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TRADE IN GENETICALLY MODIFIED FOOD: A SURVEY OF EMPIRICAL STUDIES

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Abstract

New advances in biotechnology have enhanced production of maize, soybeans, and cotton. Consumer reactions to the new technology have been mixed. Both the supply shock, from an increase in productivity or a reduction in input use, and the demand shock, which is determined by the consumer response to consuming GM foods, affect production, trade, and prices of GM foods. In this paper, we survey models that analyze the market effects of GM technology. The results depend on a number of important issues such as the cost of market segmentation and labeling, the nature of the productivity shock to producers of GM products, and the extent of any adverse reaction to GM products by consumers. The results from global trade models indicate that, if costs of labelling and market segmentation are not large, world markets can adjust to the various scenarios without generating extreme price differentials between GM and non-GM commodities or extreme changes in the pattern of world production and trade. Through market linkages, the benefits of the new technology tend to be spread widely, with adopters generally gaining more than non-adopters. In particular, developing countries will benefit if they can adopt the new technologies, and get mixed results if they are non-adopters.

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1. Introduction

New advances in biotechnology have enhanced production of selected agricultural commodities in major exporting countries such as the U.S., Argentina, Australia, and Canada.[1] Some developing countries such as China and Mexico have adopted these technologies in their domestic markets, but are not major exporters of these products. Maize, soybeans, and cotton have been the major beneficiaries to date, with active research on other crops.[2] Proponents of these new technologies argue that they can increase productivity, reduce pesticide use, and improve the nutritional quality of food. Opponents, however, worry about both the safety of consuming genetically modified (GM) foods and the impact of biotechnology on the environment.[3]

In certain high-income countries, notably Japan and the European Union (EU), the government has responded to consumer scepticism over GM products.[4] For example, the EU formalized a moratorium on the approval of additional GM crops for consumption in June 1999.[5] Labeling also addresses consumer concerns. Most OECD countries have instituted or are discussion some type of mandatory labeling. The situation is fluid and labeling rules differ across countries.[6] At one extreme, the U.S. and Canada require labeling only when the nutritional or allergenic composition has been altered through

[1] In general, these countries had devoted a high share of total acreage to biotech products in 2000: U.S. 41 percent, Argentina 84 percent, Australia 41 percent, and Canada 17.6 percent (Marra et al. 2002). The largest shares of genetically engineered crops in 1999 were found in Argentina (approximately 90 percent of the soybean crop), Canada (62 percent of the rapeseed crop), and the United States (55 percent of cotton, 50 percent of soybean and 33 percent of the maize crops) (James 1999). The proportion of GM crops grown in developing countries increased from 14 percent in 1997 to 24 percent in 2000 (James 2000).

[2] Marra (2001) lists 15 major transgenic crops that have been approved for planting in a number of countries. These include canola, carnations, chicory, corn (maize), cotton, melon, papaya, potato, rice, soybeans, squash, sugar beets, tobacco, tomatoes, and wheat.

[3] One can make a distinction between "genetically modified" (GM) organisms (or GMOs), which refer to all forms of genetic modification, including standard methods of selective breeding, and "transgenic" organisms, which involve the transfer of genetic material across species. Following common usage, we will use the term "GM" or "GMO" to refer to transgenic organisms, which are the focus of the controversies. Codex has adopted the term "agricultural biotechnology" and that is the common usage in term of common usage in the U.S. We will use it interchangeably with "GM" and "GMO".

[4] More generally, recent regulatory failures in the EU have raised consumer concerns about food safety (e.g. mad cow disease, dioxin contaminated animal feed, and foot and mouth disease). The food crisis, however, has not been caused by GM foods.

[5] The EU is developing policies to eventually resume the process of EU approval for GM crops. See Sheldon (2002) for more details on EU regulations pertaining to GM foods.

[6] See OECD (2000), table 1, pp. 13-14 for a summary of labeling legislation by country.

genetic engineering. Otherwise, labeling food containing GM ingredients is voluntary. At the other extreme, the EU has mandatory labeling for all food and food ingredients containing genetically engineered DNA/proteins above a one percent tolerance level.

