results in an income increase of $12 per acre, and a production increase of 24 million bushels of wheat.

A report released by CNN (2003) said that any economic benefit from GM crops in Britain will likely be limited in the short-term, because of the limited GM crops that are suited to British conditions and the strong consumer opposition to GM food. The report recognized that GM crops have the potential to benefit both farmers and consumers. However, the report highlighted that whether those benefits outweigh the costs will depend on public attitudes and the capacity of the regulatory system to manage uncertainties.

One of the costs associated with the introduction of GM wheat is the risk of contamination of conventional wheat supplies by GM wheat, either at the production or marketing levels. At the production level contamination may occur through volunteer wheat, cross pollination and co-mingling with GM wheat. At the marketing level contamination may happen in the elevator, in conveyor systems or elsewhere. Although cross-pollination risk in the case of wheat is very low, it still may occur (Staniland *et al*. 2000; Hucl and Matus-Cadiz, 2001). The cross-pollination risks in wheat are lower than in some other crops such as corn (Eastham and Sweet, February 2002). Nevertheless, concerns of wheat breeders about possible contamination led the Canadian Agriculture Department, in 2001, to put an end to a GM field trials at the Agriculture Canada experimental farm in Indian head Saskatchewan (Agnet, March 25, 2003). Anti-GM groups argue that releasing GM will end the purity of wheat, and that the segregation of non-GM wheat from GM wheat will be impossible or very expensive. This will lead to farmers losing any choice to plant or sell GM-free wheat. Anti-GM groups also argue that widespread GM contamination in non-GM crop fields impose additional herbicide cost for non-adopters, in order to keep an acceptable level of genetic purity (Downey and Beckie, 2002). Furtan *et al*. 2003 makes this same argument and indicate this effect makes the decision irreversible. Furthermore, this may reduce the choice of being an organic wheat farmer and threaten the future of organic industry (e.g. Hoffman and Beaudoin v. Monsanto). However, others argue that it is possible to meet acceptable levels of purity, and that it is possible to find low cost and efficient ways to segregate non-GM from GM crops (Maltsbarger and Kalaitzandonakes, 2000; Smyth and Phillips, 2002; Wilson and Dahl, 2002).

3.3.3.2. National and global impacts

Several studies have addressed national and/or global impacts of GM wheat; however, their findings were at variance because of the different assumptions. For example, Stone *et al* (2002) found that in the long-run Australia would lose its wheat and oilseeds export market to the USA and Canada if those countries adopt GM technology (including GM wheat) while Australia does not. However, they ignored the fact that consumer opposition may wipe out any gains to productivity that GM technology may give to its adopters. DeVuyst *et al* (2001) developed a mathematical programming model to investigate the effect of the introduction of GM wheat on international trade. In this model, they assume a 4.8% cost saving for GM versus non-GM wheat. Their findings indicate that the introduction of GM wheat benefits consumer worldwide. US producers win in all scenarios except when GM wheat is widely adopted. In all scenarios it is assumed that developing countries will still import GM wheat under the assumption that food safety is not the main concern and that their priority is to meet the needs of their own people. This is a strong assumption since it excludes any role for developing countries in the controversy over GM wheat, and assumes away the potential of consumers in developing countries exerting their purchasing power to reject or slow the adoption of the technology. The authors assumed that countries might reject the import of GM wheat, but still import non-GM wheat. This is unlikely because many countries have reported that they will reject the import of all wheat at once, if GM wheat is introduced, because it is difficult and costly to segregate GM and non-GM wheat. The authors also underestimate the loss of exports because of the introduction of GM wheat, since they limit the loss to only one market (Mexico). DeVuyst *et al*, (2001) concluded that the US may have first mover advantage (will gain by adopting GM wheat before other countries) even when importers reject GM wheat. In contrast Furtan *et al* (2004) concluded that neither Canada nor the USA has first mover advantage from the approval of GM wheat, and that producers in the first country approving GM wheat will suffer a loss. This conclusion was realized under the assumption that segregation of GM and non-GM wheat to the low tolerance level of many of the wheat importing countries is not affordable.

Kuntz (2001) examined the effect of the introduction of Roundup Ready wheat on western Canada. He indicated that a third of Canadian wheat exports may need to be diverted to other markets due to rejection in ten "at risk" countries. Kuntz (2001) has defined countries at risk as countries that have expressed, according to the Canadian Wheat Board, that they will stop importing wheat if GM wheat is introduced in Canada. Creating other markets is not costless as GM wheat would need to be priced lower than conventional wheat to attract "GM tolerant" buyers.

Wisner (2002) found that in the short run (2 to 6 years) US exports of hard red spring wheat would suffer a loss of around 30-50% and farm prices would decline by anywhere from 32-35% if GM wheat is introduced. The author emphasized the difficulty and the high cost of creating and operating a dual marketing system of GM and non-GM wheat. The author also questions whether buyers would pay for the additional cost of segregation while non GM wheat can be purchased from other countries.

3.4. Diffusion models of agricultural technology

3.4.1. Consumer opposition in the adoption process

In the literature, opposition to GM food, as reflected in consumer resistance, has not been recognized as an influencing factor in the adoption process. Rather, it is usually considered as a factor influencing demand of GM food, locally or internationally. Barkley (2002) introduced opposition to GM food as a factor leading to a reduction of demand by foreign buyers. Anderson *et al.* (2001) also introduced opposition to GM food as a factor leading to a consumption ban on imports from GM producing countries. Biotechnology companies and food producers did not take European consumer resistance to GM food seriously. Efforts were and are still concentrating on advertising for the benefits of this technology rather than tackling consumer concerns directly. Consumer opposition to this relatively recent technology was thought to be temporary. However, the rejection of GM food by Europe and Japan has persisted, and has translated into compulsory labeling that restricts the import of GM food.

3.4.2. Review of diffusion models

Diffusion is generally defined as the process by which a successful innovation gradually becomes broadly used through adoption by firms or individuals (Jaffe *et al*., 2000). Most diffusion models of GM crops ignore the power of consumers because the direct agronomic benefits to farmers are assumed to be the main forces driving the diffusion. Most of the studies that model agricultural innovation diffusion claim that the variation of diffusion in different regions is explained by differences in “farm factors” such as profitability or expected return from the adoption of the new technology (Griliches, 1957; Mansfield, 1961; Schulz, 1964; and Dixon, 1980). However, these farm acceptance factors are related to how the final users of the farm product perceive the new technology. If consumers perceive the new technology as a risk for them or for the environment, they may not accept the farm product, thereby reducing the incentive for farmers to adopt the technology. Recently, concerns of farmers in North America about possible introduction of GM wheat show that the strong consumer opposition in Europe and Japan to GM food cannot be ignored. Researchers such as Hanf and Böcker (2002) argued that that consumer rejection to GM food is the major reason why diffusion rates of GM crops appeared to stagnate in the early 2000s, even in the USA.

In this section, several diffusion models that vary according to their assumptions about diffusion parameters are reviewed. Diffusion curves are based on the notion that the current adoption rate is a function, not only of the current level of adoption in region i at time t (θ_{it}), but also on the ultimate or long run adoption or ceiling level in that region (K_i). The diffusion rate (or adoption change) of the technology in region i at time t can be given by:

$$d\theta_{it} / dt = f(K_i, \theta_{it}, t) \tag{3.1}$$

Most diffusion models assume that the diffusion rate is proportional to the difference between the ceiling level and the current level of adoption. These specific models are called "basic diffusion models" (Mahajan and Peterson, 1985). The basic diffusion models take the following functional form:

$$d\theta_{it}/dt = g_{it} [K_i - \theta_{it}] \tag{3.2}$$

This basic model contains four components: existing level of adoption (θ_{it}), time (t), the social system in which the innovation is being adopted, and channels of communication. The effect of the two last components is found in the diffusion coefficient g_{it} (Knudson, 1991). The diffusion coefficient indicates how fast the adoption level approaches the ceiling level.[14] Assumptions about this function lead to different types of diffusion models. If the coefficient of diffusion where $g_{it} = \Phi_i \theta_{it}$ is the natural rate of diffusion, the resulting logistic diffusion model would be:

$$d\theta it/dt = \Phi_i \theta it [K_i - \theta_{it}] \tag{3.3}$$

The unit of θi in the case of agriculture innovation often refers to percentage of acreage under adoption. The parameter Φi is the rate of acceptance of the innovation (also called natural rate of diffusion or rate of growth coefficient) in the region i. This model is referred to as the *internal influence model* or *static logistic model*. It was used by Griliches (1957) to estimate the diffusion rate of hybrid corn in the United States. This model is also known as the "contagious" or "epidemic" model in biology (Jaffe *et al*., 2000) in which the innovation spreads like a disease. According to Knudson (1991) the adoption process being modeled should satisfy six basic assumptions. Specifically, the six basic assumptions (A1-A6) of static diffusion models are:

- (A1) An individual either adopts or does not adopt;

---

[14] The coefficient of diffusion is $g_{it} = \frac{\partial(\partial\theta_{it} / \partial t)}{\partial(K_i - \theta_{it}))}$.

- (A2) There is a fixed, finite ceiling K;
- (A3) The coefficient of diffusion is fixed over time;
- (A4) Once introduced, the innovation is not modified and its diffusion is independent from the diffusion of other innovations;
- (A5) One adoption is permitted per adopting unit and this decision cannot be rescinded;
- (A6) A social system's geographical boundaries stay constant over the diffusion process.

The logistic model imposes an S-shaped symmetric diffusion trend where a maximum rate of diffusion occurs at the inflection point, which is fixed at half of the ceiling ($K_i/2$).[15] It is based on Mansfield's idea that diffusion is a process of imitation resulting from interpersonal contact among groups of homogenous producers. While some empirical studies have found the maximum rate of diffusion may occur earlier than the point of inflection $K_i/2$ (Shampine, 1998), it is common to use the traditional logistic model in agricultural innovations for its relative simplicity (Griliches, 1957; Jarvis, 1981; Knudson, 1991).

The logistic model can also be presented as the following equation (after integration of equation 3.3 and log transformation):

$$\ln[\theta_{it}/(K_i-\theta_{it})] = a_i + \Phi_i\, t \qquad (3.4)$$

---

[15] To find the maximum adoption rate differentiate equation 3 with respect to time; $d^2\theta_{it} / /dt^2 = \Phi_i\ (K_i - 2\,\theta_{it}^*) = 0$ or $\theta_{it}^* = K_i/2$. The maximum diffusion rate occurs when 50% of the potential adopters have adopted, making the diffusion trend symmetric.

The a_i parameter is a constant and it measures the adoption at time t = 0, the year agricultural technology is first introduced (considered the base time period). The term a_i is the constant of integration which positions the curve on the time scale for the region i (Griliches, 1957). Assumptions A2 and A3 -- that parameters determining the diffusion rate (Φi, Ki) are fixed over time-- allow the static logistic model to be a useful tool for forecasting future adoptions since no exogenous variables are needed and future adoption rates can be predetermined by simple extrapolation (for examples see Griliches 1957 and Mansfield 1961). However those simplifications limit what the model can say about the underlying dynamic process at work (Besley, 1993). In addition, the static diffusion model, because of assumption A5, does not allow the decline in adoption rates.

The assumptions of the static logistic model mentioned above suggest its unsuitability for crop biotechnology innovation, since adoption of agricultural technology is often a dynamic process. If some of the assumptions of static logistic diffusion are relaxed, for example allowing the rate of acceptance or the ceiling to change over time, we obtain a dynamic diffusion model. If the ceiling is allowed to change over time as a function of exogenous variables, the model is called the variable-ceiling logistic model (Jarvis, 1981; Knudson, 1991). This model is represented by the following equation:

$$\ln[\theta_{it} /(K_{it}-\theta_{it})] = a_i + \Phi_i t \qquad (3.7)$$

Two drawbacks of the variable-ceiling logistic model are that there is no guarantee that the ceiling will stay at theoretically justifiable levels (less than 1 or 100%) or that the equation will converge when the data are extremely nonlinear (Dixon, 1980). If only the slope (Φ_i) is allowed to change but the ceiling is kept at a fixed justifiable level, the diffusion model is called the dynamic variable slope logistic model and could be written as:

$$\ln[\theta_{it} /(K_i - -\theta_{it})] = a_i + \Phi_{it}\, t \qquad (3.8)$$

This model allows the rate of slope to vary. This model is easy to estimate and does not have the drawbacks of the variable ceiling logistic model for estimations using non-linear data.

3.5. Assessment of the food security literature

The evaluation of the effects of biotechnology on food security in developing countries is extremely complex, since these effects may vary by country, by sector as well as by segments of population (Leisinger, 1996), and because very few developing countries have experience with biotechnology (Qaim, and Virchow, 2000). In this section the complexity of studying the effect of biotechnology (genetic engineering) on food security in developing countries is explained graphically. This section shows whether the effect of biotechnology on food security for a given group or region is positive or negative depends on many other factors external to this technology.

The relationship between different factors affecting food insecurity is presented for the case of a small country (Figure 3.1). Food insecurity curves are used to identify and interpret the effect of biotechnology on food security at different levels (local, and household). The total supply curve is the domestic supply curve modified by stocks and imports. The demand curve shows total quantity of food demanded (effective market demand) at different prices. The aggregate food requirement "R", could be measured in calories[16].

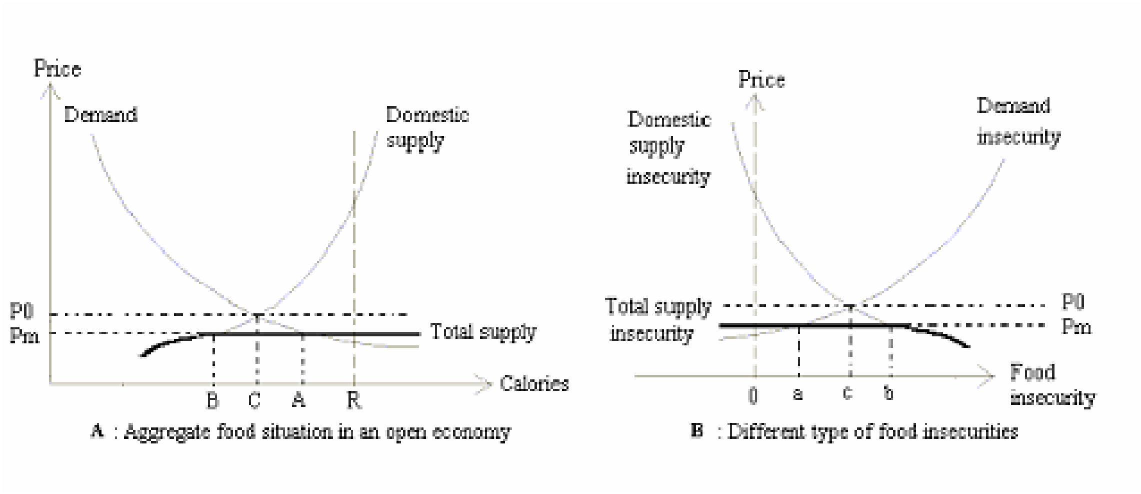


Figure 3.1 – Aggregate food situation and food insecurity curves for a given country

In Panel B, we distinguish three types of food insecurity:

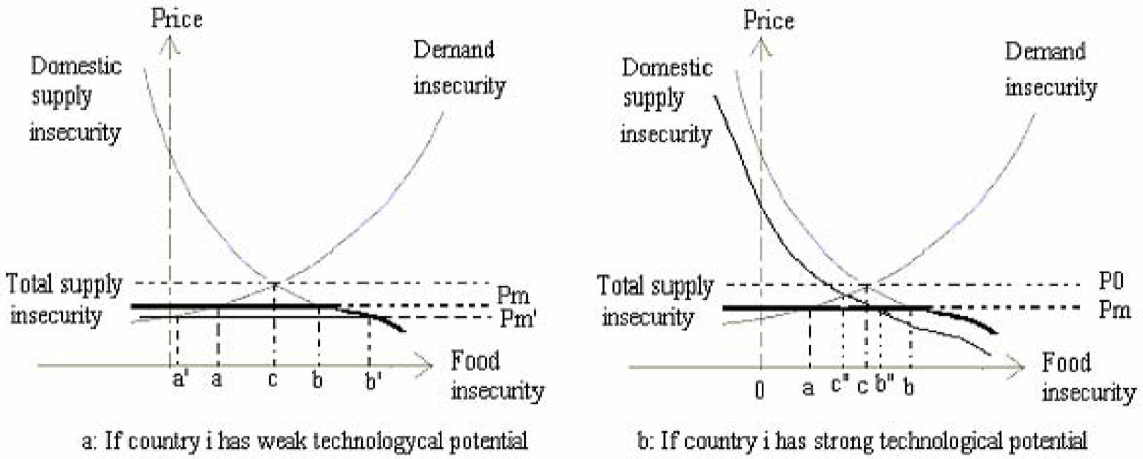
- Domestic supply insecurity is the gap between the aggregate food requirement (R) and the domestic supply of a given country**.** This indicator is a measure of the ability of a country to rely on its own food production to solve its food insecurity problem.
- Total supply insecurity is the gap between the food requirement (R) and total supply (comprising total food production, food stocks plus imports minus exports). This is a measure of food insecurity for countries that are able to complement the supplies from domestic production by food imports.

---

[16] Food requirements could be estimated in term of calorie or staple food requirements. The more unequally the food is distributed the higher the aggregate food requirements.

- Demand or consumption insecurity (or income-related food insecurity) is the gap between the requirement (R) and the effective demand. This is a measure of access to food, since food can be abundant but some people may be unable to access it due to their insufficient incomes.

Countries will be affected differently by biotechnology depending on whether the country is a net exporter or net importer of food and whether it can apply new technologies on a national scale (Commandeur and von Roozendaal, 1993; Leisinger, 1996). The effect of biotechnology on food insecurity in net importer "country i" is presented by Figure 3.2.



a: If country i has weak technologycal potential

b: If country i has strong technological potential

Figure 3.2 – Effect of biotechnology on food insecurity in country i

In Panel a, "country i" is a net importer and has a low technological capacity. In this case biotechnology is adopted by exporters. By reducing cost of production or by increasing crop productivity, biotechnology may lead to a decrease in the world price from Pm to Pm'. This price decline leads to a reduction of demand insecurity from level a to a' due to the ability to increase food imports. This improvement in food security (decrease in food insecurity) for this country is a short term benefit, since lower prices price reduce domestic supply (domestic supply insecurity could be worsened (from b to b’). The additional dependence on imports implies a greater risk from world price shocks.

In Panel b, “country i” is a net importer and has strong technological capacity. In this country, farmers are able to apply biotechnology themselves. Biotechnology (higher yielding varieties for example) leads to a rightward shift of the domestic supply curve, which means a decline of domestic and total supply insecurity. A price decline (from P0 to Pm) increases the real income, which enhances the aggregate demand leading to a decline in demand insecurity (from c to c”). The domestic supply insecurity is also reduced (from b to b”), which means that this country is moving toward food security.

Similar analysis can be done for net exporting countries. The effect of biotechnology on food security in a net exporter country depends on the speed of introducing and the capacity of using the new technology compared to its competitors. Therefore, net exporter countries unable to introduce biotechnology at the same speed as the fastest competitors will have a substantial reduction in their export earnings. The decrease of income due to this reduction in exports leads to a left shift of the aggregate demand, and thus an increase of demand insecurity. This could be the case of many African countries for which agricultural products represent more than 60 percent of their total export income. In those countries, biotechnology could (at the extreme) lead to a disaster, since a large population will have less income, making them unable to access the food they need. However, if African countries could take advantage of this technology, their export earnings could increase and so could their ability to buy more food and decrease the food insecurity and hunger of their people.

In the analysis of the effect of biotechnology on food security of a given country, further factors may be important in addition to whether a country is a net exporter or importer of agricultural products. These factors include how agriculture is structured (importance of large-scale farming against smallholders), the income structure (number of low-income consumers compared to high-income consumers) and the degree of income distribution.

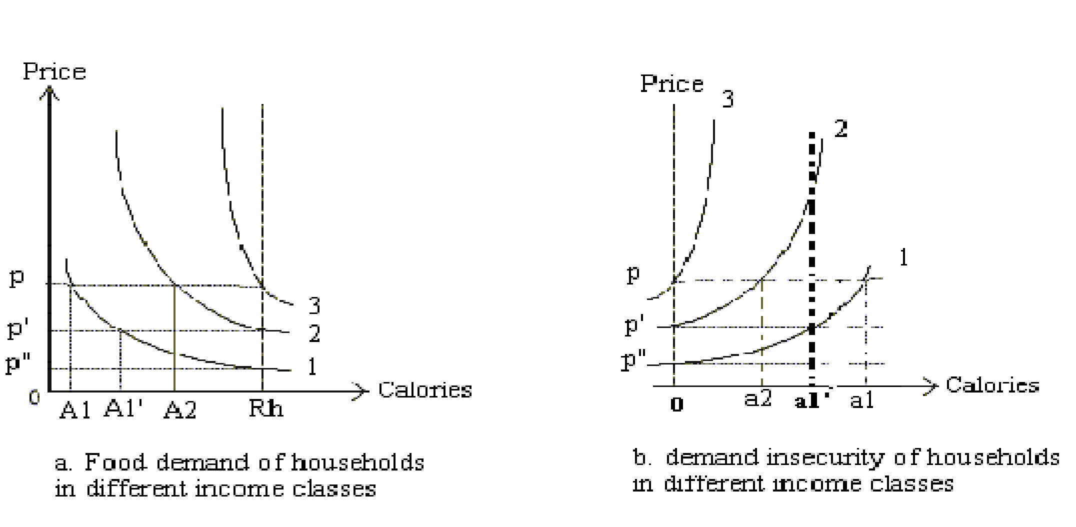
The numbers 1, 2, and 3 in Figure 3.3 represent households with low, medium and high income respectively. The household food requirement in calories is “Rh”. Looking at the second panel, a1 (Rh-A1) and a2 (Rh –A2) are the food insecurities of households 1 and 2 at the price. The food insecurity level at which a household would starve is a1’ (Rh-A1’).