While labeling would allow consumers to make informed choices, it is currently difficult and expensive for producers to preserve the identity of either the GM or the non-GM variety through the entire production chain, from raw to finished product. The issue is important and contentious. High costs of segmenting the markets for GM and non-GM commodities may well largely offset the potential gains from the new technologies, forcing producers and distributors to bear costs that they argue are unnecessary.[7] If labeling requirements become the norm, however, one might expect cost-saving technologies to emerge that could significantly reduce the costs of segmenting the markets.

These issues are especially important for developing countries, where there are many poor people who spend a large share of their income on food and derive much of that income from agriculture. In the EU and Japan, where incomes are high and agriculture is a very small share of economic activity, consumers can afford to be critical about the introduction of new agricultural technologies and production processes about which they are unsure. For developing countries, however, increasing agricultural productivity and lowering food prices is very important, and the costs to society of not adopting these new technologies is relatively much higher.[8]

The introduction of new GM technologies has raised a number of issues and challenges to the world trading system. Much of the debate to date has been highly politicized. There is a real need for better information, both about the underlying science (what are the potential new areas of application and the potential impacts on the environment, biodiversity, and health) and about the economic impacts of the new technologies. Important research questions include:

- What are the actual and potential gains in productivity and food quality, and who will benefit from them?
- What are the potential impacts on world agricultural production, prices, and trade?
- What will be the impact of restrictions on the use of GM technologies, including production and trade restrictions, changes in consumer preferences, and segmentation of GM and non-GM markets (including labeling requirements)?
- What are the differential impacts of these trends on developed and developing countries?
- How are the institutions of the world trading system dealing with, and adapting to, these technological changes?

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[7] At present, segmenting and labeling costs have not deterred U.S. farmers from expanding biotech crop acreage (Fernandez-Cornejo, Jorge and William D. McBride, 2002).

[8] For a discussion of the perspective of developing countries on biotechnology issues, see Pinstrup-Andersen and Cohen (2001) and Pardy (2001).

This paper surveys analyses of the current and potential economic impact of the new technologies, under different scenarios concerning how the world trading system and national markets handle GM commodities. We do not review studies of the science and potential impacts on the environment, biodiversity, or health. There are two basic approaches that have been used in the economics work: (1) partial analysis focusing on specific issues, some in a partial-equilibrium framework; and (2) multi-country, computable general equilibrium (CGE) world trade models. In the next section, we briefly discuss the nature of the policy issues raised by the introduction of the new GM technologies. We then survey the existing economic studies, focusing on how they address the issues raised above.

Given that the new technologies are very new and rapidly evolving, that there are major knowledge gaps about their potential impact on production and distribution costs, and that the world trading system is just starting to adapt, the economic studies we review must all be viewed as tentative, based on uncertain premises and incomplete data. Much of the work has had to rely on sensitivity analysis—identifying important parameters—and consideration of potential scenarios, rather than econometric analysis of historical data. The studies have produced a few robust conclusions, as well as identifying crucial assumptions and important information gaps.

2. Policy Debate

The debate over GM products raises a number of issues that affect trade and the world trading system.[9] Currently, countries have very different domestic regulations of GM products. U.S. regulators view GM foods as not substantially different from the conventional variety (e.g. they are "substantially equivalent"). The EU adheres to the "precautionary principal." Regulators in the EU view GM and conventional varieties as differentiated products because of the perceived risks.

These different perceptions of GM foods affect labeling requirements. In many countries, there are mandatory labeling requirements, while in others labeling remains voluntary—differences that will have impacts all along the food chain, from seed producers to food retailers. The EU, Japan, Australia-New Zealand, Korea, Switzerland, the Czech Republic, Hungary, Norway, and Iceland all have some type of mandatory labeling regulations for GM foods. The European Commission has proposed a strict system of traceability for GMOs that may be approved and implemented in late 2002 or 2003 (Sheldon 2002). In contrast, in the United States and Canada, there are no specific biotech requirements. Labeling is required only in cases where the product differs from its conventional counterpart in terms of allergenicity or nutritional content. But they are providing voluntary guidelines for those who wish to apply labels specifying non-GM. A detailed discussion of existing and pending legislation is not possible here, but the variety of labeling schemes in place or under consideration underlines the substantial differences between major exporters and importers on these issues.