In developing countries, small farmers are usually the main cohorts of low-income households. If a GM technology that target crops mainly cultivated by small farmers and consumed by poor consumers (those crops are usually for local consumption only) is available and widely adopted by small farmers, those farmers will benefit from the technology owing to the productivity growth in cultivating the GM crop.[17] This can lead to an increase in small farmers’ income. Therefore, households of small farmers could become medium income (not low-income) consumers. This means that food demand of small households will shift from level 1 to a higher level (level 2 for example) in panel a. This in turn lead to a shift of food insecurity level from level 1 (dangerous level) to level 2 (a safer level) in panel b. In this case, biotechnology might not only be advantageous for the poorest people (small farmers and low-income

---

[17] See the examples of virus-resistant sweet potatoes in Kenya and Mexico (Qaim and Virchow, 2000).

households), but it might also contribute to decreasing income inequality in a given country (Figure 3.3).



a. Food demand of households in different income classes

b. demand insecurity of households in different income classes

Figure 3.3 – Desegregation of demand insecurity

3.6. Conclusion

The potential impact of biotechnology will be a function of consumer perception to GM food. This chapter argues that the evaluation of the biotechnology effect should be dynamic rather than static, and should treat consumer opposition as an endogenous factor in the adoption decision of biotechnology rather than an exogenous one. It is unlikely that the opposition to GM food will disappear in the near future. Consumers' "right to know" and labeling requirements will create formidable barriers to trade. This opposition will have an effect on global food production and trade. While the adoption of GM crops will increase food security an empirical modeling approach is needed to estimate the magnitude of these benefits.

In Chapter 4, the four areas identified in this chapter are combined to develop a global food security model that can be used to simulate scenarios to evaluate the potential impact of pending biotechnology crops on food security.

CHAPTER 4 : MODELING THE EFFECT OF BIOTECHNOLOGY ON FOOD SECURITY: THE CASE OF GM WHEAT

4.0. Introduction

This chapter deals with modeling the impact of GM market acceptance on GM adoption rates and, ultimately, global food security. A production model is used to estimate the impact of GM market acceptance (or lack thereof) on GM adoption rates and the impact this will have on supply. A stochastic simulation model is then used to estimate the impacts on price levels and future global food security. By construction the model ignores many exogenous variables that will impact food security but are not affected by the GM acceptance.

4.1. Development of global food security model

A market model is combined with a GM adoption model to create a global food security model (Figure 4.1), which allows dynamic economic responses to food production shocks, such as climate change. GM corn is used to develop the adoption model for GM wheat, since wheat is not commercialized yet. In the adoption model, the rate of adoption of GM wheat is affected by major importers' policies through trade. The adoption rate depends on the diffusion of this technology, which is driven by consumer perception of the technology. The market model consists of both a supply and a demand side. The wheat supply in any given year is the sum of the previous year's stock and the current year's production. The quantity of wheat stock each year is estimated using a stock equation. Production is divided into a yield forecast and acreage responses. The acreage function permits the estimation of the total acreage planted with wheat. The yield forecast depends on assumptions about the productivity increases provided by GM and conventional wheat and the adoption rate of GM wheat. Yield forecasts of conventional wheat are estimated from the historical data. The yield forecast of GM wheat is estimated under specific assumptions. The realized yields depend on the climate and environmental shocks assumed to be random is this study. The demand side consists of consumption determined by a linear equation.

The adoption and market model are combined to compute the food security elements (Figure 4.1). The level of food security is assessed using several factors, including: real wheat prices, which are a good measure of food security as lower real wheat price translate into cheaper imports for developing countries; consumption, which measures whether access to food has improved or not; ending stocks, which measure whether supply outweighs demand; and volatility of prices and the probability of high prices, which tests the stability of global food security.[18]

---

[18] The use of word grain (in this case wheat) market conditions such as world stock levels and prices has been used as indicators of food insecurity since the 1970s (Paarlberg, 2000).

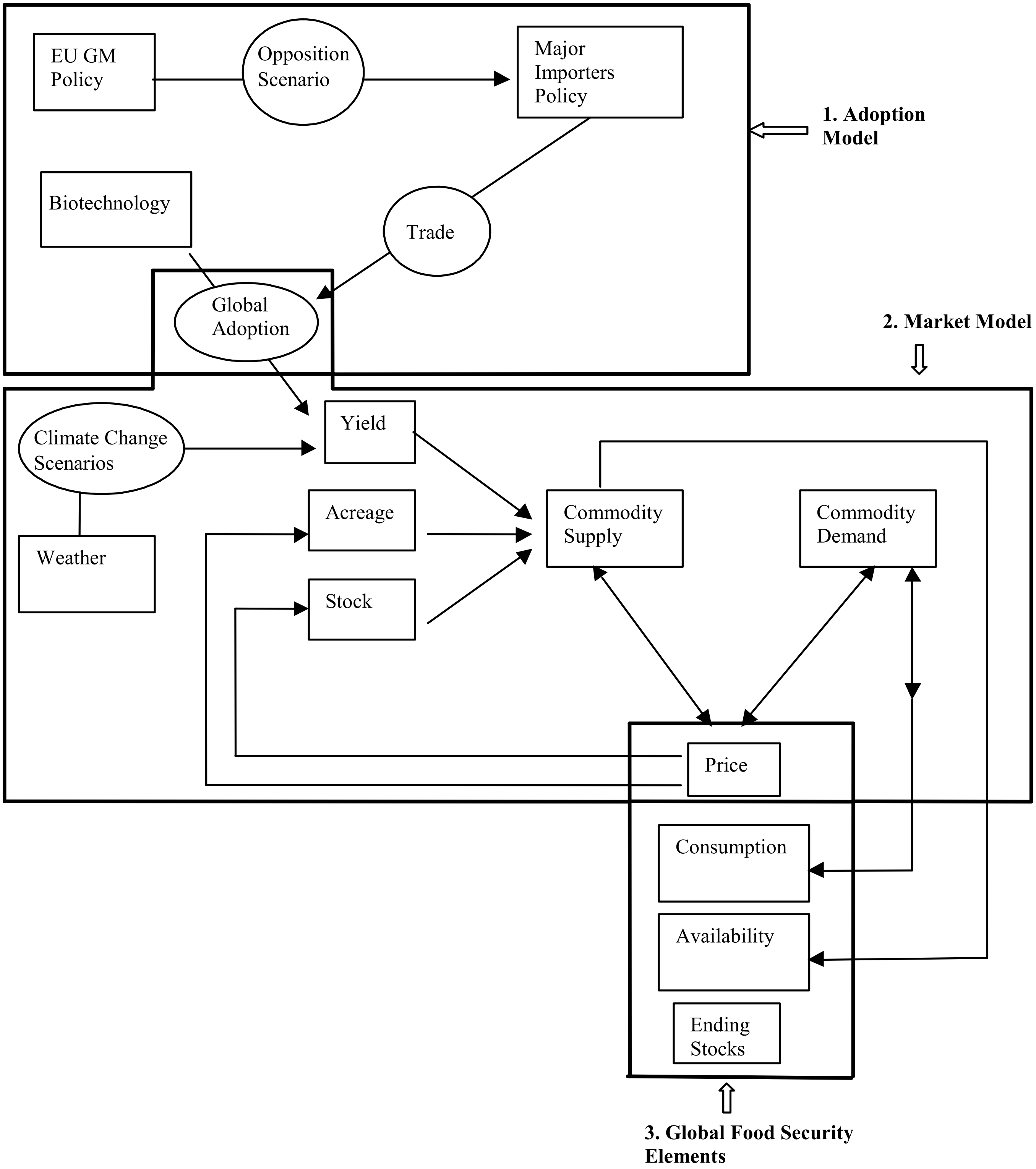


Figure 4.1 – Global Food Security Model

The main goal of this analysis is to provide the change in food security elements such as price, consumption, and ending stocks rather that forecasting their values. The analysis also provides an estimate of changes in terms of number of undernourished people in developing countries by 2030 due to the opposition to GM wheat.[19]

4.2. Adoption model

In 2000, the global acreage of GM corn was equal to 10.3 million hectares occupying the second largest area after GM soybean and 23% of the total area sown for GM crops (James, 2000). GM corn was first adopted by Canada and the USA in 1996. The acreages of GM corn in these countries were 0.001 million ha for Canada and 0.3 million ha the US, representing respectively an adoption rate of 0.1% for Canada and 1% for the US. Argentina adopted GM corn in 1997, followed by other countries including Mexico, France and South Africa in 1998 (Table 4.1).

Table 4.1 – Development of GM corn area (million ha)

Country	1996	1997	1998	1999	2000	GM% (1999)	GM% (2000)
Argentina	0	0.07	0.09	0.31	0.28	12.3	9
Bulgaria	0	0	0	0	0.01	0.00	2.1
Canada	0.001	0.27	0.3	0.5	0.4	43.8	36.8
France	0	0	0.002	0.001	0.01	0.1	0.5
Germany	0	0	0	0.01	0.01	0.0	2.7
Portugal	0	0	0	0.001	0	0.5	0.0
Mexico	0	0	0.05	0.05	0.1	0.7	1.4
South Africa	0	0	0.05	0.16	0.15	4.5	3.9
USA	0.3	2.27	8.66	10.3	9.9	36.1	33.6
Total	0.30	2.61	9.15	11.33	10.3	8	7

Source: James (1995-2000)

---

[19] The numbers and proportion of undernourished people in each developing country is a food security indicator developed by the FAO This measure is the most widely used indicator of food insecurity (Smith et al, 1998). It gives the number and proportion of people in each country or region who are consuming insufficient dietary energy to meet their requirements (See FAO, 1996b for more details about this measure).

In 2000, the global adoption level of GM corn was 7%. Canada has the highest adoption level of around 37% followed by the USA with an adoption level equal to 33.6%, Argentina with a 9% adoption level, and South Africa with a 4% adoption level. The adoption level in European countries did not exceed 3% level. The global adoption rate as well as adoption in most countries especially in Argentina, Canada and the USA has declined significantly between 1999 and 2000 (Table 4.1).

Knowing that the highest adopters of GM corn are countries where consumers are tolerant to GM food, and that the lowest adopters are countries where consumers are strongly oppose this technology an important question arises: Could consumer opposition explain the difference of GM adoption rates between different countries as well as the change in the diffusion of this technology in a given country as well as globally?.

Diffusion is generally defined as the process by which a successful innovation gradually becomes broadly used through adoption by firms or individuals (Jaffe *et al*., 2000). Most models of diffusion of GM crops ignore the power of consumers with the direct agronomic benefits to farmers assumed to be the main forces driving the diffusion. Most of the studies modeling diffusion of agricultural innovations claim that the variation of diffusion in different regions is explained by differences in "farm factors" such as profitability or expected return from the adoption of the new technology (Griliches, 1957; Mansfield, 1961; Schultz, 1964; and Dixon, 1980). However, these farm acceptance factors are related to how the final users of the farm product perceive the new technology. If consumers perceive the new technology as a risk for them or for the environment, they may not accept the farm product, thereby reducing the incentive for farmers to adopt the technology. Recently, concerns of farmers in North America about possible introduction of GM wheat show that the strong consumer opposition in Europe and Japan to GM food cannot be ignored. In the literature, opposition to GM food, as reflected in consumer resistance, has not been recognized as an influencing factor in the adoption process. Rather, it is usually considered as a factor influencing demand of GM food, locally or internationally. Barkley (2002) estimated the opposition to GM food by numerical factor (-1,0), reflecting demand reductions by foreign buyers. Anderson *et al*. (2001) also introduced opposition to GM food as a factor leading to a consumption ban on imports from GM producing countries.

My approach formally incorporates consumer response into the diffusion decision. Given that GM wheat is not yet available, I use a variable-slope dynamic diffusion model for GM corn to investigate the effect of consumer opposition on diffusion and adoption of GM technology. Using the available data about GM corn adoption,[20] I model the diffusion paths in the EU and 23 countries to identify the effect of local and foreign tolerance to GM food on the path of propagation of crop biotechnology.[21] The underlying assumptions in the model are that consumers in several countries oppose GM corn, to varying degrees, and that farmers will react to such opposition through their adoption rates of this technology. By reviewing different diffusion models in section 3.4.2, I demonstrated that the dynamic variable-slope logistic model (equation 3.8) is the most appropriate model for estimating diffusion of

---

[20] The analysis is conducted using a sample of 39 countries for which biotechnology research statistics are available, and covers 5 years of adoption of GM corn (1996 to 2000).

[21] Adoption levels for GM corn are taken from various issues of Clive James, *Global Review of Commercialized Transgenic Crops: ISAAA Briefs* (International Service for the Acquisition of Agri-biotech Applications: Ithaca, New York, 1995-2000).

biotechnological innovations. Therefore the dynamic diffusion model for GM corn can be presented by equation (4.1) which is a restatement of equation (3.8):

$$\ln[\theta_{it}/(K_i-\theta_{it})] = a_i + \Phi_{it}\, t \tag{4.1}$$

The a_i parameter, a constant, measures the adoption at time $t = 0$, the year a new agricultural technology is first introduced (considered the base time period). Adoption behavior is depicted by the percent of total acreage planted to the GM crop. The adoption ceiling (K_i) is fixed for all countries at 100% level indicating that the entire crop produced by the country is of the GM variety. The coefficient of diffusion Φ_{it} is a function of, $f(R_{it})$, where R_{it} is a vector of exogenous vectors affecting the diffusion coefficient. By defining $f(R_{it})$ as a function of foreign and national acceptance to GM food, $\Phi_1 R_{1it} + \Phi_2 R_{2it}$, this approach enables the measurement of the diffusion of GM crops for different countries.

In order to capture some of the effect of consumer perceptions on rates of adoption, information on labeling requirements in each country were used to construct a tolerance index to GM food. The national tolerance index for country i (R_{1it}) is intended to be a proxy for the local acceptability of GM food:

$$R_{1it} = T_i \tag{4.2}$$

The assumption is that the rate of adoption in a specific country is a function of local perception. In other words, consumers could oppose the introduction of a specific crop in their country on the basis of environmental concerns. The local tolerance level is taken to be inversely related to the stringency of the labeling requirements. That is, countries with voluntary labeling laws or with no labeling regulation altogether have a more tolerant attitude (higher Ti) toward GM food. In contrast countries with mandatory regulation of 0% threshold on products containing genetically modified organisms are the least tolerant to GM food. The tolerance indexes are assigned to each country based on the threshold level for percentage of GM contamination of non-GM products. Therefore, a value of 0 is assigned to countries with a 0% threshold, 1 for a 1% threshold, 2 for a 2% threshold, 3 for 5% threshold levels, 4 for 10% and above, and 5 where either voluntary or no labeling laws exist (See Appendix B.1 for local tolerance values). This method is reasonable given the limitation of information on consumer preferences. The highest adopters (Argentina, Canada, and the US) have the highest local tolerance, while slow adopters (France and Germany for example) have low local tolerance.

The foreign tolerance index facing country i (R_{2it}) is estimated as:

$$R_{2it} = \sum_{j} \frac{Export(i \ to \ j)}{Production(i)} \mathrm{T_j} \tag{4.3}$$

where T_j is the tolerance level in importer country j approximated using the assumptions discussed above. It is assumed that the rate of adoption is a function of international market acceptance. Market acceptance is a function of the size of consumer demand for GM corn in export markets (see Table B.2 for foreign tolerance index values). The formula of R_{2it} suggests that country i will be affected the most by the labeling regulation (regarding a given product) of its most important trade partner. In other words, countries will take more seriously any labeling regulations or import restriction imposed on an export product coming from a trading partner that is a large importer of that product. Annual crop export data and production data are obtained from FAOSTAT online statistics (FAO, 2000). Based on this information the following relationship is developed:

$$\Phi_{it} = \Phi_1 R_{1it} + \Phi_2 R_{2it} . \qquad (4.4)$$

Substituting Φ_{it} in equation (4.4) into the diffusion model (4.1), equation 4.5 is derived:

$$\ln[\theta_{it}/(1-\theta_{it})] = a_i + (\Phi_1 R_{1it} + \Phi_2 R_{2it})\, t \qquad (4.5)$$

Country differences are accounted for by the term a_i which represents the fixed effect, as we are dealing with panel data. If, at the initial year of introduction of the technology in the world (t=0), a country does not adopt this technology the term ai will be negative. However, if the country adopts the new technology at the initial year the term ai will be positive. Note that if the adoption rate (θit) is equal to zero the $\mathrm{Ln}[\theta_{it}/(1-\theta_{it})]$ is invalid. To solve this problem we substitute $\ln[\theta_{it}/(1-\theta_{it})]$ by $\ln[1 + \theta_{it}/(1-\theta_{it})]$.[22] Equation 4.5 now becomes

$$- \mathrm{Ln}(1- \theta_{it}) = \beta_i + (\alpha_1 R_{1it} + \alpha_2 R_{2it})\, t \qquad (4.6)$$

Adding the error term ε , the diffusion equation can be estimated as:

$$\Delta_t =- \mathrm{Ln}(1- \theta_{it}) = \beta_i + \alpha_1 R_{1it}\, t+ \alpha_2 R_{2it}\, t +\varepsilon \qquad (4.7)$$

A negative intercept $\beta_i <0$ means that there is no adoption at time zero in country i, while a positive value means the opposite. If diffusion is positive then the adoption rate in country i is equal to:

$$\theta_{it} = 1- e^{-(\Delta t)} \qquad \text{if } \Delta_t >0 \text{ and} \qquad (4.8)$$

$$\theta_{it}= 0 \qquad \text{if } \Delta_t <0 \qquad (4.9)$$

As mentioned for the term a_i, the term β_i is country specific, and is related to the initial availability or development of the technology in country i.

---

[22] $\ln[1 + \theta_{it}/(1-\theta_{it})] = \ln (1/(1-\theta_{it})) = -\ln(1-\theta_{it})$, and $\ln[\theta_{it}/(1-\theta_{it})] = \ln(\theta_{it}) - \ln(1-\theta_{it})$. At the limit $(t\rightarrow\infty)$:$\ln[1 + \theta_{it}/(1-\theta_{it})] = \ln[\theta_{it}/(1-\theta_{it})]$.

To increase the accuracy of the parameter estimates, the diffusion model is estimated using cross-country panel data over 5 years (1996-2000) assuming similar coefficients (α_1, and α_2) for different countries (Please see that pooled data in Table B.3 used for the regression) Although the coefficients of foreign and local tolerance variables are the same for all countries, the magnitude of those variables is different. The fixed effect model is used as a way to account for differences (technological) between producers in different countries. As a result, the model can perform well in cross-country analysis.

An advantage of this diffusion model is that it permits the adoption reaction (increase or decrease) due to the change over time in consumer attitude (foreign and local tolerances) toward GM food locally or internationally. Therefore, this model is appropriate for describing the dynamics involving the adoption decision. Adopters may reduce the adoption of an old technology (GM corn) or hesitate to adopt a new one that are not yet commercialized (such as GM wheat) if they realize that the opposition to this technology (local or foreign) may cause them economic loss in the local or international market.

It is expected that an increase in the magnitude of foreign and local tolerances would result in an increase in the demand for genetically engineered crops, inducing wider adoption of the technology. In other words, it is expected that if GM technology is more accepted locally and internationally that adoption will increase regionally as well as globally. Consequently, both tolerance terms are expected to have positive coefficients. The result of regression of the diffusion model is reported in Table 4.2.

Table 4.2 – Estimation of the diffusion parameters (case of corn)

Dependent Variable: Diffusion
Method: Pooled Least Squares
Sample: 1996 2000
Included observations: 5
Number of cross-sections used: 24
Total panel (balanced) observations: 120

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Local Tolerance *t	0.003	0.001	2.73	0.008
Index of Foreign Tolerance *t	0.013	0.006	2.21	0.030
Fixed Effects				
Argentina	-0.04			
Australia	-0.04			
Brazil	-0.02			
Bulgaria	-0.02			
Canada	**0.30**			
China	-0.02			
Czech Republic	-0.01			
EU (15)	-0.01			
Hungary	-0.05			
India	-0.03			
Israel	-0.02			
Japan	-0.02			
Korea	-0.02			
Liechtenstein	-0.02			
Mexico	-0.02			
New Zealand	-0.02			
Norway	-0.02			
Poland	-0.03			
Romania	-0.02			
Russian Federation	-0.02			
Slovakia	-0.02			
South Africa	-0.02			
Turkey	-0.03			
United States	**0.21**			

R-squared	0.74	Mean dependent var	0.03
Adjusted R-squared	0.68	S.D. dependent var	0.10
S.E. of regression	0.06	Sum squared resid	0.30
F-statistic	272.84	Durbin-Watson stat	1.09
Prob(F-statistic)	0.00		

The empirical results suggest that consumer opposition to GM food should be considered an endogenous variable in the adoption decision. Consumers' opposition (acceptance) measured by local and foreign tolerance proved to be the main obstacle (driver) of adopting GM technology. Both coefficients of acceptability variables have the right sign (positive) and are significant. Both foreign tolerance and local tolerance seem to perform well (significant at 1%). The ability of the two tolerance indices to count for differences in the diffusion parameters between countries appears to be significant, with 74% of the variability of the diffusion of GM crop worldwide explained by only these two variables.

The empirical results also suggest that both tolerance measures affect the diffusion rate, but foreign tolerance to GM food is more important than local tolerance[23]. This is expected, since corn is mainly destined for export. The significance of foreign tolerance suggests that foreign opposition to GM food could significantly limit the adoption of GM crops. This result helps to explain the hesitation of farmers to adopt GM wheat under the risk that they may lose export markets.