[9] See Nielsen and Anderson (2000b), Kerr (1999), and Diaz-Bonilla and Robinson (2001) for discussions of these issues.

International agencies, such as the FAO Codex Alimentarius and Convention on Biodiversity are working to provide a basis for consistent and coherent approaches to GM product trade flows. Codex currently does not include agreed standards on GM foods. An Ad Hoc Intergovernmental Task Force is focusing on developing guidance for risk analysis. There is also a committee on labeling to establish guidelines (Sheldon 2002).

The Biosafety Protocol (or Cartagena Protocol), in particular Article 18, should provide for prescriptions for the handling, transport, packaging, and identification of modified living organisms. At present these are still under discussion and, in any case, will only apply once the treaty is ratified by at least 50 signatories. While the protocol recognizes the right of a country to authorize or restrict the import of living modified organisms after assessing the associated risks, these actions require studies undertaken in a scientific manner based on recognized risk assessment techniques. In cases where such knowledge is incomplete, countries are permitted to apply the "precautionary principle" and refuse imports if these are considered to avoid or minimize risks to human health or biodiversity. They are also permitted to take into account socio-economic considerations, provided these are consistent with their international agreements. To what extent the Biosafety Protocol will facilitate or stymie trade in biotech products is as yet uncertain as this depends on its interpretation.

Members of the World Trade Organization (WTO) also have trade obligations that restrict the extent to which trade measures can be used against agricultural biotechnology without risking a case coming before the WTO Dispute Settlement Body. The establishment of international standards for the production, regulation, and labeling of these products may be helpful as a way of reducing future trade disputes. Under the Agreement on Sanitary and Phytosanitary measures (SPS) agreement, a country may apply higher standards only if these can be justified by appropriate scientific risk information.[10]

The emergence of GMOs in agricultural and food production introduces new issues that may emerge as trade disputes to be dealt with within the WTO. Sheldon (2002) notes that potential disputes may arise if a country such as the EU bans imports of a GM product, but allows imports of the conventional product. "The key issue in any GMO dispute will be the definition of 'like goods', i.e. does either genetic modification or presence of GM ingredients constitute sufficient grounds for differentiation from conventional products." (p. 166). According to the U.S. view that GM foods are substantially equivalent to conventional varieties, such an import ban would be discriminatory.

The emergence of new GM technologies has generated a great deal of uncertainty and confusion in the policy debate, both nationally and internationally. Given this uncertainty, economic studies have focused on analyzing the nature of the potential costs

[10] Some authors suggest that there is potential conflict between the Cartagena Protocol and WTO rules, which allows temporary restrictions relating to health and safety concerns in the absence of scientific evidence, but which requires that scientific studies be undertaken to substantiate the concerns. See Diaz-Bonilla and Robinson (2001) and Nielsen and Andersen (2001b).

and benefits of adoption of the new technologies, under alternative scenarios regarding changes in consumer preferences and the nature of national and international regulation.

3. Partial Analysis

Partial analyses of issues surrounding the introduction of GM technologies focus on individual commodities or particular issues, using partial equilibrium models or descriptive analysis. The studies do not put these issues in a global perspective, but rather provide more detail than the large, global trade models can include. The articles surveyed cover a diverse group of issues:

- The nature and magnitude of the actual and potential productivity gains due to the new technologies.
- Consumer attitudes towards GM products and willingness to pay for non-GM varieties.
- The costs associated with achieving market segmentation and identity preservation.
- The distribution of welfare gains and monopoly rents arising from the new technologies.

Farmers have adopted agricultural biotechnology because they expect lower production costs, yield gains, and lower pesticide use. To date, there are limited measures of the extent of productivity gains. Marra, Pardey and Alston (2002) and Marra (2001) survey the farm level studies of transgenic crops in the U.S. They find three general conclusions concerning productivity effects by crop. First, transgenic cotton will require less pesticide use and will be profitable in most U.S. states in the Cotton Belt. Yields will improve in Bt corn. Finally, soybean production (primarily "Roundup Ready" varieties) will experience savings in pesticide and tillage costs. These cost advantages outweigh the slight yield loss observed for "Roundup Ready" soybeans. Marra et al. note that their conclusions about the productivity gains by sector are relevant only for the U.S. because most of the farm level studies were done for the U.S.

Other studies note that the benefits of GM crops are mixed. For example, Shoemaker (2001) analyzes the effects of GM crops on yield, net return, and pesticide use, controlling for factors such as climate, pest management strategies, crop rotation, and tillage. She reports that herbicide tolerate cotton had statistically significant increases in yield and net return, but no significant change in herbicide use. Herbicide –tolerant soybeans generated small but statistically significant increases in yield and significant decreases in herbicide use.

Desquilbet and Bullock (2002) focus on the cost of segmenting markets and labeling non-GM varieties. They analyze which producers bear the costs of identity preservation, and how farmers and handlers are differentiated with respect to these costs. To do so, they construct a partial equilibrium model of supply and demand built up from individual agents in the economy. They consider two types of costs. First, the costs in the production process to prevent co-mingling of GM and non-GM varieties. For example the cost incurred to prevent cross-pollination and the costs of maintaining farm equipment dedicated to either GM or the non-GM varieties. The second type of costs involve convincing the purchaser that the product is GM-free. These costs include chemical testing and monitoring.

They analyze the welfare implications of non-GM segregation and identity preservation using supply and demand analysis. They consider two vertically integrated markets, a market for agricultural products at the farm stage and a market for agricultural products at the handling stage. Three types of rapeseed are produced—a non-GM variety, but for which no effort is made to prevent co-mingling with the GM variety, a GM variety, and a non-GM variety for which special efforts are made to prevent co-mingling with GM rapeseed. Handlers buy the rapeseed from farmers and produce either regular rapeseed or identity preserved (IP) rapeseed that is classified as non-GM. IP rapeseed can only use non-GM farm rapeseed in production. Consumers buy regular rapeseed and IP rapeseed from handlers. There are heterogeneous consumers, some get utility from consuming only IP rapeseed, while others are willing to consume either. In this framework, they consider three simultaneous shifts in supply and/or demand in three markets. First, GM technology lowers production costs for some subset of all farmers, shifting the supply curve. Second, some consumers may shift demand away from GM towards non-GM varieties. This preference shift will increase the demand for segregation and identity preservation of non-GM varieties. Farmers, handlers, and consumers are heterogeneous agents. This allows them to quantify welfare effects depending on various characteristics of the agents. The model also has two regions, the domestic market, modeled after the EU, and the rest of world.

Desquilbet and Bullock consider two simulations. First, they introduce GM technology in the domestic market when consumers are indifferent between GM and non-GM varieties. Then they introduce GM technology in conjunction with a shift in consumer preferences towards the non-GM variety and the need for identity preservation. In the first scenario, they find that the price of regular farm rapeseed declines by 0.7 percent and handled supply of regular rapeseed increases by 1.5 percent. Domestic welfare increases by 78 million euros. When consumers shift away from GM rapeseed, the price of regular farm rapeseed declined by 2.7 percent and farm price of IP rapeseed is 7.6 percent higher than the price of farm rapeseed in the baseline. The price of handled IP rapeseed is 11 percent higher than the price of handled regular rapeseed. In the analysis, they identify different types of farmers, handlers and consumers who pay the costs of non-GM segregation and identity preservation.

Other studies indicate the general magnitude of segregation costs. For example, Lin (2002) finds that, on average, across the surveyed elevators in the U.S., segregation could add $.22 per bushel for non-GM corn or 12 percent of the average farm price for corn, from country elevators to export ports. Lin further estimates that the cost of segregation for non-GM soybeans for the 2001-crop at about $0.18 per bushel for non-GM soybeans (based on the high oil corn identity preservation (IP) system), or about 4 percent of the average farm price of soybeans.

Lence and Hayes (2001) describe market conditions under which a premium price for non-GM or a discount for GM products will arise. They begin with the strong assumption that consumers who prefer non-GM products will consume GM varieties at a discount if there is not sufficient GM available. They argue that when the non-GM output share exceeds the demand share, there will be a relative surplus of non-GM products. The consumer who is indifferent will consume the GM product, the consumer who prefers non-GM products will pay a premium.