The coefficients β_i, $\alpha_{1,}$ and α_2 estimated in this section and presented in Table 4.2 (for GM corn) are used to forecast the diffusion of GM wheat for specific countries (Argentina, Australia, Canada, China, and the USA). Foreign tolerance indices are re-calculated to reflect wheat trade shares rather than corn markets. Export over production

---

[23] The foreign and the local tolerance indices were calculated differently, therefore some may suggest that a direct comparison of estimated parameters is not possible. Therefore, I recalculated the local tolerance index as R_{1it} = local consumption i/production i. This approach treats foreign and domestic sales symmetrically and makes the direct comparison between the two tolerance measures possible. The model is re-estimated, and the results are presented in Appendix B.4. The index of foreign tolerance is twice more economically significant in the adoption decision than local tolerance. The model now is slightly less fit than previously as the coefficient of determination declined slightly. The foreign tolerance became less statistically significant in this model. This could be explained by the fact that in this new model I used fewercountries due to lack of the data.

shares used to calculate the foreign tolerances are based on eleven-year averages (1990-200) calculated from Canada Grains Council (2002).

The global adoption rate of GM wheat at time t is θb_t calculated as the area (ha) of GM wheat harvested over total wheat hectares. The global adoption of GM wheat is:

$$\theta_{bt} = \sum_{1}^{k} \frac{A_{it}\ \theta_{it}}{A_t} = \sum_{1}^{k} SA_{it}\ \theta_{it} \tag{4.10}$$

where A_{it} is the hectares of wheat in country i (i.e. a potential adopter for GM wheat) at time t. θ_{it} is the adoption of GM wheat in country i at time t. At is the global acreage of wheat. SA_{it} is the area share of country i from the global hectares. Area shares used to calculate the global adoption are based on ten-year averages (1991-2000) calculated from Canada Grains Council (2002) as presented in Table 4.3.

Table 4.3 – Area shares of major wheat producers (ten-year average from 1991-2000)

Country	Average Acres (1000 ha)	Average Share
Argentina	5,412	2.5%
Australia	10,036	4.6%
Canada	11,803	5.4%
China,	29,448	13.4%
EU	16,965	7.7%
USA	24,185	11.0%

Source: (Canada Grains Council, 2002; and Author's calculations)

4.3.The market and food security elements of the model

The market and food security components of the GM diffusion model are outlined here for completeness. In this section the analysis focuses on the estimation of wheat yields for two periods: 1960-2005 and 2005-2030. The first period reflects the contribution of conventional wheat varieties to yield growth. The second is the period where GM wheat is expected to be introduced and adopted. The contribution of plant breeding to yield increase could range from 20% to 80% across different crops (Evans, 1993). Huang *et al* (2002) reported that scientists and observers from different countries (both developed and developing) have agreed that conventional technology will continue to contribute to the increases in productivity, and that by 2010 and beyond, biotechnology should have a major impact on yield increase.

The yield growth of conventional wheat is forecasted under a constant yield growth assumption. In the report "World agriculture towards 2015/2030", FAO (2002b) projected a yield growth of 1.1% per year between 2000 and 2030. This yield growth is under the assumption that no more new technology will become available. This yield growth appears to be exaggerated if the historical trend is considered. Therefore in this model a rate of growth of 1.01% is assumed, which is implies that conventional technology will manage to maintain the rate of growth observed between 1989 and 2002. The maximum obtainable yield minus the actual yield is defined as the yield gap. According to the "World Agriculture towards 2015/2030" report, most countries have a yield gap similar to that of France, which was around 20% in 1999.[24]

GM technology may narrow the yield gap in the future. According to Kalaitzandonakes (2003) over time GM crops should lead to higher yield through the reduction of production risks. According to Virmani *et al* (1993) it is possible to increase wheat yields (among other cereal yields) by as much as 20% just by extending hybrid variety development. For the development of the estimation it is assumed that the yield gap globally in 1999 is 20%. The maximum obtainable yield can be estimated at the global level using conventional varieties (in 1999):

$$\text{MaxYc}_{1999} = (1+ \text{yield gap}_{1999}) * \text{Yc}_{1999} = 3.30 \text{ tonne/Ha} \qquad (4.11)$$

---

[24] This value is calculated as follow: yield gap = [(average obtainable yield-average actual yield)/average actual yield]*100. The values are taken from the FAO report.

Assuming conventional technology can keep the growth rate (gc) between the years 2000 and 2030 at the level of annual yield growth in the period 1989-2002 (gc = 1.01%), the yield for conventional production at time t is:

$$Yc_t = Yc_{t-1}(1+gc) \tag{4.12}$$

In contrast the yield of conventional production in 2030 will be:

$$Yc2030 = Y_{2002}(1+0.0101)^{t-2002} = 3.57 \text{ tonne/Ha.} \tag{4.13}$$

If conventional technology can maintain the growth rate at 1.01%, the conventional yield would be unable to reach 4 tonne/ha by 2042. The value of 4 tonne/ha is thus used as the maximum yield for the conventional technology in the future decades.[25] GM wheat may contribute to closing the yield gap from 2005 to time T:

$$Ybt = Yct + 0.1\ \delta 1\ (t-2005)\ \text{Yield gap}_{2005} \tag{4.14}$$

The constant 0.1 is an assumed annual decrease in the yield gap due to biotechnology. Here it is assumed that this decrease is a linear function of time. The term δ1= 0 if the first generation of GM wheat is not developed or commercialized, and δ1=1 if it is commercialized. Before 2005, the term δ1 is equal to zero. Substituting Yct by its expression, the following equation representing biotechnology yield is:

$$Ybt = Yc2005\ (1+0.01)^{t-2005} + 0.1\ \delta 1\ (t-2005)\ \text{Yield gap}_{2005} \tag{4.15}$$

Solving this equation for the time when biotechnology will close the yield gap (T), it is determined that the yield gap is closed when

$$Yb_T = MaxYc_t \tag{4.16}$$

Substituting Ybt into equation 4.15 yields:

$$Max\ Yct = Yc_{2005}\ (1+0.01)^{T-2005} + 0.1\ (T-2005)\ \text{Yield gap}_{2005} \tag{4.17}$$

Solving this equation for time (T) we find that the yield gap is closed in 2013. From 2013 to 2030, the effect of biotechnology on yield depends on whether any subsequent generations are developed and commercialized or not. Gray *et al* (2001b) suggest that the introduction of GM crops will attract private investment to the industry and accelerate the yield growth rate by 50%, such that the biotechnology yield beyond 2013 could be estimated by the following equation:

$$Ybt = Yb_{2013}(1+ gc + \delta_2 xg)^{(t-2013)} \tag{4.18}$$

where xg is the extra growth that biotechnology could offer. The term xg is assumed to be equal to (0.5 gc). The term δ_2 equals 0 if the second generation of GM wheat is not developed or commercialized; it equals 1 if GM wheat is developed and commercialized. Here it is assumed that once the second generation is commercialized, it will totally substitute for the first generation since it is offers superior performance. Global yield of wheat is determined by:

$$Y_t = \theta b_t Yb_t + \theta c_t Yc_t = \theta b_t Yb_t + (1- \theta b_t) Yc_t \tag{4.19}$$

where θb_t is the global adoption rate of GM wheat at time t, and θc_t is the global adoption rate of conventional wheat varieties at time t.

Yield data of wheat from FAO (2004) database (FAOSTAT) is used to calculate yield variability. Under the assumption of no climate change, the random variables are generated each year to create a yield variability pattern resembling that of the period 1989-2002. The expected variance is 1.6%, which is the yield variance that actually occurred over the period 1989-2002 (see Table 4.4). The yield variability for 1961-1974 is chosen to serve as climate change value, since it is a midpoint between the other two

---

[25] This value is a long run upper limit and not technical maximum yield.

periods and therefore represents not the most variable or least variable conditions experienced over the last three decades. Therefore, to simulate greater variability under the assumption of climate change the random variables are selected at random each year to create a pattern resembling that of period 1961-1974 (see Table 4.4).

Table 4.4 – Historical wheat yield variability

	1961-1974	1975-1988	1989-2002
Variance	3.85%	5.88%	1.59%
Standard deviation	19.61%	24.24%	12.62%

Source: Author's calculations from FAO (FAOSTAT)

Based on these simulated yield variability data the realized yield for the given year for each point j is estimated by:

$$Y_{rt} = Y_t\,(1+ v) \tag{4.20}$$

where v is a random variable generated based on the expected variance. The key parameters in the market model are the price elasticity of demand, price elasticity of area (or area response), and price elasticity of stock, which are based on other estimates. For the present study, the price elasticity of global consumption (or global demand) for wheat is chosen to be equal to –0.15.[26] In this study, the global area elasticity is assumed equal to 0.5.[27] The stock elasticity is calculated by dividing the demand elasticity by the average stock-to-use ratio in the 1961-2000 period using USDA data (in order to take

---

[26] The overall elasticity of demand for wheat is regarded as highly inelastic. According to Alstonne et al (1997) the elasticity of demand for food wheat overall elasticity is equal to -0.2. In this study, the results did not change for the elasticity of demand in the range of –0.1 and –0.2. This range is similar to the one that Alstonne et al (1994) assumed for the overall elasticity of demand for milling wheat and durum wheat. Sullivan et al (1989) reported price elasticity of demand for major importers ranging from –0.1 to –0.4, with the rest of the world (ROW) having a demand elasticity equal to –0.25. Benirshka and Koo (1995) determine elasticities of demand for different countries and regions. The elasticity values vary from -0.005 for Japan to -0.3 for Australia. DeVuyst (2001) calculates the demand elasticity for the the rest of the world (ROW) from this data and it found it equal to -0.1.

[27] The intermediate-run value of acreage response was estimated by Alstonne et al (1994) to be equal to 0.5 (or less) for Canada and the rest of the world (ROW). The Organization for Economic Cooperation and Development (OECD, 1986) estimates the supply elasticity to be 0.5 for the US and 0.46 for the EU.

into account the variability in stock-to-use ratio over the years), which yields a stock price elasticity of -0.55, indicating that storage is more responsive to price changes than consumption.

Global consumption at time t is estimated by equation 4.21. It is assumed that future global income growth will reduce the global consumption of wheat per capita (wheat is considered an inferior food) just enough to offset population increase. [28]Therefore the global consumption equation is:

$$GC_t = a + b * P_t \qquad (4.21)$$

where a and b are the intercept and the slope of the consumption function respectively. The realized global production (PR_t) is the most important variable for supply. Global production is the product of wheat acreage (At) and realized yield (Y_{tr}).

$$A_t = c + d * P_t \qquad (4.22)$$

where c and d are the intercept and the slope of the acreage function respectively.

$$PR_t = A_t \, Y_{tr} \qquad (4.23)$$

The total global supply (GS_t) of wheat is the sum of initial stock (st-1) and production.

$$GS_t = PR_t + S_{t-1} \qquad (4.24)$$

where the term S_{t-1} is the ending global stock from the previous year. The global stock equation is calculated as:

$$S_t = e + f * P_t \qquad (4.25)$$

where e and f are the intercept and the slope of the stock function respectively.

---

[28] This assumption is mainly to simplify the modeling. A more complicated approach would be to assume that demand is affected by income growth, and population growth and adjust the demand each year according to income and population projections. However this will complicate the analysis since in this case it is necessary to break the demand growth by level of income and have different income elasticites of each income level.

The equilibrium condition is satisfied when total demand is equal to total supply. Solving for the price to ensure the equilibrium will provide the real price at time t:

$$GCt + St = GS_t \qquad \Rightarrow \qquad Pt = Pt^* \tag{4.26}$$

To check the effect of opposition to GM wheat on volatility of future prices, the expected prices—converted to inflation-adjusted terms using the US GDP price deflator index 2000—are arranged in two intervals. These intervals consist of low to medium expected prices [expected prices <High price], and high expected prices [expected prices ≥ High price]. For each year, High Price is calculated as one standard deviation above the mean hence the high price would adjust as the mean price falls.

The base price for wheat (for the year 2000) is estimated to be $145/tonne.[29] Consumption, acreage, and stock parameters are calibrated using this price. These specific calibrated parameters for the world are presented in Table 4.5.

Table 4.5 – Calibrated consumption, acreage, and stock parameters

	Consumption Parameters		Acreage Parameters		Stock Parameters	
	a	b	C	d	e	F
World	682.4	-0.6	107.1	0.7	176.4	-0.4
Source: Authors' calculations.						

4.5. Conclusion

In this chapter, the adoption of GM crops is estimated as a function of consumer acceptance or tolerance. The results show that factors such as local and foreign tolerances to GM food may be not only the driving factors of diffusion of GM crops in the past, but may also control the future of this technology. The diffusion model developed is integrated into global food security models to predict the effect of GM wheat on global food security under different scenarios of local or foreign tolerances. This global food security model is dynamic and responsive to environmental factors such as climate change as well as technology-related factors such as opposition to GM food. Chapter 5 will use the global food security model developed in this chapter to simulate the effect of different degrees of opposition to GM wheat on food security.

---

[29] Estimated from average US dollar-denominated free on board Gulf of Mexico export price for US HRS No2.

CHAPTER 5 : SCENARIOS

5.0. Introduction

Opposition to GM crops is based on environmental and food safety concerns over GM food. On the other hand support for biotechnology is based on the promise of “great” benefit for both consumers and producers, and even the environment. The debate over what good or bad can come from this new technology was and still is the focus of an abundant literature. However, there is no study that connects opposition to this technology to its potential benefits. In this chapter, the effect of opposition to GM wheat on what biotechnology can offer in terms of global food security is examined and quantified. This chapter presents quantitative analysis using the global food security model developed in the previous chapter. The adoption model is shocked with different levels of EU tolerance to GM wheat while the supply model is shocked by different assumptions about how future GM wheat may affect the yield growth along the GM wheat development path until the year 2030. The research will enrich the GM debates through quantitative work covering a wide range of scenarios combining both degrees of opposition to GM food and benefits.

5.1. Scenarios

A number of scenarios were developed using the diffusion model specified in the previous chapters. Each of the scenarios represents a set of alternative conditions that may exist in future development paths. In all scenarios, it is assumed that agricultural biotechnology will target genetic modification of yield potential in wheat. This may be achieved by the development of GM wheat with multiple traits including pest resistance and yield increasing and could increase the yield growth effectively. Each of the scenarios developed is summarized in Table 5.1.

Scenario 1.a involves the EU remaining GM resistant (GM free) even in the face of climate change. In this scenario, the EU opposition induces widespread opposition to GM wheat in major wheat importing countries. This widespread rejection of GM wheat would give no incentive for GM food producing countries to introduce GM wheat. Scenario 2.a involves the EU accepting GM crops in response to climate change. In this scenario, EU consumers have maximum tolerance to GM wheat. If the EU has maximum tolerance to GM wheat, it is most likely that EU wheat farmers will adopt GM wheat in order to avoid lagging behind other exporting countries in wheat productivity. EU acceptance of GM wheat will induce high consumer tolerance in major importing countries, since this European acceptance will be taken as endorsement of GM wheat and as an ending of the debate over the safety of GM food.

The other scenarios where climate change is assumed are identified as Scenario 1.b, 1.d, and Scenario 2.d. The purpose of these additional scenarios is to create data points for comparison to allow the estimation of the impact of EU policy on food security. In Scenario 1.b, China adopts GM wheat despite the widespread rejection of the product which is plausible given that China is not an exporter of wheat. In Scenario 1.d, the EU opposition induces opposition to GM wheat in only Maghreb countries (Tunisia, Algeria, and Morocco), Japan and South Korea. In Scenario 2.d, the EU acceptance will not induce acceptance in Japan and South Korea.

In order to account for the possibility of no climate change and to evaluate the relative impact of climate change conditions, the EU non-GM/GM scenarios' 1.a and 2.a were rerun under an assumption of no climate change. Scenario 1.c examines widespread opposition if climate change does not happen while Scenario 2.c involves widespread acceptance under similar climatic conditions (see Table 5.1).

Table 5.1 – Opposition scenarios

	EU NON GM SCENARIOS				EU GM SCENARIOS		
	Scenario 1.a	Scenario 1.b	Scenario 1.c	Scenario 1.d	Scenario 2.a	Scenario 2.c	Scenario 2.d
Weather: Climate Change	Yes	Yes	No	Yes	Yes	No	Yes
Potential Adopters: Adopt or Not							
Australia	No	No	No	Yes	Yes	Yes	Yes
Argentina	No	No	No	Yes	Yes	Yes	Yes
Canada	No	No	No	Yes	Yes	Yes	Yes
China	No	Yes	No	Yes	Yes	Yes	Yes
USA	No	No	No	Yes	Yes	Yes	Yes
EU	No	No	No	No	Yes	Yes	Yes
Major Importers: Import or Not							
Maghreb	No	No	No	No	Yes	Yes	Yes
Japan	No	No	No	No	Yes	Yes	No
South Korea	No	No	No	No	Yes	Yes	No
Others	No	No	No	Yes	Yes	Yes	Yes

It is important to note that "Yes" for a major adopter or a major importer in table 5.1 indicates total acceptance by that country, and the country is given a maximum tolerance (value of 5). In contrast "No" by an importer indicates that GM wheat is banned by that country and it is given a zero tolerance index. Saying “No” by an adopter means that GM wheat is not adopted, and that the tolerance to GM wheat is equal to zero. This tolerance scale (0-5) was introduced in the diffusion model (Chapter 4).

In each scenario, the model developed in Chapter 4 is used to simulate how food security is affected by various consumer responses to GM wheat. In each scenario estimation involved the following steps: 1) local tolerance was assumed depending on each scenario (equation 4.2); 2) the foreign tolerance index facing potential GM wheat adopters is calculated (equation 4.3); 3) the adoption rate in each of those countries is estimated (equation 4.4 to equation 4.9); 4) the global adoption rates of GM wheat are determined (equation 4.10); and 5) the global adoption rate is then combined with the market model to compute global food security. It is important to emphasize that the goal from these scenarios is not the prediction of prices in the next decades. The main goal is the estimation of the impact that opposition to GM wheat will have on the expected price levels and variability compared with what would otherwise prevail.

The comparison between the scenarios is used to estimate the impacts of the EU policy on global adoption of GM wheat and on global food security (see Table 5.2).

- Scenario 1.a compared to Scenario 1.b provides estimates of the impact of Chinese adoption despite the widespread opposition.
- Scenario 1.a compared to Scenario 2.a provides estimates of the impact of EU policy when there is widespread induced opposition.
- Scenario 1.d compared to Scenario 2.a estimates the impact of EU policy when there is limited induced opposition.

- Scenario 2.a compared to Scenario 2.d estimates the role of Japan and Korea policies on food security.
- Scenario 1.c compared to Scenario 2.c estimates the impact of EU policy when there is widespread induced opposition under no climate change.
- Scenario 2.c compared to Scenario 2.a estimates the effect of climate change.

Table 5.2 – Summary of analysis provide by scenario comparisons

	Scenario 1.a (Full rejection; Climate change)	Scenario 1.c (Full rejection; No climate change)	Scenario 1.d (Limited rejection; Climate change)	Scenario 2.a (Full acceptance; Climate change)
Scenario 2.a (Full acceptance; Climate change)	Effect of Widespread opposition with climate change		Effect of Limited opposition with climate change	
Scenario 1.b (Only China adopts; Climate change)	Effect of Chinese Adoption			
Scenario 2.d (Japan and South Korea Oppose, Climate change)				Effect of Japan and South Korean opposition with climate change
Scenario 2.c (Full acceptance; No climate change)		Effect of widespread opposition with no climate change		Effect of climate change

5.1.1. Local and foreign tolerance indices for the specified opposition scenarios

The first step to compute the adoption rates of potential adopters is to determine the level of tolerance level (foreign tolerance index) facing those countries. Table 5.3 reports the local and the index of foreign tolerance facing major wheat exporters and China in all selected scenarios. In full rejection scenarios (Scenario 1.a or Scenario 1.c) the EU not only refrains from adopting GM wheat, but the region also bans any wheat import from GM adopting countries. The EU strong opposition will induce widespread opposition to GM wheat by all importing countries. Due to this full rejection, all importing countries will impose a ban on both GM wheat and non-GM wheat from GM wheat producing countries. This opposition means that all wheat exporters are faced by an index of foreign tolerance equal to zero. The widespread opposition causes major wheat exporters to not introduce GM wheat (zero local tolerance). In this case, GM wheat is adopted neither regionally nor globally.

Table 5.3 – Local and foreign tolerance indices for the specified opposition scenarios

		Argentina	Australia	Canada	China	EU	USA
Scenario 1.a or Scenario 1.c	Local Tolerance	0	0	0	0	0	0
	Index of Foreign Tolerance*	0	0	0	0	0	0
Scenario 1.b	Local Tolerance	0	0	0	5	0	0
	Index of Foreign Tolerance*	0	0	0	0	0	0
Scenario 1.d	Local tolerance	5	5	5	5	0	5
	Index of foreign Tolerance*	3	3	2	0	1	2
Scenario 2.a or Scenario 2.c	Local Tolerance	5	5	5	5	5	5
	Index of Foreign Tolerance*	3	4	2	0	1	2
Scenario 2.d	Local Tolerance	5	5	5	5	5	5
	Index of Foreign Tolerance*	3	3	2	0	1	2

Source: Author's calculations. *the index of foreign tolerance is calculated using equation 4.12. The foreign tolerance indices are base on assumptions about local tolerance of different countries in different scenarios.

In Scenario 1.b all importers but China ban the import of GM wheat. China adopts as well as imports GM wheat. Despite the fact that in this scenario China has maximum local tolerance, the calculated index of foreign tolerance facing major wheat exporters is still equal to zero (see table 5.3). The index of foreign tolerance facing major wheat exporters can be rounded to zero. This indicates that China's acceptance will not be enough to encourage major wheat exporters to introduce GM wheat, since all other importers would have zero tolerance to GM wheat. China is not a wheat exporter, and therefore the only factor driving the adoption decision in China is the local tolerance.

In scenario 1.d, the EU still opposes GM wheat and neither adopts GM wheat nor imports wheat from GM adopting countries. But, unlike in Scenario 1.a, only the Maghreb countries, Japan, and South Korea follow the EU policy— all other countries become GM tolerant. Table 5.3 reports the index of local and foreign tolerance facing China and major wheat exporters in Scenario 1.d. Among wheat exporters, Australia has the highest foreign tolerance, and the EU has the lowest. This is because the EU exports a higher share of its wheat production to Magreb countries than Australia does (see Appendix C). Australia exports only about 12% of its production to potential rejecters.

In full acceptance scenarios under climate change (Scenario 2.a) and no climate change (Scenario 2.c), the EU has maximum tolerance to GM wheat. This acceptance will lead to maximum tolerance by all countries in the world. In this case major wheat exporters and China will adopt GM wheat. The index of foreign tolerance is highest for Australia (see Table 5.3) due to a larger share of Australia's wheat production is destined for export as compared to others.

In Scenario 2.d, Japan and South Korea might sustain a ban on the import of wheat from GM adopting countries regardless of the EU policy. If this were to occur, among the major exporters, Australia and Argentina would have the highest index of foreign tolerance (Table 5.3). This can be explained by the fact that both Australia and Argentina export a larger share of their production to GM tolerant countries, and a smaller share of its production to Japan and South Korea (see Appendix C). The EU has the smallest index of foreign tolerance (after China), due to its small export to production share. Despite this opposition, the otherwise relatively high foreign tolerance to GM wheat would act as a driver for the adoption of GM wheat by major wheat exporters.

5.1.2. GM wheat adoption rates under the specified opposition scenarios

The tolerance levels calculated above are used to compute the adoption rates of potential adopters in each scenario (see Table 5.4) using the model described in chapter 4. In the full rejection scenarios (Scenario 1.a or Scenario 1.c) GM wheat is not adopted by any country. In scenario 1.b, China will start adopting GM wheat in 2007. The level of adoption of GM wheat in China will increase to reach the level of 30% in 2030. Since China is the only adopter, the global adoption of GM wheat is forecast to be low, not exceeding the 4% level (Table 5.4).

In the limited rejection scenario (scenario 1.d), despite the opposition to GM wheat, major wheat-exporters (except the EU) will adopt GM wheat. Canada and the USA are the early adopters. In 2030, the adoption rate is 70% in the USA, and over that in Argentina, Australia, and Canada. In this scenario, the global adoption rate will reach over 20% in 2030. In scenario 2.a and scenario 2.c, Canada and the USA are the first adopters of this new technology starting in 2005. Other exporters follow in 2006, and China in 2007. Argentina, Australia, Canada, and the USA have very high adoption rates, exceeding 70% in 2030. The EU however has an adoption rate lower that 50% in 2030. In all scenarios, it is assumed that GM wheat will be adopted mainly by major wheat exporters and China, therefore the rest of the world adoption rates is kept at zero.

In these scenarios, the global adoption rate increases from 3% in 2005 to reach 25% in 2030 (Table 5.4).

Table 5.4 – GM wheat adoption rates in major exporters, China and the World

		Argentina	Australia	Canada	China	EU	USA	World
Scenario 1.a or Scenario 1.c	Adoption rate in 2005	0%	0%	0%	0%	0%	0%	0%
	Adoption rate in 2030	0%	0%	0%	0%	0%	0%	0%
Scenario 1.b	Initial Adoption year				2007			2007
	Adoption rate in 2005	0%	0%	0%	0%	0%	0%	0%
	Adoption rate in 2030	0%	0%	0%	30%*	0%	0%	4%
Scenario 1.d	Initial Adoption year	2006	2006	2005	2007		2005	2005
	Adoption rate in 2005	0%	0%	26%	0%	0%	19%	3%
	Adoption rate in 2030	71%	73%	72%	30%*	0%	70%	21%
Scenario 2.a or Scenario 2.c	Initial Adoption year	2006	2006	2005	2007		2005	2005
	Adoption rate in 2005	0%	0%	26%	0%	0%	19%	3%
	Adoption rate in 2030	71%	78%	77%	30%*	48%	75%	25%
Scenario 2.d	Initial Adoption year	2006	2006	2005	2007		2005	2005
	Adoption rate in 2005	0%	0%	26%	0%	0%	19%	3%
	Adoption rate in 2030	71%	73%	73%	30%*	48%	72%	25%

*The adoption rate in China is small because it is mainly driven by local tolerance, which was assigned a less coefficient index in the diffusion model than that for the foreign tolerance. For more detailed regional and global adoption results please see Appendix D.
Source: Author calculations

In scenario 2.d, Canada would have the highest adoption rate during the whole period, reaching an adoption rate of 73% in 2030. Australia would attain the same level in 2030. Along with Australia and Canada, Argentina and the USA also have relatively high adoption rates, exceeding 70% in 2030. The EU however has an adoption rate around 48% in 2030. In this scenario, the global adoption rate will increase rapidly from only 3% in 2005 to 25% in 2030 (Table 5.4).

5.1.3. Food security elements under the specified opposition scenarios

The global adoption rates calculated above for each scenario are integrated in the market model in order to compute food security elements. The results are presented in Table 5.5. Before explaining these results, it is important to check first whether the simulation results are consistent with past trends. This check is done for scenario 1.a by comparing expected prices from this scenario with past trends of prices. Historical prices from 1980 to 2000 (not simulated) are plotted in the same figure as the simulated average, minimum and maximum expected price from 100 runs in Scenario 1.a from 2000 to 2030 (see Figure 5.1). Since 1980, there have been three price spikes –in 1980, 1988, and 1995. The price spikes were short lived, and the long-term decline in real wheat prices continued. The result of the simulation is consistent with this trend. It is expected that the long-term decline in real wheat prices will continue with the probability of some price spikes occurring during the simulation horizon. Figure 5.1 also shows the maximum expected price declining over time.

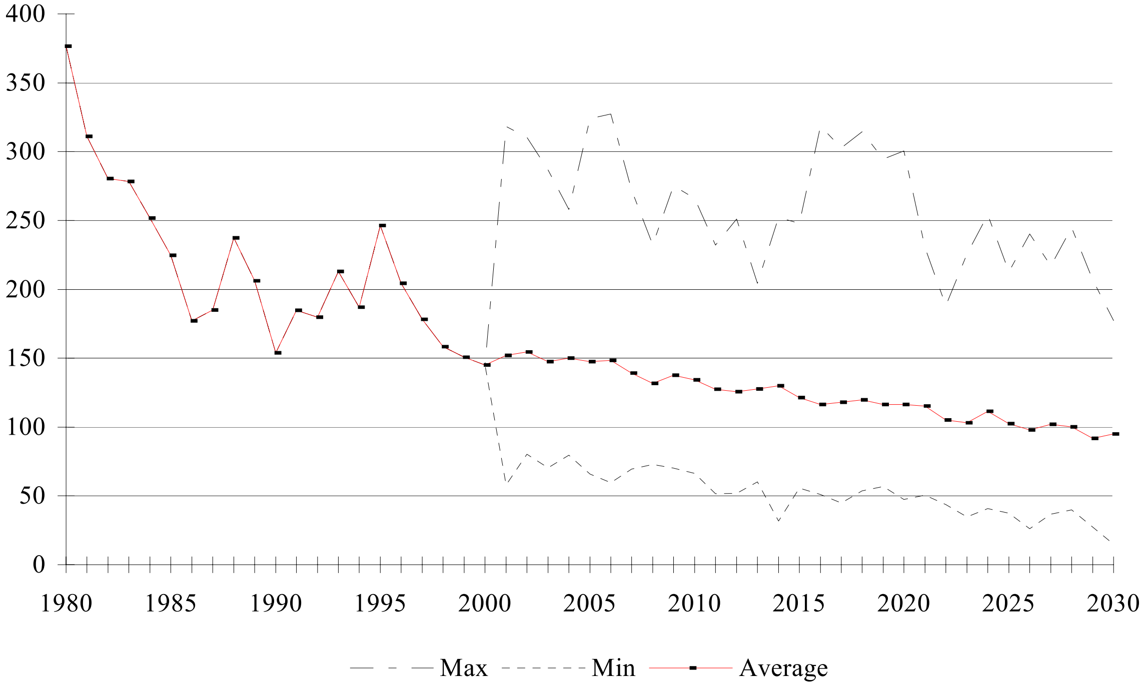


Figure 5.1 – Average, minimum, and maximum expected prices 1980-2030

In Table 5.5, the results of scenario 1.a along with the results of other scenarios are presented in more details. By not adopting GM wheat (Scenario 1.a or Scenario 1.c), the world will not take advantage of the productivity gain that GM wheat may offer. Therefore, in these two scenarios, conventional varieties are the only production technology that could be used. The effect of conventional technology on future prices will be influenced by whether climate change will occur or not (Scenario 1.a or Scenario 1.c). In scenario 1.a, conventional wheat varieties will permit the increase of wheat availability by 7% from 2000 to 2030. This increase in availability will lead to a decline in expected world wheat prices by 34% from 2000 to 2030. The decline in prices will induce a 5% increase in consumption. The ending stock of wheat is predicted by the model to increase by 19% from 2000 to 2030. Therefore, global food security is predicted by the model to improve from year 2000 to 2030 (Table 5.5).

Table 5.5 – Change in availability, expected price, consumption, ending stock, and probability of high prices between 2000 and 2030.

	Availability	Expected Price	Consumption	Ending stock
Scenario 1.a	7%	-34%	5%	19%
Scenario 1.c	8%	-37%	6%	19%
Scenario 1.b	8%	- 36%	5%	20%
Scenario 1.d	9%	- 42%	6%	23%
Scenario 2.a	9%	- 44%	7%	24%
Scenario 2.c	10%	- 46%	7%	26%
Scenario 2.d	9%	- 43%	7%	24%

Source: Authors' calculation from simulation results. For more detailed results see Appendix E.

In Scenario 1.c, GM wheat is fully rejected, but climate change does not occur. Expected prices, and ending stocks are characterized with the same trend as in Scenario 1.a. Conventional technology will increase the availability of wheat by 8% from 2000 to 2030. As a result, expected prices are predicted to decline by 37% from 2000 to 2030. Consumption will increase by around 6% in the same period. The stock of wheat will increase by 19% from 2000 to 2030. Therefore the global food security situation is expected to improve in the coming decades (Table 5.5).

In scenario 1.b, GM wheat in combination with the conventional varieties, will increase the global availability of wheat by 8%. It is estimated that this increase in availability will lead expected wheat prices to decline by 36% from 2000 to 2030. The consumption is expected to increase by 5% from 2000 to 2030. The ending stock is projected to increase by 20% from 2000 to 2030 (Table 5.5).

In scenario 1.d (limited opposition and climate change), the adoption of GM wheat (along with conventional varieties) will increase availability of wheat by 9% between 2000 and 2030. This increase in availability will cause a decline in expected world wheat prices by 42% from 2000 to 2030. Consumption of wheat will increase by 6% as a result of the expected price decline. The ending stock is expected to increase by 23% from 2000 to 2030 (Table 5.5).

If GM wheat is fully accepted and climate change occurs (Scenario 2.a) wheat availability will go up by 9% from 2000 to 2030. This increase in availability will drive expected wheat prices down by 44% from 2000 to 2030. Consumption goes up by 7% due to the expected price decline (Table 5.5).

If GM wheat is fully accepted but climate change does not occur (2.c), the adoption of GM wheat will increase wheat availability by 10%. As a result of the increase in availability, the expected wheat price would decline by 46% between 2000 and 2030. Consumption is predicted to rise by 7% as a response to the expected price decline and the ending stock is projected to decline by 26 % between 2000 and 2030 (Table 5.5).

In scenario 1.d, the relatively high adoption rate despite the opposition would increase availability by 9% from 2000 to 2030, which would lead to an expected price decline of 43%. This expected price decline would increase consumption by 7%. The ending stock would be expected to increase by 24% from 2000 to 2030. The adoption of GM wheat would contribute to stabilizing expected prices despite the opposition of Japan and South Korea (Table 5.5).

In all scenarios, future prices are expected to continue to vary between 2000-2005 and 2025-2030 periods (see Table E.5). The probability of high prices will continue to be high exceeding 14% in all periods and exceeding 18% in 2010-2015 and 2020-2025 (Table E.4).

In conclusion, the results of the simulations suggest that:

- Whether climate change occurs or not over the next three decades, the food situation will continue to improve. The long-term decline in real wheat prices will continue, with the probability of some price spikes occurring. The conventional technology will be able to expand the wheat availability to cover the increasing consumption in the coming decades and will permit some increase availability of food. This improvement will lead the expected prices of wheat to fall from their level in 2000. This decline of expected prices between 2000 and 2030 will induce higher consumption.
- Even with climate change the adoption of GM wheat by only China is expected to help improve the global food security situation in the coming decades.
- Despite some expected rejection of GM wheat, the adoption of GM wheat will be relatively high. This will allow the global food security situation to improve further, with increased food availability and reduced expected prices.
- Regardless of whether climate change happens, the adoption of GM wheat by major wheat exporters and China would enable expected prices to decline significantly by increasing the availability of food, which would ease food insecurity problems, especially for the poor who are the most sensitive to prices.

5.2. Effect of opposition on GM wheat adoption

The scenarios can be compared to derive estimates of the impacts of the EU policy on regional as well as global adoption of GM wheat and on global food security (Table 5.6).

Widespread opposition (with or without climate change) would greatly affect adoption rates of GM wheat in major wheat exporters. At the country level, the adoption reaction to this opposition is above 70% in 2030 for Canada, the USA, Argentina and Australia. However, the adoption reaction is around 48% for the EU. This is because Argentina, Australia, Canada, and USA export a larger share of their wheat production, and therefore GM wheat adoption is more limited by foreign opposition. The adoption reaction to widespread opposition is particularly small for China (30% in 2030). This is because almost none of the production is sold in foreign markets; therefore only the local opposition influences the adoption reaction there.

Widespread induced opposition would cause the global adoption rate to be lower (comparing scenarios 1.a and 2.a). The results (Table 5.6, column 1 and column 2) suggest that if the EU induces widespread opposition (whether climate change occurs or not), there will be a decline in the GM adoption rate by as much as 25% by 2030. It is important to mention that the underlying assumption in the adoption model—that only the major wheat exporters and China are likely to adopt GM wheat in any circumstances—may under-estimate the effect of widespread opposition on global adoption. The effect of widespread opposition varies depending on whether climate change occurs. If climate change occurs, widespread opposition would deprive the world of a range of potentially more productive varieties (GM wheat). Therefore, overall potential availability declines by as much as 1.8%, causing the world price for wheat to be more than 16% higher in 2030 than it otherwise might be. The increased expected world prices would cause consumption to decline by about 1.3% in 2030. Widespread opposition would negatively affect the ending stock, by up to 4% in 2030 (Table 5.6). It is important to mention that consumption of wheat in poor countries is more sensitive to expected price changes, and therefore it is expected that most of the consumption decline due to expected price increase would be in poor countries.

If climate change does not occur and there is widespread opposition (comparing scenarios 1.b and 2.b, column 2, table 5.6), the results are slightly different. Widespread opposition would lower availability by 2%, leading to an expected price rise of 17% in 2030. This increase in expected price would reduce consumption by 1.2% in the year 2030. As a result of this expected price increase, the ending stock would shrink by around 5% in 2030. The probability of high expected prices is not predicted to increase in 2025-2030 because of widespread opposition, whether climate change occurs or not (Table E.5). However the variability of prices seems to increase beyond 2010 especially under the climate change assumption (see Table E.5).

If the EU induces limited opposition (comparing scenarios 1.d and 2.a, column 3, Table 5.6), the adoption response of potential adopters is small in the case of Argentina, Australia, Canada and the USA because only a very small share of their wheat production is sold to those markets (see Appendix C). Due to the limited opposition induced by the EU, potential GM adopters slightly decrease their GM wheat adoption by 1% to 5%. The adoption response to this opposition is zero for China (China adopts GM wheat), since that market is independent of export market. In contrast, if the EU itself opposes GM wheat, there would be significant losses of potential adoption equal to 48% in the EU in 2030. The global reaction to the limited opposition is only 5% in 2030. The decline in global adoption due to limited rejection would decrease wheat availability by not more than 0.3%. This decline in availability, although small, would lead expected prices to be 3% higher than otherwise in 2030. The expected price increase would decrease consumption by only 0.2% (Table 5.6). Limited opposition is not expected to change the probability of high expected prices (Table E.5), nor the variability of future prices by much (Table E.5).

Table 5.6 – Effect of opposition to GM wheat on adoption and food security elements in 2030

	Widespread Opposition With climate Change	Widespread Opposition With No Climate Change	Limited Opposition With Climate Change	Japan and South Korea Opposition	China Adoption	Effect of Climate Change
Adoption Rates						
World	- 25%	- 25%	- 5%	-1%	+4%	0%
Argentina	-71%	-71%	0%	0%	0%	0%
Australia	-78%	-78%	-5%	-5%	0%	0%
Canada	-77%	-77%	-5%	-3%	0%	0%
China	-30%	-30%	0%	0%	+30%	0%
EU	-48%	-48%	-48%	0%	0%	0%
USA	-75%	-75%	-5%	-3%	0%	0%
Food Security Elements						
Expect Price	+16.33%	+17.01%	+2.94%	+0.46%	-2.30%	+4.96%
Availability	-1.81%	-2.02%	-0.32%	-0.05%	0.30%	-0.52%
Consumption	-1.29%	-1.28%	-0.23%	-0.04%	0.21%	-0.37%
Ending Stock	-4.10%	-5.32%	-0.74%	-0.12%	0.70%	-1.17%

Source: Author's calculation from the food security model simulations. See Appendix D and E for more detailed results.

In contrast to the above results if Japan and South Korea oppose the technology (comparing scenarios 2.a and 2.d, column 4, Table 5.6), there will only be a small effect on regional as well as global adoption. Chinese adoption of GM wheat is independent of whether or not Japan and South Korea ban GM wheat, because as mentioned before, China is not a wheat exporter. The decision of China to adopt GM wheat is completely determined by local policy. Neither the EU's nor Argentian adoption of GM wheat are affected by Japan and South Korea opposition because they export less that 0.2% of their production to South Korea, and do not export to Japan. Australia is the most affected by this opposition, since over 11% of its production goes to Japan and South Korea. The response of Australia to Japan and South Korea opposition would be to lower Australia's GM wheat adoption by 5% in 2030. Canada and the USA will equally respond to the opposition to GM wheat by a decline in their adoption rates by 3% in 2030. Japanese and South Korean opposition equally affects Canada and the USA, since both countries export approximately 8% of their production to these countries. The slight adoption response to Japan and South Korea opposition in Australia, Canada and the USA means that Japan and South Korea opposition is not an essential factor in the global adoption of GM wheat. As seen in Table 5.6, the adoption response to this opposition is a decline of global adoption of only 1%. If only Japan and South Korea oppose GM wheat, there would only be a very small influence on the availability of wheat. The greatest impact this opposition might have would be to decrease the availability by 0.1% in 2030. As a result, the effect of Japan and South Korea opposition on expected prices does not exceed 0.5%. This is expected to have only a very small effect on the future consumption. This opposition has no effect on the probability of high expected prices (Table E.5) nor on the price variability in the future (Table E.6).

There is a real possibility that China might adopt GM wheat, regardless of what others do. If China adopts GM wheat (comparing scenario 1.a and 1.b, column 5, Table 5.6), its adoption rate could reach 30% by the year 2030. The adoption of GM wheat by China would not likely induce adoption by major wheat exporters. Argentina and the EU export less than 1% of their production to China, which is too little to motivate these two countries to adopt GM wheat. Meanwhile, Australia and the USA export over 4% of their production to China, whereas Canada exports about 10% of its production to China. Overall, this share of production is small, and the risk of losing other markets would discourage most of these exporters from adopting GM wheat. China’s adoption of GM wheat would alone lead to global adoption equal to 4% by 2030. This would lead to an increase in global wheat availability, thereby lowering expected prices by 2.3% in 2030. The expected price decline would lead to consumption increasing by 0.2% in 2030. The ending stock would increase by 0.7% in 2030 (Table 5.6). China’s adoption would have no obvious effect on the volatility of expected prices (Table E.6), or on the probability of high expected prices (Table E.5). Therefore, the simulation results indicate that China’s decision about GM wheat will have a more significant impact on global food security than either the impact of the Magreb countries or Japan and South Korea.

In the diffusion model, climate change was not included as a driving factor—climate change is assumed to neither motivate nor discourage countries to adopt GM wheat. However, climate change is expected to affect availability, expected price, consumption, and ending stocks by affecting the variation of yields (comparing scenarios 2.a and 2.c, column 6, Table 5.6). Climate change by itself will decrease the availability of wheat by as much as 0.5% in 2030 and could raise prices by 5% from status quo prices. The consumption reaction to this expected price increase would be a decrease of 0.37%, and the ending stocks would decline by more than 1%. Perhaps most importantly, climate change is expected to significantly increase the variability of prices in the coming decades, which would particularly imperil poor consumers in developing countries (Table E.6).

The price changes due to the opposition to GM wheat will affect the number of undernourished people in developing countries by affecting their ability to acquire adequate amount of food. Estimations of number of undernourished people are represented in the last row of Table 5.7. It is assumed here that only wheat will be affected by this opposition to GM food. The increase in wheat prices due to the opposition to GM wheat will lead to a decline of wheat consumption in developing countries. It is estimated by FAO (2002b) that wheat demand will present 40.35% of cereal demand in 2030 and that cereal will contribute to 43.41% of the total consumption. Therefore, wheat will contribute by 17.52% to total food consumption or average food intake in developing countries. The Sixth World Food Survey released by the FAO estimates that by 2030, 6% of the population in developing countries will be food insecure (FAO, 1996). This estimate was obtained by specifying that in 2030 the average food intake (average food consumption) is equal to 2980 kcal/person/day, and that the threshold below each a person is considered undernourished is equal to 1882 kcal/person/day. The change in wheat prices will lead to a change in food consumption (or average food intake) and the percentage of undernourishment, and therefore the number of undernourished people.[30]

---

[30] If for example the change in price is 16.33% (widespread opposition with climate change), wheat consumption will change by -4.08%, and total food consumption or average intake will change by -4.08%*17.52%=-0.72%, which mean that the new average is equal to 2980 *(1-0.72%) = 2959 kcal/person/day. The new average intake and the threshold of 1882 are used to calculate the percentage and number of undernourished people in 2030 as a result of the opposition to GM wheat under climate change.

Table 5.7 – Effect of opposition to GM wheat on the incidence of undernourishment in developing countries in 2030 (demand elasticity =0.25)*

	Widespread Opposition With climate Change	Widespread Opposition With No Climate Change	Limited Opposition With Climate Change	Japan and South Korea Opposition	China Adoption	Effect of Climate Change
Expected Price	+16.33%	+17.01%	+2.94%	+0.46%	-2.30%	+4.96%
Wheat Consumption	-4.08%	-4.25%	-0.74%	-0.12%	0.56%	-1.24%
Food Consumption	-0.72%	-0.74%	-0.13%	-0.02%	0.1%	-0.22%
Percentage of Undernourished	0.33%	0.35%	0.06%	0.01%	-0.04%	0.1%
Number of undernourished People (million)	23	24	4	1	-3	7

* The demand elasticity of wheat for developing countries is assumed to be equal 0.25, which is the price elasticity of demand for the rest of the world reported by Sullivan *et al* (1989).
Source: Author's calculation from simulation results and data from FAO (1996) and FAO (2002b).

Widespread opposition to GM wheat will deprive 23 to 24 million people from a chance to escape food insecurity depending of whether climate change occurs or not. If climate change occurs without GM opposition it will expose 7 million people to the risk of hunger by the year 2030. The number of people that may be exposed to the risk of hunger due to limited opposition and Japan and South Korean opposition are 4 million and 1 million respectively in the year 2030. If China adopts GM wheat it will offer enough food to 3 million people by 2030.

5.3. Conclusion

Whether the opposition to GM wheat production and consumption will ease or increase in the coming decades will have a major effect on what this technology can offer in term of food security, through higher and more stable yields in the future. The opposition to GM food in some regions, especially the EU, will affect the worldwide diffusion of GM wheat. This loss in adoption would translate into losses in terms of potential productivity increases that GM wheat may offer.

It is noteworthy that the world may lose in terms of food security due to the opposition to GM wheat. However, these losses are related directly to the degree of this opposition to GM wheat, and whether climate change will occur or not. In summary the simulation results indicated that:

- If the EU induces a widespread opposition (whether climate change occurs or not), potential GM adopters are likely to react by not adopting GM wheat. This will deprive the world of the additional productivity that GM wheat might offer in the future leading to a decline in wheat availability and a significant increase in future prices. The rise of expected prices would translate into a decline in consumption. Malnourished people are spending a very large proportion of their income on food, and it is expected that this consumption decline would occur for them since they are more sensitive to expected price changes. The widespread opposition to GM wheat will deprive around 24 million people from a chance to escape hunger and starvation in 2030.
- If the EU induces opposition in only few countries (e.g., Tunisia, Algeria, Morocco, Japan, and South Korea), the diffusion of GM wheat will not be affected significantly. Therefore this degree of opposition will have only a very small effect on availability, expected price, consumption and ending stocks. This opposition will mean the continuation of

undernourishment for 4 million people in developing countries by the year 2030.

- If China adopts GM wheat in spite of widespread rejection by all other countries, global availability would increase, leading to lower expected prices, and higher consumption. It is important to note that the effect of China's adoption has a similar magnitude (although has the opposite sign) to the limited opposition scenario. China's adoption to GM wheat could save 3 million people from the risk of undernourishment in 2030.
- The opposition of Japan and South Korea will not affect future consumption, since its effect on adoption rates, and therefore availability and expected prices, is minimal. An additional one million people will continue to live under the risk of hunger because of this opposition.
- Climate change would decrease the availability of wheat, leading to higher expected prices, and lower consumption. Climate change would also increase the volatility of expected prices, by increasing the probability of high expected prices. Climate change will cause the undernourishment of 7 million people by the year 2030.

CHAPTER 6 : CONCLUSIONS

6.0. Summary of conclusions

Modern agricultural biotechnology, which has enabled the development as such products as GM wheat, has the potential to ease the food security problem that is facing the world. GM wheat has the potential to increase yield growth significantly, helping to produce more food to meet the increasing needs of the world population. If widely adopted, GM wheat could improve global food security by decreasing the world wheat price and therefore make wheat more accessible to poor and import-dependent countries. The opposition to biotechnology in general, and to GM crops specifically, may be a major constraint to the adoption of GM wheat and its diffusion worldwide, thereby affecting the global food security. The global adoption of GM wheat and therefore global food security depends on the degree of worldwide resistance that the EU's opposition may induce.

The main goal of this thesis was to estimate the impact of EU opposition to GM wheat on global food security. To do so, a global food security model was developed by combining a market model with a GM adoption model. This model was then adapted to food production shocks such as climate change. A number of scenarios were analyzed to consider the range of potential effects of the EU opposition to GM wheat on global food security.

The most important finding of this study is that opposition to GM wheat might deprive the world from a potential tool to improve global food security and reducing the number of undernourished people in developing countries. The magnitudes of these losses are directly related to the degree of opposition to GM wheat. If the EU induces widespread opposition (whether climate change occurs or not) this will greatly diminish global food security since it deprives the world of the benefits that GM wheat may offer. Widespread opposition to GM wheat would lead to a global decline in the adoption of this technology, which varies, from 3% in 2005 to 25% in 2030. This would reduce the availability, leading to a 16% increase in expected prices by 2030. The price increase leads to a decline in consumption, and ending stocks. The price increase will deprive 23 to 24 million of people from accessing enough food exposing them to the risk of hunger.

However, if the EU induces only limited opposition by affecting the position of only a few countries, such as the Maghreb countries (Tunisia, Algeria, and Morocco) or Japan and South Korea, this will not have a significant effect on global food security. The limited opposition to GM wheat would lead to a small global adoption reaction, varying from 1% in 2007 to 5% in 2030. Therefore, this degree of opposition will have a very small effect on availability, price, as well as consumption and ending stocks. However, even these small changes in prices could expose 4 million people in developing countries to the risk of hunger.

It is interesting to note that global food security was improved if China adopted GM wheat which would almost offset the effect of limited opposition elsewhere. Driven by its local policy only, China's adoption could rise to 30% by 2030, which would depress wheat prices by approximately 3% in 2030. This price decline will save 3 million people from hunger.

An import ban on GM wheat in Japan and Korea would reduce global adoption by only 1%, since the adoption reaction of wheat exporting countries would be very small. The effect on price and availability is therefore minimal, and future consumption is not expected to be affected by this degree of opposition. However, 1 million people in developing countries will be undernourished because of this price increase. One million might be small numerically, but it can not be ignored since we are dealing with human lives.

It is important to note that if climate change occurs, lower availability of wheat would lead to higher prices. Climate change would also greatly increase the volatility of prices. Climate change is expected to increase the probability of high prices escalating the risk of food insecurity.

The results of this research are important in terms of future policy and regulations regarding release as well as trade of GM products. Many countries still oppose GM crops. GM exporting countries should not ignore those concerns. We have learned from recent BSE and bird influenza outbreaks that consumer perception of safety of a given product can fundamentally alter the trade of those products. It is obvious that consumer concern can be the main driver as well as the main obstacle to adoption. Regardless of the reasons or concerns behind this resistance, those concerns should be taken into account in the development and evaluation of new products before their release and commercial development. Opposing (consumers) countries should similarly recognize that their opposition might deprive the world of more food.

Consumer concern over GM food is an issue that needs attention, whether this opposition is based on science or not. It is urgent that opponents and proponents of GM food arrive at a midpoint that satisfies both parties. The failure to do so will deprive the world of a technology that may help to feed the hungry. It is understandable that interests of different parties over the issue of GM food may conflict. However, all parties should consider food security as an important component in the international trade negotiations over GM food.

To help ease the opposition to biotechnology and to GM food products more specifically, it is recommended that biotech corporations should deliver GM crops with clear benefits for consumers and farmers. They should also be more open about the GM products they export, so consumers can enjoy the benefits of the technology while avoiding possible risks.

Perceptions about GM foods among exporters on one side, and the EU and developing countries on the other, are different. Exporters of GM food should realize that the perception that they are imposing GM food on consumers might only lead to stronger opposition. The EU should realize that its stance on GM food might induce a widespread rejection to GM food and thereby worsening global food insecurity. Continuing international negotiation appears to be an important component of a resolution to this dilemma.

6.1. Study limitations

The empirical model used in this research has several important limitations. The first limitation is related to the global aggregation of the model. This aggregation does not account for regional heterogeneity in population growth, in yield growth, in climate effects, and in the magnitude of climate change. Although this was necessary since the goal was to estimate food security at the global level and not at the regional level, those factors were central to the generation of estimates of regional food insecurity. In addition, aggregation of food security measures may underestimate the effect of opposition to GM wheat, since small change in global responses may mask extremely significant regional effects.

The second limitation concerns the use of only one commodity (wheat). By using only one commodity, the analysis does not allow for substitution in consumption as well as in production. On the production side, declining world wheat prices might cause farmers to switch to crops that are more profitable. On the consumption side, rising wheat prices may cause consumers to substitute it with cheaper imported or local food.

The third limitation is related to the difficulty of asserting consumer opposition. In modeling adoption, consumer opposition/tolerance indexes were assigned to each country based on their labeling threshold levels. Values assigned in this research varied from zero for countries with a 0% threshold to five for country having voluntary or no labeling laws. This method was used due to the limitation of information on consumer preferences.

The fourth limitation is in the opposition scenarios. In opposition scenarios countries are faced with the decision to fully accept (maximum tolerance equal to five) or fully reject (zero tolerance) GM wheat. This situation means that importers chose between two extremes: they can ban imports from GM wheat adopting countries, or accept all trade without any constraints on GM wheat. This reflects an implicit assumption that GM free and GM tolerant markets can not coexist. This also implicitly assumes that there is no cheap form of segregation. In this model, while it is possible to introduce a wider range of opposition scenarios allowing for this coexistence, that would complicate the analysis.

6.2. Recommendations for further research

This research serves as an attempt to evaluate the effect of EU opposition to GM wheat on global food security. Both the diffusion model and global food security model developed in this thesis have the potential to be applied to a wide range of research problems that focus on GM crops regionally or worldwide. The diffusion model can be extended to better understand how opposition to GM food has affected the adoption processes of any GM crop. This may be realized by applying the diffusion model to several GM crops (regionally and globally). The global food security model developed here can be further extended for related studies that focus on the regional and global effect of EU opposition to GM food. The following are a few examples of possible further research.

1) The food security model can be extended to include more commodities (e.g., rice and corn) and more countries. Including more commodities besides wheat would permit the interaction between different commodity markets. Including different countries allows for technological

and economical differences between regions and the computation of food security at the regional level.

2) A second model extension would be to estimate changes in producer and consumer surpluses due to the opposition of EU to GM wheat. This research would estimate the forgone benefits to consumers and producers caused by the possible worldwide opposition to GM wheat.

3) One possible extension of the diffusion model would be to analyze how different institutions and biotechnology companies respond to the opposition to GM food. Do they recognize that this opposition can affect the future path of biotechnology itself or do they think it is a temporary obstacle that will disappear with time? If there are some responses, are they effective or not? Many GM crops can be used as case studies to answer the above questions. The canola case in Canada is a good example, where consumer opposition in the EU led to an almost total loss of the European export market.

4) A second extension of the diffusion model could be to identify other reasons (political, cultural, religious, and development issues) that may explain the response of specific governments and consumers to GM food. Evaluating the responses of Muslim governments, consumers and producers would be one interesting case to study. Many questions remain unanswered about how the Muslim world will respond to biotechnology. Little is known about what agricultural biotechnology might offer to the Muslim world. Understanding Muslim opinions toward GM food and biotechnology itself is a great challenge, but could have great benefits as well.

5) Another possible extension is to analyze the transmission of consumer concerns (local and foreign) about GM food to production and policy decision makers in developing countries. Zambia's rejection of GM food-aid could be used as a case study. This research would allow us to understand the transmission methods related to technologies that are not universally accepted or rejected (such as biotechnology). By studying the case of Zambia we might be able to understand how such government policy is taken? What are the drivers of such policy? Who makes decisions? What institutions or structures do they use? Why was the decision made and how did government policy affect producers' and consumers' attitudes (if at all) toward GM food?

REFERENCES

Abernathy, W., and Utterberback, J. 1978. "Patterns of industrial innovation." *Technology Review* 80:40-47.

Adams, R. M., and B. H. Hurd. 1999. "Graphically Speaking: Climate Change and Agriculture: Some Regional Implications." *Choices* 14:22.

Agnet. 2003. "Indian Head Trial Ended." in *Agnet*, March 25, 2003.

Alexandratos, N. 1995. *World Agriculture:Towards 2010. An FAO study*: Food and Agricultural organization of the United Nations and John Wiley and Sons.

Alston, J. M., R. Gray, and D.A. Sumner. 1994. "The Wheat War of 1994." *Canadian Journal of Agricultural Economics* 42:231-251.

Alston, J.M., C.A. Carter, R. Gray, and D.A. Sumner. 1997. "Third-Country Effects and Second-Best Grain Trade Policies: Export Subsidies and Bilateral Liberalization." *American Journal of Agricultural Economics* 79:1300-1310.

Alston, J.M., G.W. Norton, and P.G. Pardey. 1998. *Science under scarcity: Principles and practice for agricultural research evaluation and priority setting*. Wallingford, U.K: CAB International.

Altieri, M. A., and P. Rosset. 1999. "Ten reasons why biotechnology will not ensure food security, protect the environment and reduce poverty in the developing world." *AgBioForum* 2:155-162.

Altieri, M.A. 1995. *Agroecology: the science of sustainable agriculture*. Boulder: Westview Press.

Anderson, J. R., *et al*. 1988. "Changing variability in cereal production in Australia." *Review of Marketing and Agricultural economics* 56:270-286.

Anderson, K., C. P. Nielsen, S. Robinson, and K. Thierfelder. 2001. "Estimating the Global Economic Effects of GMOs." Pp. 49-74 in *The Future of Food: Biotechnology Markets and Policies in an International Setting*, edited by P.G. Pardey. Washington, D.C: International Food Policy Research Institute.

Angelo, I., F. Masiga, and L. Musiita. 2003. "Africa's Dilemma in Genetically Modified food War." in *allAfrica.com*. Kampala.

Antle, J.M., and V. H.Smith. 1999. "An Overview of World Wheat Markets." Pp. 3-19 in *The Economics of World Wheat Markets*, edited by J.M. Antle, and V.H. Smith.

Antle, J.M., D. Hayes, and S. Mohanty. 1999. "Long-term Supply and Demand Trends: Whither the Real Price of Wheat?" Pp. 39-65 in *The Economics of World Wheat Markets*, edited by J.M. Antle, and V.H. Smith.

Barkley, A. P. 2002. "The Economic Impacts of Agricultural Biotechnology on International Trade, Consumers, and Producers: The case of corn and soybeans in the USA." in *6th International ICABR Conference*. Ravello, Italy.

BBC. 2002. "Zambia turns down GM aid." in *BBC News*, 17 August 2002.

Benirshka, M., and W.W. Koo. 1995. "World Wheat Policy Simulation Model: Descriptive and Computer Program Documentation." Agricultural Economics Report No. 340, Department of Agricultural Economics, North Dakota State University, Fargo.

Besley, T., and A. Case. 1993. "Modeling Technology Adoption in Developing Countries." *The American Economic Review* 83:396-402.

Blackshaw, R. E., and K. N. Harker. 2002. "Selective weed control with glyphosate in glyposate-resistant spring wheat (Triticum aestivum)." *Weed Technology* 16:885-892.

Brown, L. R. 1995. *Who Will Feed China: Wake-Up Call for a Small Planet*. Washington, D.C: Worldwatch Environmental Alert Series.

Brown, L. R., and H. Kane. 1994. *Full House: Reassessing the Earth's Population Carrying Capacity*. New York: The Worldwatch Institute.

Byerlee, D., and K. Fischer. 2002. "Accessing Modern Science: Policy and Institutional Options for Agricultural Biotechnology in Developing Countries." *World Development* 30:931-948.

Byerlee, D., and P. Moya. 1993. "Impacts of International Wheat Breeding Research in the Developing World, 1969-1990." Mexico, D.F: CIMMYT.

Canadian Grain Council. 2002. "Canadian Grains Industry Statistical Handbook." Winnipeg, Manitoba.

Canadian Wheat Board. 2003. "Current State of Market Acceptance and Non-acceptance of GM Wheat." Winnipeg, Manatoba.

Cassman, K., and P. Pingali. 1995. "Extrapolating Trends from Long-Term Experiments to Farmers' Fields: The Case of Irrigated Rice Systems in Asia." Pp. 63-84 in *Agricultural Sustainability: Economic, Environmental and Statistical Considerations*, edited by V. Barnett, R. Payne, and R. Steiner. New York: Wiley.

CBAC. 2001. "CBAC Interim Report on Improving the Regulation of Genetically Modified Foods and other Novel Foods in Canada." Ottawa: CBAC.

Chan-Halbrendt, C. 1996. "Socioeconomic Consideration for Agricultural Biotechnology Priority Setting and Planning." in *Turning Priorities into Feasible Programs: Proceedings of a Seminar on Planning, Priorities and Policies for Agricultural Biotechnology*, edited by J. Komen, J.I. Cohen, and Z. Pfor. South Africa: Intermediary Biotechnology Service, The Hague.

Chrispeels, M.J. 2000. "Biotechnology and the poor." *Plant Physiol* 124:3-6.

CIMMYT.1996. World Wheat Facts and Trends 1995/96: Understanding Global Trends in the Use of Wheat Diversity and International Flows of Wheat Genetic Resources. Mexico, D.F.: CIMMYT.

CNN. 2003. "UK: GM economic benefit 'limited'." CNN, July 11 2003.

Commandeur, P., and Von Roozendaal, G.1993. “The Impact of Biotechnology on Developing Countries. Opportunities for Technology-Assessment Research and Development Co-operation”. A Study Commissioned by the Büro für Technikfolgen-Abschätzung beim Deutschen Bundestag (TAB). Bonn 1993, Chap. 3, pp. 49-52.

Consultative Group on International Agricultural Research. Press Release - October 29,1995. “Wheat is century’s miracle crop.” http://www.worldbank.org/html/cgiar/press/wheat3.html

Cropchoice news. 2003. GM wheat seen getting mixed reception in Asia. June 17, 2003. http://www.cropchoice.com.

Daily Times, August 25, 2003. Pakistan Feels EU Labeling Pressure. http://www.dailytimes.com.pk/

Diaz-Bonilla, E., and S. Robinson. 2003. "Biotechnology, Trade, And Hunger." in *Biotechnology and Genetic Resource Policies*, edited by P.G. Pardey and B. Koo. Washington, DC: International Food Policy Research Institute.

Dixon, R. “Hybrid Corn Revisited.” Econometrica 48(1980): 1451-61.

Downey RK, and Beckie H. 2002. “Isolation Effectiveness in Canola Pedigree Seed Production”. Internal Research Report, Agriculture and Agri-Food Canada, Saskatoon Research Centre, Saskatoon.

Eastham, K., and J. Sweet. 2002. "Genetically modified organisms (GMOs): the significance of gene flow through pollen transfer." Environmental Issue Report No. 28. Brussels, Belgium: European Environment Agency.

Ehrlich, P. R., and A. H. Ehrlich. 1990. *The population explosion*. New York: Simon and Schuster.

Evans, L.T. 1993. *Crop Evolution, Adaptation and Yield*. Cambridge: Cambridge University Press.

Evenson, R. E., and D. Gollin. 2003. "Assessing the Impact of the Green Revolution, 1960 to 2000." *Science* 300:758-762.

Evenson, R.E., V. Santaniello, and D. Zileberman. 2002. "Introduction." Pp. 7-23 in *Market Development for Genetically Modified Foods*, edited by R.E. Evenson V. Santaniello, and D. Zileberman. Oxon, UK: CABI International.

FAO. 1985. "Report of the Tenth Session of the Committee on World Food Security." Rome, Italy: Food and Agriculture Organization of the United Nations.

FAO. 1996a. "World Food Summit. Rome Declaration on World Food Security and World Food Summit Plan of Action." Rome, Italy: Food and Agriculture Organization of the United Nations.

FAO. 1996b. "The Sixth World Food Survey." Rome: Food and Agricultural Organization of the United Nations.

FAO. 1998. "Regional Development Partnerships Programme (RDPP)." Rome, Italy: Food and Agriculture Organization of the United Nations.

FAO. 1999. "The Importance of Food Quality and Safety for Developing Countries." in *Report of the Tenth Session of the Committee on World Food Security*. Rome, Italy: Food and Agriculture Organization of the United Nations.

FAO. 2000. "FAO Statement on Biotechnology. Biotechnology in Food and Agriculture." Rome, Italy: Food and Agriculture Organization of the United Nations.

FAO. 2000. "FOSTAT Database." Rome, Italy: Food and Agriculture Organization of the United Nations.

FAO. 2002a. "The State of Food Insecurity in the World 2002:Agriculture and global public goods ten years after the Earth Summit." Rome, Italy: Food and Agriculture Organization of the United Nations.

FAO. 2002b. *World Agriculture: towards 2015-2030*: FAO and Earthscan Publications Ltd London.

FAO. 2002c. "Food insecurity: When people must live with hunger and fear starvation. The State of Food Insecurity in the World." Rome, Italy: Food and Agriculture Organization of the United Nations.

FAO. 2003. "The State of Food Insecurity in the World 2003:Monitoring Progress towards the World Food Summit and Millenium Development Goals." Rome, Italy: Food and Agriculture Organization of the United Nations.

FAO. 2004. "FOSTAT Database." Rome, Italy: Food and Agriculture Organization of the United Nations.

Fishel, W.L. 1987. "The Economics of Agricultural Biotechnology: Discussion." *American Journal of Agricultural Economics,* 69:438-439.

Flack-Zepeda, J., G. Traxler, and R. Nelson. 1999. "Rent creation and distribution from biotechnology innovations: The case of Bt cotton and herbicide-tolerant soybeans." in *Transitions in Agbiotech: Economics of Strategy and Policy, NE-165 conference*. Washington, D.C.

Forsythe, D. 2002. "GM wheat: Customer acceptability survey results from Asia." Washington, DC: U.S. Wheat Associates.

Fulton, M., H. Furtan, R. Gray, and G. Khachatourians. 2003. "Genetically Modified Wheat." Pp. A11 in *The Globe and Mail*. Saskatoon.

Furtan, W. H., R.S. Gray, and J .J. Holzman. 2003. "The optimal time to license a biotech lemon." *Contemporary Economic Policy* 21:433-444.

Furtan.W.H, R.S. Gray and J.J. Holzman. 2004. "Regularoty Approval Decisions in the Presence of Market Externalities: The Case of Genetically Modified Wheat." Department of Agricultural Economics, University of Saskatchewan.

Gaskel, G., M. Baur, and J. Durant. 1998. "Public Perceptions of Biotechnology: Eurobarometer 46.1." in *Biotechnology in the Public Sphere*, edited by M.Bauer and G. Gaskel J.Durant. London, UK: Science Museum.

GENET-news: European. NGO Network on Genetic Engineering. 15 May 2001. 3-Food: StarLink issue fuels Japan opposition to GM wheat. http://www.gene.ch/genet/2001/May/msg00035.html

GENET-news: European. NGO Network on Genetic Engineering. 27 Mar 2000.7-Business: Australia's global markets shun GM wheat. http://www.gene.ch/genet/2000/Mar/msg00074.html

Genome Prairie. 2001. “Functional Genomics of Abiotic Stress in Crops.” Project led by G. Scoles, University of Saskatchewan.

Gianessi, L. P., C. S. Silvers, S. Sankula, and J. E. Carpenter. 2002. "Plant biotechnology: Current and potential impact for improving pest management in U.S. agriculture - An analysis of 40 case studies." Washington, DC: National Center for Food and Agricultural Policy.

Gillam, C. 2002. "Asian opposition to biotech spring wheat steadfast." in *Reuters*.

Gray, R., M. Fulton, H. Furtan, D. Gosnell, J. Hobbs, J. Holzman, K. Bill, J. McNaughten, J. Stevens, and D. Stovin. 2001a. "Transforming Agriculture, The

Benefits And Costs Of Genetically Modified Crops." The Canadian Biotechnology Advisory Committee Project Steering Committee on the Regulation of Genetically Modified Foods.

Gray, R., S. Malla, and S. Ferguson. 2001b. “Agriculture Research Policy For Crop Improvement in western Canada: Past Experience and Future Directions.” A final report prepared for Saskatchewan Agriculture and Food. Centre for Studies in Agriculture, Law and the Environment, University of Saskatchewan..

Gretchen, C. D., and P. R. Ehrlich. 1990. "An Exploratory Model of the Impact of Rapid Climate Change on the World Food Situation." *Proceedings: Biological Sciences* 231:232-244.

Griliches, Z. “Hybrid Corn: An Exploration in the Economics of Technological Change,” Econometrica.25: 501-522. 1957.

Hamstra, A. M. 1995. "Consumer Acceptance Model for Food Biotechnology." The Hague: The SWOKA Institute.

Hanf, C.-H., and A. Böcker. 2002. "Is European Consumers' Refusal of GM Food a Serious Obstacle or a Transient Fashion?" Pp. 49-52 in *Market Development for Genetically Modified Foods*, edited by R. E. Evenson V Santaniello, and D. Zilberman: CABI Publishing.

Havlicek, J.Jr. 19990. "Role of Economics and Other Social Sciences in Biotechnology Research." *Southern Journal of Agricultural Economics* 22:69-72.

Hazell, Peter B.R. 1985. "Sources of increased variability in world cereal production since the 1960s." *Journal of Agricultural Economics* 36:145-159.

Herdt, R. W. 1999. "The Future of Green Revolution." Pp. 127-141 in *The Economics of World Wheat Markets*, edited by J.M. Antle, and V.H. Smith.

Hoffman and Beaudoin v. Monsanto Canada, Inc. and Aventis CropScience Canada Holding Inc. A copy of the Statement of Claim is available at the Saskatchewan Organic Directorate website (http://www.saskorganic.com).

Holzman, J. 2001. "The Economics of Herbicide Tolerance Wheat in Western Canadian Crop Rotations." Master’s Thesis in *Department.of Agricultural Economics*. Saskatoon: University of Saskatchewan.

Huang, J., and S. D. Rozelle. 1995. "Environmental stress and grain yields in China." *American Journal of Agricultural Economics* 77:246-256.

Huang, J., R. Hu, C. Pray, F. Qiao and S. Rozelle. 2001.; “Biotechnology as an alternative to chemical pesticides: A case study of Bt Cotton in China.” Paper presented to the ICABR Conference, Ravello, Italy, June 14-18.

Hucl, P., and M. Matus-Cadiz. 2001. "Isolation distances for minimizing outcrossing in spring wheat." *CropSci* 41:1348-1351.

Institute of food science and technology (UK), 1999. “Genetic Modification and Food”.

IPCC. 2001. "The Regional Impacts of Climate Change: An Assessment of Vulnerability." Online at http://www.ipcc.ch

Ismael, Y., Beyers, L., and Thirtle, C. 2001. "smallholder adoption and economic impcts of Bt cotton in the Makhatini Flats." Republic of South Africa: University of Reading, Imperial College, University of London, UK, and University of Pretoria, South Africa. DFID Natural Resources Policy Research Programme.

Izquierdo, J. 2000. "Plant biotechnology and food security in Latin America and the Caribbean." *Electronic Journal of Biotechnology* 3.

Jaffe, A.B., R.G. Newell, and R.G. Stavins. 2000. "Technological Change and the Environment." in *Resources for the Future*. Washington, DC.

James, C. 1996. Global Review of the Field Testing and Commercialization of Transgenic Plants, 1986 to 1995: The First Decade of Crop Biotechnology. ISAAA Brief No. 1. International Service for the Acquisition of Agri-Biotech Applications. Ithaca, New York.

James, C. 1997. Global Status of Transgenic Crops. ISAAA Brief No. 5. International Service for the Acquisition of Agri-Biotech Applications. Ithaca, New York. pp.31.

James, C. 1998. *Global Review of Commercialized Transgenic Crops*. ISAAA Brief No. 8. International Service for the Acquisition of Agri-Biotech Applications. Ithaca, New York.

James, C. 1999. *Global Review of Commercialized Transgenic Crops*. ISAAA Brief No. 12. International Service for the Acquisition of Agri-Biotech Applications. Ithaca, New York.

James, C. 2000. *Global Review of Commercialized Transgenic Crops*. ISAAA Brief No. 21. International Service for the Acquisition of Agri-Biotech Applications. Ithaca, New York.

James, C. 2003. *Global Review of Commercialized Transgenic Crops*. ISAAA Brief No. 24. International Service for the Acquisition of Agri-Biotech Applications. Ithaca, New York.

Jarvis, L.S. 1981. "Predicting the Diffusion of Improved Pastures in Uruguay." *American Journal of Agricultural Economics* 3:495-502.

Jauhar, P. P., and G. S. Khush. 2003. "Importance of Biotechnology in Global Food Security." Pp. 107-128 in *Food Security and Environmental Quality in the Developing World*, edited by R. Lal, D. Hansen, N. Uphoff, and S.Slack: LEWIS PUBLISHERS.

Kalaitzandonakes, N. 2000. "Agrobiotechnology and Competitiveness." *American Journal of Agricultural Economics* 82:1224-1233.

Kalaitzandonakes, N. 2003. "Economic and environmental impacts of agrobiotechnology: an Introduction." Pp. 1-18 in *The Economic and Environmental Impacts of Agbiotech : A Global Perspective*, edited by N. Kalaitzandonakes: Kluwer Academic Publishers.

Kendall, H. W., and D. Pimentel. 1994. "Constraints on the expansion of the global food supply." *Ambio* 23:198-205.

Knudson, M. K. 1991. "Incorporating Technological Change in Diffusion Models." *American Journal of Agricultural Economics* 3:724-733.

Kuntz, G. M. 2001. "Transgenic Wheat: Potential Price Impacts for Canada's wheat Export Market." Master's Thesis in *Department of Agricultural Economics*. Saskatoon, Canada: University of Saskatchewan.

Lacy, W., and L. Busch. 1986. "Food security in the United States: Myth or reality." Pp. 222-223 in *New Dimensions in Rural Policy: Building Upon Our Heritage*. Washington, D.C: Subcommittee on Agriculture and Transportation, Joint Economic Committee, Congress of the United States. U.S.Government Printing Office.

Lappe, F. M., J. Collins, and P. Rosset. 1998. *World Hunger: twelve myths*. NY: Grove Press.

Leisinger, K. M. 1996. "Sociopolitical Effects of New Biotechnologies in Developing Countries." 2020 Vision Brief 35. Washington, D.C: International Policy Research Institute.

Luce, E. 2003. "India Rejects US Food Shipment over GM Content." in *The Financial Times*. New Delhi.

Mahajan, V., and R.A. Peterson. 1978. "Innovation diffusion in a Dynamic Potential Adopter Population." *Management Sci* 24:1589-97.

Mahajan, V., and R. Peterson. 1985. *Models for Innovation Diffusion*. Beverly Hills, CA: Sage Publications.

Malla, S., R. Gray, and P. Phillips. 2004. "Gains to Research in the Presence of Intellectual Property Rights and Research Subsidies." *Review of Agricultural Economics* 26: 63-81.

Maltsbarger, R., and N. Kalaitzandonakes. 2000. "Studies reveal hidden costs in IP supply chain." *Feedstuffs* 72:Special Report on Cover.

Mansfield, E. 1961. "Technical Change and the Rate of Imitation." *Econometrica*:741-66.

Marra, M. 2001. "Agricultural Biotechnology: A Critical Review of the Impact Evidence to Date." Pp. 155-184 in *The Future of Food; Biotechnology Markets and Policies in an International Setting*, edited by P.G. Pardley. Washington DC: IFPRI.

McCalla, A.F. 1994. *Agriculture and Food Needs to 2025: Why We Should Be Concerned*. Washington, D.C: Consultative Group on International Agricultural Research.

McElroy, D. 1999. "Moving Agbiotech-downstream." *Nature biotechnology* 17:1071-1074.

Maxwell, D. G. 1996. "Measuring food insecurity: the frequency and severity of "coping strategies"." *Food Policy,* 21:291-303.

Maxwell, S. 1996. "Food Security: A Post-modern Perpective." *Food Policy* 21:155-170.

Monsanto. 2001. “Our vision for biotechnology in wheat”. Monsanto Technical Bulletin.

Moschini, G., H. Lapan, and A. Sobolevsky. 2000. "Roundup Ready Soybeans and welfare Effects in the Soybean Complex." *Agribusiness* 16: 33-55.

Naylor, R., W. Falcon, and E. Zavaleta. 1997. "Variability and Grwoth in Grain Yields, 1950-94: Does the Record Point to Greater Instability?" *Population and Development Review* 23:41-58.

Network of Concerned Farmers. 2003. “Monsanto refuse to withdraw license appliation despite threat to Canadian Wheat industry”. http://www.no-gm-farmers.com

Nielsen, C. P., K. Thierfelder, and S. Robinson. 2001. "Genetically Modified Foods, Trade, And Developing Countries." Washington, DC: International Food Policy Research Institute.

Nielsen, C. P., and K. Anderson. 2001. "Global Market Effects of European Responses to Genetically Modified Organisms." *Weltwertschaftliches Archiv* 137:320-46.

Noussair, C., S. Robin, and B. Ruffieux. 2004. "Do Consumers Really Refuse To Buy Genetically Modified Food?" *The Economic Journal* 114:102-120.

Novartis Foundation for Sustainable Development (NFSD), 2001. “The Socio-Political Impact of Biotechnology in Developing Countries.” http://www.foundation.novartis.com/

OECD. 1986. "Update of Elasticities Tables for the MTM Model." Paris, France: Organization for Economic Co-operation and Development.

OECD, 1996. “The Agricultural Outlook: Trends and Issues to 2000.” Paris, France: Organization for Economic Co-operation and Development.

OECD. 2001. "Economic impacts of Genetically Modified Crops on the Agri-Food Sector: A Synthesis." Paris, France.: Working document, The Directorate-General for Agriculture.

Ogg, A.G., and P.J. Jackson. 2001. "Agronomic benefits and concerns for Roundup-Ready wheat." *Proceedings of the western weed science society meetings*:80-90.

OTA. 1989. “New Developments in Biotechnology: Patenting Life.” Special Report by the Office of Technology Assessment of the United States Congress, US Government Printing Office, Washington, DC.

Paarlberg, R. L. 2000. "The weak link between world food markets and world food security." *Food Policy* 25:317-335.

Paarlberg, R. L. 2001. "Governing the GM Crop Revolution: Policy Choices for Developing Countries." Pp. 251-255 in *THE UNFINISHED AGENDA. Perspectives on Overcoming Hunger, Poverty, and Environmental Degradation*, edited by Pinstrup-Andersen-Andersen and Rajul Pandya-Lorch. Washington, D.C.: International Food Policy Research Institute.

Pardey, P.G., C. Chan-Kang, and S. Wood. 2000. “The Changing Structure of Latin American Agriculture: A Quantitative Regional Perspective.” Report prepared for the Inter-American Development Bank. Washington D.C: IFPRI.

Parry, M., N. Arnell, M. Hulme, P. Martens, R. Nicholls, and A. White. 1999. "The global impact of climate change: a new assessment." *Global Environmental Change* 9:1-2.

Parry, M., C. Rosenzweig, A. Iglesias, G. Fischer, and M. Livermore. 1999. "Climate Change and World Food Security: A New Assessment (1990-2080)." *Global Environmental Change* 9:51-67.

Perrin, R. K., and G.M. Scobie. 1981. "Market Intervention Policies for Increasing the Consumption of Nutrients by Low Income Households." *American Journal of Agricultural Economics* 63:73-82.

Persley, G. J., and J. J. Doyle. 2001. "Biotechnology for Developing Country Agriculture, Problems and Opportunities." Pp. 239-243 in *THE UNFINISHED AGENDA. Perspectives on Overcoming Hunger, Poverty, and Environmental Degradation*, edited by Pinstrup-Andersen-Andersen and Rajul Pandya-Lorch. Washington, D.C.: International Food Policy Research Institute.

Phillips, P. 2003a. "Policy, National Regulation, and International Standards for GM Foods." in *Biotechnology and Genetic Resource Policies*, edited by P.G. Pardey and B. Koo. Washington, DC: International Food Policy Research.

Phillips, P. 2003b. "The economic impact of herbicide tolerant canola in Canada." Pp. 119-139 in *The Economic and Environmental Impacts of Agbiotech : A Global Perspective*, edited by N. Kalaitzandonakes: Kluwer Academic Publishers.

Phillips, P., and G. Khachatourians. 2002. "The Economic and Political Consequences of Transgenic Food Plants." Pp. 311-325 in *The Handbook of Transgenic Plants*, edited by A. McHughen G. Khachatourians, R. Scorza, W.K. Nip and Y. Hui: Marcel Dekker.

Pierce John, 1999. Using Biotechnology to Enhance and Safeguard The Food Supply: Delivering The Benefit of The Technology. In NABC REPORT 11: World Food Security and Sustainability: The Impact of Biotechnology an Industrial Consolidation.

Pierce, J. 1999. "Using Biotechnology to Enhance and Safeguard The Food Supply: Delivering The Benefit of The Technology." in *NABC REPORT 11: World Food Security and Sustainability: The Impact of Biotechnology an Industrial Consolidation*, edited by D. P. Weeks, J. B. Segelken, and R. W.F. Hardy. Ithaca, New York: National Agricultural Biotechnology Council.

Pingali, P.L., and P.W.Heisey.2001. Cereal- crop productivity in developing countries: Past trends and future prospects. In Agricultural Science Policy: Changing Global Agendas, ed. J.M. Alston, P.G. Pardey, and M.J. Taylor.Published for the International Food Policy Research Institute. The Johns Hopkins University press Baltimore and London.

Pinstrup-Andersen-Andersen, P. 1984. "A Methodological Note on the Measurement of the Nutrition Impact of Agricultural Research." Paper Prepared for workshop on Methodological Problems in Measuring Research Impact. Washington, DC: CGIAR Secretariat, World Bank.

Pinstrup-Andersen-Andersen, P., and E, Schioler. 2001. *Seeds of Contention : World Hunger and the Global Controversy Over GM (Genetically Modified) Crops*. Baltimore and London: The Johns Hopkins University Press.

Pinstrup-Andersen-Anderson, P. and M. J. Cohen 2001. “Rich and Poor Country Perspectives on Biotechnology” Presented at “Agricultural Biotechnology: Markets and Policies in an International Setting” Adelaide, Australia, January 22.

Pinstrup-Andersen-Andersen, P. 1999a. "Agricultural biotechnology, trade, and the developing countries." *AgBioForum* 2:215-217.

Pinstrup-Andersen-Anderson, P; Rajul Pandya-Lorch, and Mark W. Rosegrant. 1999b. “World Food Prospects Critical Issues for the Early Twenty-First Century”. Food

Policy Statement No. 29.Washington, DC : International Food Policy Research Institute.

Qaim, M, and D. Virchow. 2000. "The role of biotechnology for global food security." *Agrarwirtschaft* 49:348-356.

Rauch, T. A., and D. C. Thill. 2001. “Weed Control in Glyphosate-Resistant Spring Wheat.” Western Society of Weed Science Research Progress Report

Rosegrant, M.W., M.A. Sombilla, and N.D. Perez. 1995. "Global Food Projections to 2020:Implications for Investment." Washington, D.C: International Food Policy Research Institute.

Rosegrant, M.W., M.A. Sombilla, R.V. Gerpacio, and C. Ringler. 1997. "Global food markets and US exports in the twenty-first century." in *World Food and Sustainable Agriculture Program Conference, Meeting the Demand for Food in the 21stCentury: Challenges and Opportunities*. University of Illinois, Urbana-Champaign.

Rosegrant. M. W., M. S. Paisner., S. Meijer and J. Witcover. 2001. "Global Food Projections to 2020: Emerging Trends and Alternative Futures." Washington, DC: International Food Policy Research Institute.

Sayre, K.D. 1996. "The role of crop management research at CIMMYT in addressing bread wheat yield potential issues." Pp. 203-207 in *Increasing Yield Potential in Wheat: Breaking the Barriers*, edited by M.P. Reynolds, S. Rajaram, and A. McNab. Mexico, D.F: CIMMYT.

Schultz, T, W. 1964. *Transforming Traditional Agriculture*: New Haven: Yale University Press.

Sen, A. 1981. *Poverty and Famines.* Oxford: Clarendon Press.

Serageldin, I. 1999. "Biotechnology and Food Security in the 21st Century." *Science* 285:387-389.

Sergeldin, I. 1995. "Nurturing Development: Aid and Cooperation in Today's Changing World." Washington D. C: World Bank.

Shampine, A. 1998. "Compensating for Information Externalities in Technology Diffusion Models." *American Journal of Agricultural Economics* Volume 80:387-395.

Singh, A. J. and D. Byerlee. 1990. "Relative variability in wheat yields across countries and over time." *Journal of Agricultural Economics* 41:21-32.

Smith, L. C., A. E. El Obeid, and H. H. Jensen. 2000. "The Geography and Causes of Food Insecurity in Developing Countries." *Agricultural Economics* 22:199-215.

Smith, L. C. 1998. "Can FAO's Measure of Chronic Undernourishment be Strengthened?" *Food Policy* 23:425-445.

Smyth, S., and P. Phillips. 2002. "Product Differentiation Alternatives: Identity Preservatin, Segregation, and Traceability." *AgBioForum* 5.

Staniland B.K., P.B.E. McVetty, L.F. Friesen, S. Yarrow, G. Freyssinet and M. Freyssinet. 2000. "Effectiveness of border areas confining the spread of transgenic Brassica napus pollen." *Can. J.Plant Sci* 80:521-526.

Stone, S., A. Matysek, and A. Dolling. 2002. "Modeling Possible Impacts of GM Crops on Australian Trade." Melbourne, Australia: Productivity Commission.

Sullivan, J., J. Wainio, and V.O. Roningen. 1989. "A Data Base for Trade Liberalization Studies." Washington DC: U.S. Department of Agriculture, ERS Staff Report No. 89.

Sunding, D., and D. Zilberman. 2001. "The Agricultural Innovation Process: Research and Technology Adoption in a Changing Agricultural Sector." Pp. 231 in *Handbook of Agricultural Economics (volume 1A)*, edited by Bruce L. Gardner and Gordon C. Rausser. New York: Elsevier.

Sustainability Council, February 2003. “Market Rejection of GM Foods: the US experience”. www.sustainabilitynz.org.

Sygentia.2002 “AWB and Syngenta seal deal to breed wheat of the future.” March 8, http://www.syngenta.com.

The Economist. Apr 3rd 2003 From The Economist print edition. http://www.economist.com

Thompson, P. 2000. “Food and Agricultural Biotechnology: Incorporating Ethical Considerations.” CBAC Commissioned Study available at http://www.cbac.gc.ca/english/reports/

Traxler, G., S. Godoy-Avila, J. Flack-Zepeda, and J. Espinoza-Arellano. 2003. "Transgenic Cotton in Mexico: A Casse Study of the Comarca Lagumera." Pp. 183-202 in *The Economic and Environmental Impacts of Agbiotech : A Global Perspective*, edited by N. Kalaitzandonakes: Kluwer Academic Publishers.

Deininger, D. U, and S. Shapouri. 2003. "Food Security: Is India at Risk?" Pp. 31-52 in *Food Security and Environmental Quality in the Developing World*, edited by R. Lal, D. Hansen, N. Uphoff, and S.Slack: LEWIS PUBLISHERS.

USDA. 1999. "Genetically Engineered Crops for Pest Management." Washington, DC: USDA Economic Research Service.

Virmani, S.S., Khush, G.S, and P.L. Pingali. 1993. "Hybrid rice for the Tropics: Potentials, research priorities, and policy issues." in *Hybrid Research and Development Needs in Major Cereals in the Asia-Pacific Region*, edited by R.S. Paroda, and M. Rai. Bangkok, Thailand: Food and Agriculture Organization of the United Nations, Regional Office for Asia and the Pacific.

Watson, R. T. 2001. "The Challenge of Climate Change: Poor Farmers at Risk." Pp. 8-12 in *CGIAR Annual Report 2000*. Washington, DC: Consultative Group on International Agricultural Research Secretariat, The World Bank.

Wilson, S. E. 2001. "Global Warming Changes the Forecast for Agriculture." Pp. 151-156 in *THE UNFINISHED AGENDA. Perspectives on Overcoming Hunger, Poverty, and Environmental Degradation*, edited by Pinstrup-Andersen-Andersen and Rajul Pandya-Lorch. Washington, D.C.: International Food Policy Research Institute.

Wilson, W. W., and B. L. Dahl. 2002. "Costs and Risks of Testing and Segregating GM Wheat." Agribusiness and Applied Economics Report No 501, Department of Agribusiness and Applied Economics, North Dakota State University, Fargo.

Wisner, R. 2002. "GMO Spring Wheat: Its potential short-term impacts on U.S. wheat export markets and prices." Iowa State University, Department of Economics.

Wolpers, K.H. 1996. "Biotechnology in Crop Production-Its Potentials and Problems." *Agriculture and Rural Development* 3:3-6.

World Bank. 1986. "Poverty and Hunger: Issues and Options for Food Security in Developing Countries." Washington, DC: The World Bank.

World Bank. 1992. "World Development Report 1992. Development and the Environment." Washington, DC: The World Bank.

APPENDIX A –WHEAT DATA

Table A.1 – Sources of calories consumed, 1961 and 1997

Rank	1961		1997
	(Percentage)		(Percentage)
Developing Countries			
1 Rice	28.1	Rice	27.3
2 Wheat	12	Wheat	18.8
Total Calories	1932		2650
Developed Countries			
1 Wheat	26.7	Wheat	23.5
Total Calories	2948		3240
World			
1 Rice	18.2	Rice	21.1
2 Wheat	18.1	Wheat	20.1
Total Calories	2257		2782

Source: Pardey, Chan-Kang, and Wood (2000). Table 10, pp. 60-61.

Table A.2 – World production, consumption, trade and ending stocks, 1960-2000 (in million tonnes)

Year	Production	Consumption	Trade	Ending stocks
1960/61	233.5	228.6	41.5	82.8
1961/62	220.0	232.2	46.8	69.9
1962/63	246.8	237.7	43.9	75.8
1963/64	230.4	234.3	55.1	70.3
1964/65	264.9	251.0	51.4	78.5
1965/66	259.3	276.1	61.7	60.7
1966/67	300.7	273.0	56.8	87.6
1967/68	291.9	280.6	53.0	97.7
1968/69	323.8	298.4	47.8	121.3
1969/70	304.0	317.4	52.6	103.5
1970/71	306.5	328.9	55.1	80.5
1971/72	344.1	335.7	56.6	89.2
1972/73	337.5	352.6	65.4	74.9
1973/74	366.1	351.6	60.1	82.7
1974/75	355.2	353.3	59.8	81.4
1975/76	352.6	346.8	64.9	86.7
1976/77	414.3	369.5	58.5	127.4
1977/78	377.8	399.0	70.5	109.2
1978/79	438.9	405.2	68.0	134.8
1979/80	417.5	428.6	83.1	120.5
1980/81	435.9	443.5	89.6	112.7
1981/82	445.1	441.8	97.2	112.5
1982/83	472.8	447.9	93.7	129.9
1983/84	484.4	465.2	97.5	145.3
1984/85	509.0	484.2	102.4	168.0
1985/86	494.9	482.6	80.6	178.3
1986/87	524.1	508.6	86.7	191.1
1987/88	496.0	531.0	113.6	156.7
1988/89	495.0	515.9	101.8	133.1
1989/90	533.2	526.4	98.3	135.2
1990/91	588.1	547.9	97.8	170.5
1991/92	542.9	549.9	109.6	162.0
1992/93	561.7	547.0	109.1	175.7
1993/94	558.1	548.1	99.2	180.5
1994/95	523.8	545.6	99.3	160.2
1995/96	538.1	543.2	96.5	153.3
1996/97	581.9	565.5	100.6	164.7
1997/98	610.1	578.7	101.7	195.4
1998/99	589.7	577.7	99.6	206.1
1999/00	586.1	581.6	109.8	207.0
2000/01	582.1	583.6	101.3	204.3

Source: USDA

Table A.3 – Wheat yield data in hg/ha

	World	Developed Countries	Developing Countries
1961	10,889	12,687	7,754
1962	12,060	13,755	8,970
1963	11,320	12,479	9,301
1964	12,413	14,103	9,419
1965	12,151	13,349	9,986
1966	14,079	16,390	9,793
1967	13,392	15,022	10,430
1968	14,532	16,661	10,809
1969	14,170	16,106	11,041
1970	14,939	17,445	11,237
1971	16,245	18,983	12,139
1972	16,048	18,439	12,751
1973	16,837	19,860	12,240
1974	16,154	18,441	12,755
1975	15,700	16,868	13,960
1976	17,910	19,911	15,069
1977	16,718	18,848	13,575
1978	19,328	22,091	15,392
1979	18,521	19,957	16,565
1980	18,554	20,538	15,653
1981	18,800	20,144	16,774
1982	19,991	20,991	18,532
1983	21,258	22,402	19,736
1984	22,200	23,164	20,891
1985	21,718	22,574	20,593
1986	23,207	24,176	21,960
1987	22,899	24,236	21,265
1988	22,921	23,748	21,900
1989	23,734	24,941	22,239
1990	25,616	27,782	22,893
1991	24,488	25,450	23,374
1992	25,410	26,325	24,314
1993	25,318	26,014	24,515
1994	24,513	24,680	24,329
1995	25,082	24,955	25,227
1996	25,761	25,759	25,764
1997	27,106	26,661	27,632
1998	26,932	27,585	26,233
1999	27,562	28,121	26,965
2000	27,150	27,220	27,070
2001	27,584	28,297	26,751
2002	26,952	27,340	26,506

Source: FAO database (FAO 2000)

APPENDIX B – THE CORN DIFFUSION MODEL DATA

Table B.1 – Local tolerance (case of corn)

Country (tolerance level)	1996	1997	1998	1999	2000
Argentina	5	5	5	5	5
Australia	5	5	5	5	4
Austria	5	1	1	1	1
Bel-lux	5	1	1	1	1
Brazil	5	5	5	5	0
Bulgaria	5	1	1	1	1
Canada	5	5	5	5	5
China	5	5	5	5	4
Czech Republic	5	5	0	0	0
Denmark	5	1	1	1	1
Finland	5	1	1	1	1
France	5	1	1	1	1
Germany	5	1	1	1	1
Greece	5	1	1	1	1
Hungary	5	5	5	4	4
India	5	5	5	5	5
Ireland	5	1	1	1	1
Israel	5	5	5	5	1
Italy	5	1	1	1	1
Japan	5	5	5	5	3
Korea republic of	5	5	5	5	4
Liechtenstein	5	5	5	5	5
Luxembourg	5	1	1	1	1
Mexico	5	5	5	5	5
Netherlands	5	1	1	1	1
New Zealand	5	5	5	5	1
Norway	5	5	5	2	2
Poland	5	5	5	5	5
Portugal	5	1	1	1	1
Romania	5	5	5	5	1
Russian Federation	5	5	4	4	4
Slovakia	5	5	5	5	5
South Africa	5	5	5	5	4
Spain	5	1	1	1	1
Sweden	5	1	1	1	1
Switzerland	5	1	1	1	1
Turkey	5	5	5	5	5
United Kingdom	5	1	1	1	1
United States	5	5	5	5	5
Others	5	5	5	5	5

Source: Author’s calculation from the labeling data

Table B.2 – Foreign tolerance (case of corn)

Country (tolerance level)	1996	1997	1998	1999	2000
Argentina	5	3	2	3	3
Australia	0	0	0	1	1
Brazil	0	0	0	0	0
Bulgaria	0	0	0	1	1
Canada	0	0	0	0	0
China	0	0	0	0	0
Czech Republic	0	1	0	1	0
EU	5	1	1	1	1
Hungary	0	1	1	1	1
India	0	0	0	0	0
Israel	0	0	0	0	0
Japan	0	0	0	0	0
Korea republic of	0	0	0	0	0
Liechtenstein	0	0	0	0	0
Mexico	0	0	0	0	0
New Zealand	0	0	0	0	0
Norway	0	0	0	0	0
Poland	0	0	0	0	0
Romania	0	0	0	0	0
Russian Federation	0	0	0	0	0
Slovakia	0	2	1	1	0
South Africa	0	1	1	0	0
Turkey	0	0	0	0	0
United States	1	1	1	1	1

Source: Author’s calculation

Table B.3 – Pooled data for the diffusion model (case of corn)

Time	Country	Diffusion	R1t	R2t
1996	Argentina	0.00	0.00	0.00
1996	Brazil	0.00	0.00	0.00
1996	Bulgaria	0.00	0.00	0.00
1996	Canada	0.00	0.00	0.00
1996	China	0.00	0.00	0.00
1996	Czech Republic	0.00	0.00	0.00
1996	Hungary	0.00	0.00	0.00
1996	India	0.00	0.00	0.00
1996	Israel	0.00	0.00	0.00
1996	Japan	0.00	0.00	0.00
1996	Korea	0.00	0.00	0.00
1996	Liechtenstein	0.00	0.00	0.00
1996	Mexico	0.00	0.00	0.00
1996	New Zealand	0.00	0.00	0.00
1996	Norway	0.00	0.00	0.00
1996	Poland	0.00	0.00	0.00
1996	Romania	0.00	0.00	0.00
1996	Russian Federation	0.00	0.00	0.00
1996	Slovakia	0.00	0.00	0.00
1996	South Africa	0.00	0.00	0.00
1996	Switzerland	0.00	0.00	0.00
1996	Turkey	0.00	0.00	0.00
1996	United States	0.01	0.00	0.00
1996	EU(15)	0.00	0.00	0.00
1997	Argentina	0.02	0.85	5.00
1997	Brazil	0.00	0.00	5.00
1997	Bulgaria	0.00	0.00	1.00
1997	Canada	0.30	0.00	5.00
1997	China	0.00	0.18	5.00
1997	Czech Republic	0.00	0.58	5.00
1997	Hungary	0.00	0.50	5.00
1997	India	0.00	0.00	5.00
1997	Israel	0.00	0.00	5.00
1997	Japan	0.00	0.00	5.00
1997	Korea	0.00	0.00	5.00
1997	Liechtenstein	0.00	0.00	5.00
1997	Mexico	0.00	0.00	5.00
1997	New Zealand	0.00	0.00	5.00
1997	Norway	0.00	0.00	5.00
1997	Poland	0.00	0.00	5.00
1997	Romania	0.00	0.09	5.00
1997	Russian Federation	0.00	0.02	5.00
1997	Slovakia	0.00	0.02	5.00
1997	South Africa	0.00	0.16	5.00
1997	Switzerland	0.00	0.00	1.00
1997	Turkey	0.00	0.00	5.00
1997	United States	0.08	0.50	5.00
1997	EU (15)	0.00	0.01	1.00

Table B.3 Continue

Time	Country	Diffusion	R1t	R2t
1998	Argentina	0.03	1.62	10.00
1998	Brazil	0.00	0.00	10.00
1998	Bulgaria	0.00	0.00	2.00
1998	Canada	0.31	0.21	10.00
1998	China	0.00	0.21	10.00
1998	Czech Republic	0.00	0.59	0.00
1998	Hungary	0.00	0.67	10.00
1998	India	0.00	0.00	10.00
1998	Israel	0.00	0.00	10.00
1998	Japan	0.00	0.00	10.00
1998	Korea	0.00	0.00	10.00
1998	Liechtenstein	0.00	0.00	10.00
1998	Mexico	0.01	0.02	10.00
1998	New Zealand	0.00	0.03	10.00
1998	Norway	0.00	0.00	10.00
1998	Poland	0.00	0.00	10.00
1998	Romania	0.00	0.06	10.00
1998	Russian Federation	0.00	0.00	8.00
1998	Slovakia	0.00	0.00	10.00
1998	South Africa	0.01	0.16	10.00
1998	Switzerland	0.00	0.00	2.00
1998	Turkey	0.00	0.00	10.00
1998	United States	0.35	1.13	10.00
1998	EU(15)	0.00	0.01	2.00
1999	Argentina	0.13	2.73	15.00
1999	Brazil	0.00	0.00	15.00
1999	Bulgaria	0.00	0.99	3.00
1999	Canada	0.58	0.20	15.00
1999	China	0.00	0.18	15.00
1999	Czech Republic	0.00	1.90	0.00
1999	Hungary	0.00	0.84	12.00
1999	India	0.00	0.00	15.00
1999	Israel	0.00	0.00	15.00
1999	Japan	0.00	0.00	15.00
1999	Korea	0.00	0.00	15.00
1999	Liechtenstein	0.00	0.00	15.00
1999	Mexico	0.01	0.01	15.00
1999	New Zealand	0.00	0.03	15.00
1999	Norway	0.00	0.00	6.00
1999	Poland	0.00	0.00	15.00
1999	Romania	0.00	0.10	15.00
1999	Russian Federation	0.00	0.00	12.00
1999	Slovakia	0.00	4.73	15.00
1999	South Africa	0.05	0.01	15.00
1999	Switzerland	0.00	0.00	3.00
1999	Turkey	0.00	0.00	15.00
1999	United States	0.45	1.72	15.00
1999	EU(15)	0.00	0.02	3.00

Table B.3 Continue

Time	Country	Diffusion	R1t	R2t
2000	Argentina	0.09	1.59	20.00
2000	Brazil	0.00	0.39	0.00
2000	Bulgaria	0.02	0.42	4.00
2000	Canada	0.46	0.17	20.00
2000	China	0.00	0.95	16.00
2000	Czech Republic	0.00	1.04	0.00
2000	Hungary	0.00	0.53	16.00
2000	India	0.00	0.00	20.00
2000	Israel	0.00	0.00	4.00
2000	Japan	0.00	0.00	12.00
2000	Korea	0.00	0.00	16.00
2000	Liechtenstein	0.00	0.00	20.00
2000	Mexico	0.01	0.00	20.00
2000	New Zealand	0.00	0.00	4.00
2000	Norway	0.00	0.00	8.00
2000	Poland	0.00	0.00	20.00
2000	Romania	0.00	0.00	4.00
2000	Russian Federation	0.00	0.00	16.00
2000	Slovakia	0.00	2.76	20.00
2000	South Africa	0.04	0.66	16.00
2000	Switzerland	0.00	0.00	4.00
2000	Turkey	0.00	0.01	20.00
2000	United States	0.41	1.54	20.00
2000	EU(15)	0.00	0.04	4.00

Source: Author's calculation

Table B.4 – Estimation of the diffusion parameters (case of corn)

Dependent Variable: Diffusion
Method: Pooled Least Squares
Sample: 1996 2000
Included observations: 5
Number of cross-sections used: 21
Total panel (balanced) observations: 105

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Local Tolerance *t	0.003	0.001	2.86	0.005
Index of Foreign Tolerance *t	0.006	0.004	1.35	0.181
Fixed Effects				
Argentina	**0.03**			
Australia	-0.03			
Brazil	-0.03			
Bulgaria	-0.03			
Canada	**0.30**			
China	-0.02			
Czech Republic	-0.03			
EU (15)	-0.03			
Hungary	-0.03			
India	-0.02			
Israel	-0.02			
Korea	-0.03			
Mexico	-0.02			
New Zealand	-0.03			
Poland	-0.02			
Romania	-0.03			
Russian Federation	-0.02			
Slovakia	-0.02			
South Africa	0.00			
Turkey	-0.01			
United States	**0.23**			
R-squared	0.72	Mean dependent var		0.03
Adjusted R-squared	0.65	S.D. dependent var		0.11
S.E. of regression	0.06	Sum squared resid		0.32
F-statistic	214.75	Durbin-Watson stat		1.10
Prob(F-statistic)	0.00			

APPENDIX C – KEY MARKETS FOR MAJOR WHEAT EXPORTERS

Table C.1 – Key markets for Argentina's wheat (eleven-year average from 1990-2000, thousands of tonnes)

Key Importing Countries	Average Export	Share from Total export	Export over production
Algeria	49	0.69%	0.39%
Brazil	4,280	60.32%	33.94%
China (including Taiwan)	82	1.16%	0.65%
Egypt	151	2.12%	1.19%
EU*	36	0.50%	0.28%
India	20	0.28%	0.16%
Indonesia	248	3.50%	1.97%
Iran	227	3.19%	1.80%
Japan	0	0.00%	0.00%
Korea, South	24	0.33%	0.19%
Malaysia	0	0.00%	0.00%
Mexico	4	0.05%	0.03%
Morocco	69	0.97%	0.55%
Pakistan	0	0.00%	0.00%
Philippines	0	0.00%	0.00%
South Africa	0	0.00%	0.00%
Tunisia	45	0.63%	0.36%
Turkey	149	2.09%	1.18%
USSR, former	23	0.32%	0.18%
Venezuela	25	0.36%	0.20%
Others	1,665	23.46%	13.20%

Source: Canada Grains Council (2002); and Author's calculations

Table C.2 – Key markets for Australia's wheat (eleven-year average from 1990-2000, thousands of tonnes)

Key Importing Countries	Average Export	Share from total export	Export over production
Algeria	0	0	0.00%
Brazil	0	0	0.00%
China (including Taiwan)	754.11	5.86%	4.21%
Egypt	1178.35	9.15%	6.57%
EU*	126.94	0.99%	0.71%
India	444.5	3.45%	2.48%
Indonesia	1467.74	11.40%	8.19%
Iran	1545.62	12.00%	8.62%
Japan	1137.57	8.84%	6.35%
Korea, South	925.64	7.19%	5.16%
Malaysia	664.0	5.16%	3.70%
Mexico	0	0	0.00%
Morocco	20.6	0.16%	0.11%
Pakistan	579.5	4.50%	3.23%
Philippines	119.6	0.93%	0.67%
South Africa	0	0	0.00%
Tunisia	6.9	0.05%	0.04%
Turkey	0	0	0.00%
USSR, former	223.33	1.73%	1.25%
Venezuela	0	0.0%	0.00%
Others	3680.37	28.59%	20.54%

Source: Canada Grains Council, 2002; and Author's calculations

Table C.3 – Key markets for Canada's wheat (eleven-year average from 1990-2000, thousands of tonnes)

Key Importing Countries	Average Export	Share from total export	Export over production
Algeria	55	0.35%	0.20%
Brazil	868.9	5.63%	3.23%
China, Peoples' Rep.	2642.63	17.13%	9.84%
Egypt	45.845	0.30%	0.17%
EU*	719.075	4.29%	2.68%
India	78.93	0.51%	0.29%
Indonesia	848.7	5.50%	3.16%
Iran	1635.7	10.60%	6.09%
Japan	1346	8.72%	5.01%
Korea, South	854.85	5.54%	3.18%
Malaysia	210.84	1.37%	0.78%
Mexico	686.91	4.45%	2.56%
Morocco	64	0.42%	0.24%
Nigeria	83.01	0.54%	0.31%
Pakistan	150.74	0.98%	0.56%
Philippines	293.05	1.90%	1.09%
South Africa	148.185	0.96%	0.55%
Tunisia	8.05	0.05%	0.03%
Turkey	46.68	0.30%	0.17%
United States	1206.64	7.82%	4.49%
USSR, Former	564.83	3.66%	2.10%
Venezuela	313.46	2.03%	1.17%
Others	2,555	16.56%	9.51%

Source: Canada Grains Council, 2002; and Author's calculations

Table C.4 – Key markets for EU's wheat (eleven-year average from 1990-2000, thousands of tonnes)

Key Importing Countries	Average Export	Share from total export	Export over production
Algeria	1541.17	9.32%	1.64%
Brazil	117.71	0.71%	0.13%
China (including Taiwan)	681.36	4.12%	0.72%
Egypt	872.35	5.28%	0.93%
India	0	0	0.00%
Indonesia	110.41	0.67%	0.12%
Iran	347.83	2.10%	0.37%
Japan	0	0	0.00%
Korea, South	166.78	1.01%	0.18%
Malaysia	0	0	0.00%
Mexico	13.9	0.08%	0.01%
Morocco	1069.04	6.47%	1.14%
Pakistan	69	0.42%	0.07%
Philippines	0	0	0.00%
South Africa	0	0	0.00%
Tunisia	422.12	2.55%	0.45%
Turkey	240.7	1.46%	0.26%
USSR (former)	2485.16	15.03%	2.64%
Venezuela	50.22	0.30%	0.05%
Others	8344.23	50.47%	8.87%

Source: Canada Grains Council, 2002; and Author's calculations

Table C.5 – Key markets for the USA’s wheat (eleven-year average from 1990-2000, thousands of tonnes)

Key Importing Countries	Average Export	Share from Total export	Export over production
Algeria	781	2.50%	1.24%
Brazil	232.88	0.74%	0.37%
China (including Taiwan)	2964.83	9.48%	4.70%
Egypt	4,025	12.88%	6.38%
EU*	873.71	2.80%	1.38%
India	120	0.4%	0.19%
Indonesia	212	0.7%	0.34%
Iran	0	0	0.00%
Japan	3180.6	10.17%	5.04%
Korea, South	1,563	5.00%	2.48%
Malaysia	0	0	0.00%
Mexico	1056.65	3.38%	1.67%
Morocco	638	2.04%	1.01%
Pakistan	1,420	4.5%	2.25%
Philippines	1682.12	5.38%	2.67%
South Africa	255	0.81%	0.40%
Tunisia	280	0.90%	0.44%
Turkey	171.33	0.55%	0.27%
USSR (former)	2206.01	7.06%	3.50%
Venezuela	571	1.83%	0.90%
Others	9025.62	28.87%	14.30%

Source: Canada Grains Council, 2002; and Author's calculations

APPENDIX D – DIFFUSION MODEL RESULTS

Table D.1 – Global adoption of GM wheat under different scenarios

	SC2.a	SC2.c	SC2.d	SC1.b	SC1.d	SC1.a	SC1.c
2005	3%	3%	3%	0%	3%	0%	0%
2006	4%	4%	4%	0%	4%	0%	0%
2007	6%	6%	5%	0%	5%	0%	0%
2008	7%	7%	7%	0%	6%	0%	0%
2009	8%	8%	8%	0%	7%	0%	0%
2010	9%	9%	9%	1%	8%	0%	0%
2011	10%	10%	10%	1%	9%	0%	0%
2012	12%	12%	11%	1%	10%	0%	0%
2013	13%	13%	12%	1%	10%	0%	0%
2014	14%	14%	13%	1%	11%	0%	0%
2015	15%	15%	14%	2%	12%	0%	0%
2016	15%	15%	15%	2%	13%	0%	0%
2017	16%	16%	16%	2%	13%	0%	0%
2018	17%	17%	17%	2%	14%	0%	0%
2019	18%	18%	17%	2%	15%	0%	0%
2020	19%	19%	18%	2%	15%	0%	0%
2021	20%	20%	19%	3%	16%	0%	0%
2022	20%	20%	20%	3%	17%	0%	0%
2023	21%	21%	20%	3%	17%	0%	0%
2024	22%	22%	21%	3%	18%	0%	0%
2025	22%	22%	22%	3%	18%	0%	0%
2026	23%	23%	22%	3%	19%	0%	0%
2027	24%	24%	23%	4%	19%	0%	0%
2028	24%	24%	23%	4%	20%	0%	0%
2029	25%	25%	24%	4%	20%	0%	0%
2030	25%	25%	25%	4%	21%	0%	0%

Source: Results from the diffusion model

Table D.2 – GM wheat adoption rates in Argentina from 2000 to 2030 under different scenarios

	SC2.a or Sc2.c	SC2.d	SC1.d	SC1.a or SC1.c	SC1.b
2005	0%	0%	0%	0%	0%
2006	1%	1%	1%	0%	0%
2007	6%	6%	6%	0%	0%
2008	11%	11%	11%	0%	0%
2009	15%	15%	15%	0%	0%
2010	20%	20%	19%	0%	0%
2011	24%	24%	23%	0%	0%
2012	28%	28%	27%	0%	0%
2013	31%	31%	31%	0%	0%
2014	35%	35%	34%	0%	0%
2015	38%	38%	37%	0%	0%
2016	41%	41%	40%	0%	0%
2017	44%	44%	43%	0%	0%
2018	47%	47%	46%	0%	0%
2019	50%	49%	49%	0%	0%
2020	52%	52%	51%	0%	0%
2021	54%	54%	54%	0%	0%
2022	57%	57%	56%	0%	0%
2023	59%	59%	58%	0%	0%
2024	61%	61%	60%	0%	0%
2025	63%	63%	62%	0%	0%
2026	65%	65%	64%	0%	0%
2027	67%	67%	66%	0%	0%
2028	68%	68%	67%	0%	0%
2029	70%	70%	69%	0%	0%
2030	71%	71%	71%	0%	0%

Source: Results from the diffusion model

Table D.3 – GM wheat adoption rates in Australia from 2000 to 2030 under different scenarios

	SC2.a or Sc2.c	SC2.d	SC1.d	SC1.a or SC1.c	SC1.b
2005	0%	0%	0%	0%	0%
2006	3%	2%	2%	0%	0%
2007	8%	7%	7%	0%	0%
2008	14%	12%	12%	0%	0%
2009	19%	17%	16%	0%	0%
2010	24%	21%	21%	0%	0%
2011	28%	25%	25%	0%	0%
2012	33%	29%	29%	0%	0%
2013	37%	33%	33%	0%	0%
2014	41%	36%	36%	0%	0%
2015	44%	40%	39%	0%	0%
2016	47%	43%	43%	0%	0%
2017	51%	46%	46%	0%	0%
2018	54%	49%	48%	0%	0%
2019	56%	51%	51%	0%	0%
2020	59%	54%	54%	0%	0%
2021	61%	56%	56%	0%	0%
2022	64%	59%	58%	0%	0%
2023	66%	61%	61%	0%	0%
2024	68%	63%	63%	0%	0%
2025	70%	65%	65%	0%	0%
2026	72%	67%	66%	0%	0%
2027	73%	69%	68%	0%	0%
2028	75%	70%	70%	0%	0%
2029	76%	72%	71%	0%	0%
2030	78%	73%	73%	0%	0%

Source: Results from the diffusion model

Table D.4 – GM wheat adoption rates in Canada from 2000 to 2030 under different scenarios

	SC2.a or Sc2.c	SC2.d	SC1.d	SC1.a or SC1.c	SC1.b
2005	26%	26%	26%	0%	0%
2006	29%	29%	29%	0%	0%
2007	32%	32%	31%	0%	0%
2008	35%	34%	34%	0%	0%
2009	38%	37%	37%	0%	0%
2010	41%	40%	39%	0%	0%
2011	44%	42%	41%	0%	0%
2012	46%	44%	43%	0%	0%
2013	49%	46%	46%	0%	0%
2014	51%	49%	48%	0%	0%
2015	53%	51%	50%	0%	0%
2016	55%	53%	52%	0%	0%
2017	57%	55%	53%	0%	0%
2018	59%	56%	55%	0%	0%
2019	61%	58%	57%	0%	0%
2020	63%	60%	58%	0%	0%
2021	64%	61%	60%	0%	0%
2022	66%	63%	62%	0%	0%
2023	68%	64%	63%	0%	0%
2024	69%	66%	64%	0%	0%
2025	70%	67%	66%	0%	0%
2026	72%	68%	67%	0%	0%
2027	73%	70%	68%	0%	0%
2028	74%	71%	69%	0%	0%
2029	75%	72%	71%	0%	0%
2030	77%	73%	72%	0%	0%

Source: Results from the diffusion model

Table D.5 – GM wheat adoption rates in China from 2000 to 2030 under different scenarios

	SC2.a or Sc2.c	SC2.d	SC1.d	SC1.a or SC1.c	SC1.b
2005	0%	0%	0%	0%	0%
2006	0%	0%	0%	0%	0%
2007	1%	1%	1%	0%	1%
2008	2%	2%	2%	0%	2%
2009	4%	4%	4%	0%	4%
2010	5%	5%	5%	0%	5%
2011	6%	6%	6%	0%	6%
2012	8%	8%	8%	0%	8%
2013	9%	9%	9%	0%	9%
2014	11%	11%	11%	0%	11%
2015	12%	12%	12%	0%	12%
2016	13%	13%	13%	0%	13%
2017	14%	14%	14%	0%	14%
2018	16%	16%	16%	0%	16%
2019	17%	17%	17%	0%	17%
2020	18%	18%	18%	0%	18%
2021	19%	19%	19%	0%	19%
2022	21%	21%	21%	0%	21%
2023	22%	22%	22%	0%	22%
2024	23%	23%	23%	0%	23%
2025	24%	24%	24%	0%	24%
2026	25%	25%	25%	0%	25%
2027	26%	26%	26%	0%	26%
2028	27%	27%	27%	0%	27%
2029	29%	29%	29%	0%	29%
2030	30%	30%	30%	0%	30%

Source: Results from the diffusion model

Table D.6 – GM wheat adoption rates in the EU from 2000 to 2030 under different scenarios

	SC2.a or Sc2.c	SC2.d	SC1.d	SC1.a or SC1.c	SC1.b
2005	0%	0%	0%	0%	0%
2006	2%	2%	0%	0%	0%
2007	5%	5%	0%	0%	0%
2008	7%	7%	0%	0%	0%
2009	9%	9%	0%	0%	0%
2010	12%	12%	0%	0%	0%
2011	14%	14%	0%	0%	0%
2012	16%	16%	0%	0%	0%
2013	19%	19%	0%	0%	0%
2014	21%	21%	0%	0%	0%
2015	23%	23%	0%	0%	0%
2016	25%	25%	0%	0%	0%
2017	27%	27%	0%	0%	0%
2018	29%	29%	0%	0%	0%
2019	31%	31%	0%	0%	0%
2020	32%	32%	0%	0%	0%
2021	34%	34%	0%	0%	0%
2022	36%	36%	0%	0%	0%
2023	37%	37%	0%	0%	0%
2024	39%	39%	0%	0%	0%
2025	41%	41%	0%	0%	0%
2026	42%	42%	0%	0%	0%
2027	44%	44%	0%	0%	0%
2028	45%	45%	0%	0%	0%
2029	47%	47%	0%	0%	0%
2030	48%	48%	0%	0%	0%

Source: Results from the diffusion model

Table D.7 – GM wheat adoption rates in the USA from 2000 to 2030 under different scenarios

	SC2.a or Sc2.c	SC2.d	SC1.d	SC1.a or SC1.c	SC1.b
2005	19%	19%	19%	0%	0%
2006	23%	22%	22%	0%	0%
2007	26%	26%	25%	0%	0%
2008	30%	29%	28%	0%	0%
2009	33%	32%	31%	0%	0%
2010	36%	34%	34%	0%	0%
2011	39%	37%	36%	0%	0%
2012	42%	40%	39%	0%	0%
2013	44%	42%	41%	0%	0%
2014	47%	45%	43%	0%	0%
2015	49%	47%	46%	0%	0%
2016	52%	49%	48%	0%	0%
2017	54%	51%	50%	0%	0%
2018	56%	53%	52%	0%	0%
2019	58%	55%	54%	0%	0%
2020	60%	57%	55%	0%	0%
2021	62%	59%	57%	0%	0%
2022	64%	61%	59%	0%	0%
2023	65%	62%	60%	0%	0%
2024	67%	64%	62%	0%	0%
2025	68%	65%	63%	0%	0%
2026	70%	67%	65%	0%	0%
2027	71%	68%	66%	0%	0%
2028	73%	69%	67%	0%	0%
2029	74%	71%	69%	0%	0%
2030	75%	72%	70%	0%	0%

Source: Results from the diffusion model

APPENDIX E – FOOD SECURITY MODEL RESULTS

Table E.1 – Real world wheat prices under different opposition scenarios

	SC2.a	SC2.c	SC2.d	SC1.b	SC1.d	SC1.a	SC1.c
2000	145	145	145	145	145	145	145
2001	152	149	152	152	152	152	149
2002	155	150	155	155	155	155	150
2003	147	145	147	147	147	147	145
2004	150	146	150	150	150	150	146
2005	148	143	148	148	148	148	143
2006	148	142	148	148	148	148	142
2007	138	136	138	139	138	139	136
2008	130	129	130	132	130	132	131
2009	135	131	135	137	135	138	133
2010	131	127	131	134	131	134	131
2011	123	121	123	127	124	128	126
2012	120	118	120	125	121	126	124
2013	120	117	121	127	122	128	124
2014	122	117	122	129	121	130	125
2015	113	110	113	120	114	121	119
2016	107	106	108	115	109	116	115
2017	109	106	109	117	110	118	115
2018	110	105	110	119	112	120	115
2019	106	102	106	115	108	116	112
2020	106	101	106	115	108	116	112
2021	104	99	105	114	106	115	110
2022	94	92	94	103	96	105	103
2023	92	90	92	101	94	103	101
2024	99	93	100	110	102	111	105
2025	90	87	91	101	92	102	99
2026	86	83	86	96	88	98	95
2027	89	85	90	100	91	102	97
2028	87	83	87	98	89	100	96
2029	79	77	79	90	81	92	90
2030	82	78	82	93	84	95	91

Source: These prices are the averages of simulated prices obtained from the 100 futures.

Table E.2 – Availability of wheat (million tonnes) under different opposition scenarios

	SC2.a	SC2.c	SC2.d	SC1.b	SC1.d	SC1.a	SC1.c
2000	707.02	707.02	707.02	707.02	707.02	707.02	707.02
2001	699.54	703.00	699.54	699.54	699.54	699.54	699.54
2002	697.06	702.24	697.06	697.06	697.06	697.06	697.06
2003	704.46	707.43	704.46	704.46	704.46	704.46	704.46
2004	701.79	706.46	701.79	701.79	701.79	701.79	701.79
2005	704.40	709.61	704.40	704.40	704.40	704.40	704.40
2006	703.74	710.27	703.73	703.40	703.71	703.40	703.40
2007	713.96	716.93	713.94	713.08	713.87	713.07	713.08
2008	722.46	723.40	722.40	720.88	722.25	720.81	720.88
2009	717.43	721.71	717.33	714.97	717.06	714.82	714.97
2010	721.96	725.66	721.80	718.51	721.39	718.25	718.51
2011	730.18	732.21	729.97	725.69	729.39	725.29	725.69
2012	733.40	735.38	733.13	727.75	732.37	727.19	727.75
2013	732.91	736.25	732.59	725.99	731.61	725.23	725.99
2014	731.21	736.74	730.85	723.67	726.86	722.78	723.67
2015	740.70	743.58	740.33	732.82	739.43	731.83	732.82
2016	746.30	747.91	745.92	738.08	744.69	737.00	738.08
2017	745.05	748.35	744.66	736.42	743.31	735.23	736.42
2018	743.79	748.86	743.38	734.74	741.94	733.45	734.74
2019	747.76	751.78	747.35	738.37	745.83	736.98	738.37
2020	748.10	753.23	747.68	738.39	746.09	736.89	738.39
2021	749.81	754.97	749.39	739.76	747.72	738.17	739.76
2022	760.61	762.51	760.19	750.49	758.48	748.84	750.49
2023	762.90	765.06	762.48	752.60	760.73	750.87	752.60
2024	754.82	760.99	754.39	744.04	752.54	742.18	744.04
2025	764.46	767.85	764.04	753.62	762.16	751.71	753.62
2026	769.17	771.79	768.76	758.25	766.84	756.28	758.25
2027	765.50	770.23	765.09	754.24	763.10	752.17	754.24
2028	767.70	772.14	767.29	756.23	765.24	754.07	756.23
2029	776.25	778.53	775.86	764.85	773.81	762.65	764.85
2030	773.31	777.36	772.92	761.64	770.80	759.35	761.64

Source: simulation results

Table E.3 – Consumption of wheat (million tonnes) under different opposition scenarios

	SC2.a	SC2.c	SC2.d	SC1.b	SC1.d	SC1.a	SC1.c
2000	593.41	593.41	593.41	593.41	593.41	593.41	593.41
2001	589.03	591.05	589.03	589.03	589.03	589.03	591.05
2002	587.57	590.60	587.57	587.57	587.57	587.57	590.60
2003	591.91	593.65	591.91	591.91	591.91	591.91	593.65
2004	590.34	593.08	590.34	590.34	590.34	590.34	593.08
2005	591.87	594.93	591.87	591.87	591.87	591.87	594.93
2006	591.48	595.31	591.48	591.29	591.47	591.29	595.11
2007	597.48	599.22	597.46	596.96	597.42	596.95	598.70
2008	602.46	603.01	602.43	601.53	602.34	601.50	602.04
2009	599.51	602.02	599.45	598.07	599.29	597.98	600.49
2010	602.17	604.34	602.08	600.14	601.83	599.99	602.17
2011	606.98	608.18	606.86	604.35	606.52	604.12	605.31
2012	608.87	610.03	608.72	605.56	608.27	605.23	606.40
2013	608.59	610.55	608.40	604.53	607.83	604.09	606.06
2014	607.59	610.83	607.38	603.17	608.19	602.65	605.92
2015	613.15	614.84	612.94	608.53	612.41	607.95	609.66
2016	616.43	617.38	616.21	611.62	615.49	610.98	611.93
2017	615.70	617.64	615.47	610.64	614.68	609.94	611.89
2018	614.96	617.94	614.73	609.66	613.88	608.90	611.90
2019	617.29	619.65	617.05	611.79	616.16	610.97	613.36
2020	617.49	620.50	617.25	611.80	616.31	610.92	613.97
2021	618.50	621.52	618.25	612.60	617.27	611.67	614.75
2022	624.82	625.94	624.58	618.90	623.58	617.93	619.06
2023	626.17	627.44	625.92	620.13	624.90	619.12	620.39
2024	621.43	625.05	621.18	615.11	620.09	614.02	617.71
2025	627.08	629.07	626.84	620.73	625.73	619.61	621.64
2026	629.84	631.38	629.60	623.44	628.48	622.29	623.84
2027	627.70	630.47	627.45	621.09	626.29	619.88	622.71
2028	628.98	631.59	628.74	622.26	627.54	620.99	623.67
2029	634.00	635.33	633.76	627.31	632.56	626.02	627.38
2030	632.27	634.65	632.04	625.43	630.80	624.09	626.52

Source: simulation results

Table E.4 – End stock of wheat (million tonnes) under different opposition scenarios

	SC2.a	SC2.c	SC2.d	SC1.b	SC1.d	SC1.a	SC1.c
2000	113.61	113.61	113.61	113.61	113.61	113.61	113.61
2001	110.52	111.95	110.52	110.52	110.52	110.52	108.49
2002	109.49	111.63	109.49	109.49	109.49	109.49	106.45
2003	112.55	113.78	112.55	112.55	112.55	112.55	110.81
2004	111.45	113.38	111.45	111.45	111.45	111.45	108.71
2005	112.53	114.68	112.53	112.53	112.53	112.53	109.47
2006	112.25	114.95	112.25	112.11	112.24	112.11	108.28
2007	116.48	117.71	116.47	116.12	116.45	116.11	114.38
2008	120	120.39	119.97	119.34	119.91	119.32	118.83
2009	117.92	119.69	117.88	116.9	117.77	116.84	114.48
2010	119.79	121.32	119.73	118.36	119.56	118.26	116.34
2011	123.19	124.03	123.11	121.33	122.87	121.17	120.38
2012	124.52	125.34	124.41	122.19	124.1	121.96	121.36
2013	124.32	125.71	124.19	121.46	123.79	121.15	119.93
2014	123.62	125.91	123.47	120.5	118.67	120.13	117.75
2015	127.55	128.74	127.39	124.28	127.02	123.88	123.16
2016	129.86	130.53	129.7	126.46	129.2	126.01	126.15
2017	129.35	130.71	129.18	125.77	128.63	125.28	124.53
2018	128.82	130.92	128.66	125.08	128.06	124.54	122.84
2019	130.47	132.13	130.3	126.58	129.67	126.01	125.01
2020	130.61	132.73	130.44	126.59	129.78	125.97	124.41
2021	131.32	133.45	131.14	127.16	130.45	126.5	125.01
2022	135.78	136.57	135.61	131.6	134.9	130.91	131.44
2023	136.73	137.63	136.56	132.47	135.83	131.75	132.21
2024	133.39	135.94	133.21	128.93	132.44	128.16	126.32
2025	137.38	138.78	137.2	132.89	136.42	132.1	131.98
2026	139.33	140.41	139.16	134.81	138.36	133.99	134.41
2027	137.81	139.77	137.64	133.15	136.81	132.29	131.53
2028	138.72	140.55	138.55	133.97	137.7	133.08	132.56
2029	142.26	143.2	142.09	137.54	141.24	136.63	137.47
2030	141.04	142.71	140.88	136.21	140	135.26	135.12

Source: simulation results

Table E.5 – Probability of high prices

	Sc1.a	Sc1.b	Sc1.c	Sc1.d	Sc2.a	Sc2.c	Sc2.d
2000-2005	14%	14%	15%	14%	14%	15%	14%
2005-2010	17%	17%	17%	17%	17%	17%	17%
2010-2015	19%	19%	19%	19%	19%	20%	19%
2015-2020	14%	14%	15%	15%	15%	15%	14%
2020-2025	19%	18%	19%	19%	18%	19%	18%
2025-230	14%	14%	15%	14%	14%	15%	14%

Source: Author's calculation form simulation results

Table E.6 – Price variability between 2000 and 2030

	Sc1.a	Sc1.b	Sc1.c	Sc1.d	Sc2.a	Sc2.c	Sc2.d
2000	0%	0%	0%	0%	0%	0%	0%
2001	30%	30%	19%	30%	30%	19%	30%
2002	30%	30%	19%	30%	30%	19%	30%
2003	27%	27%	17%	27%	27%	17%	27%
2004	26%	26%	16%	26%	26%	16%	26%
2005	33%	33%	20%	33%	33%	20%	33%
2006	33%	33%	21%	33%	33%	21%	33%
2007	25%	25%	16%	25%	25%	16%	25%
2008	26%	26%	17%	26%	26%	17%	26%
2009	30%	30%	19%	30%	30%	19%	30%
2010	29%	29%	18%	29%	30%	18%	30%
2011	30%	30%	20%	31%	31%	20%	31%
2012	29%	29%	18%	30%	30%	19%	30%
2013	26%	27%	17%	27%	28%	18%	28%
2014	33%	33%	21%	35%	34%	22%	34%
2015	31%	32%	20%	33%	33%	21%	33%
2016	31%	31%	19%	33%	33%	20%	33%
2017	35%	35%	21%	36%	37%	23%	37%
2018	38%	39%	23%	40%	41%	25%	41%
2019	32%	32%	19%	33%	34%	21%	34%
2020	36%	36%	23%	38%	39%	25%	39%
2021	33%	33%	21%	35%	36%	23%	35%
2022	32%	32%	21%	34%	35%	22%	34%
2023	37%	37%	23%	40%	40%	25%	40%
2024	36%	36%	23%	39%	39%	25%	39%
2025	37%	38%	24%	40%	41%	26%	41%
2026	40%	41%	26%	44%	45%	28%	45%
2027	39%	39%	24%	42%	43%	27%	42%
2028	34%	35%	22%	37%	38%	24%	38%
2029	40%	40%	25%	44%	45%	28%	44%
2030	36%	37%	23%	40%	41%	26%	41%

Source: Author's calculation form simulation results