A number of partial equilibrium models investigate the welfare implications of GM technology. For example, Moschini, Lapan and Sobolevsky (2000) evaluate the welfare effects of Roundup Ready Soybeans. For U.S. producers who use GM soybeans, trade allows them to exploit economies of scale. At the same time, monopoly producers sell the latest technology to countries that compete with U.S. soybean producers. The net effect GM technology has on the U.S. then depends on both the gains to U.S. producers and exporters, as well as the cost of increased competition from foreign producers to whom U.S. multinationals sell GM technology. Moschini et al ask how exports of U.S. technology affect U.S. producers and welfare. They find that U.S. welfare is slightly improved as Roundup Ready technology is exported.

Other studies address demand issues. For example, James and Burton (2002) focus on consumer attitudes. They use choice modeling methods to determine the extent to which Australian consumers are willing to pay to avoid GM food. Their analysis provides a quantitative study to supplement qualitative studies which suggest that consumers in Western Europe and Japan are the most concerned about GM technology and those in the U.S. are the least concerned. They surveyed consumers, asking them to rank options ("food baskets") with different combinations of attributes about production technology, the food bill, and the levels of health and environmental risks.[11]

They find that consumer willingness to pay to avoid GM foods varies by age and gender. It also varied by type of GM technology used to produce foods, with consumers more willing to pay to avoid products which used gene technology involving plants and animals as opposed to gene technology involving only plants. For example, for the average woman between ages 31 and 40 years of age, the average food bill would have to drop 18 percent before food produced with plant gene technology would be purchased. The food bill would have to drop 59 percent for this consumer to purchase food containing animal gene technology. They conclude that additional studies of consumer choice in different countries are necessary to better quantify demand for GM and non-GM varieties.

Also focusing on consumer choice issues, Giannakas and Fulton (2002) analyze the effect of genetically modified foods on the purchasing decisions of consumers and welfare under different assumptions about labeling. They develop a model with heterogeneous consumers who differ in the utility derived from the consumption of GM foods and therefore have a different willingness to pay for GM products. They find that

[11] Note that consumer attitude studies may not necessarily predict market behavior. Consumers may not have responded truthfully because of the hypothetical nature of their choices.

the greater the segregation costs associated with mandatory labeling, “no labeling” is more likely to be the superior regime. When consumers have a high aversion to GM foods, and there is little price reduction for GM foods, mandatory labeling is a rational outcome.

4. Global Trade Models

The multi-country, computable general equilibrium (CGE) trade models surveyed below focus on different countries and sectors. They also incorporate different assumptions about: (1) how GM technology affects productivity; (2) the transfer of GM-technology across countries; (3) market segmentation; and (4) the nature of the shift in consumer preferences in developed countries. All these models are based on world trade and production data from the Global Trade Analysis Project (GTAP) based at Purdue University. The project has gathered social accounting matrices (SAMs) for a large number of countries and also detailed international trade data by sector, consistent with the country SAM data.[12]

The models, the scenarios they analyze, and their key findings are summarized in the appendix. We expand on the summary in the table in the discussion below.

Anderson and Yao (2001)

Anderson and Yao evaluate the effect of China developing GM technology. They note that China has been investing heavily in biotech research and development since the 1980s. They allow GM technology to improve productivity in four crops, rice, cotton, corn and soybeans. They also take into account that some countries—North America, the Southern Cone of South America (Argentina, Chile, and Uruguay) and Southeast Asia—already use GM technology in these crops. When they discuss the benefits to China of adopting GM technology, they note that these gains would be less if they took into account the research and development costs.

They conclude that China will gain from GM technology if there are no environmental externalities and no adverse consumer reactions. They find that the welfare gains from GM adoption depend on retaining market access abroad. Market access is important for direct sale of GM products and indirect links via the sale of products such as textiles and apparel which use a GM-potential input in production. However, one must also account for the cost of R&D development that are not included in the welfare measure they report. Furthermore, adverse consumer reactions will reduce the benefits of adopting GM technology in China. China, as a new WTO member, has incentive to ensure that the GM debate does not lead to excessive denial of market access for GM products.

[12] The GTAP project also includes global modeling software, which some of the articles use in specifying and solving their models. See Hertel (1997). Others use different modeling software, typically the General Algebraic Modeling System (GAMS). Both are flexible modeling systems that are widely used.

Huang et al. (2002)

Huang et al. also evaluate the effects of GM technology on China's production and trade. They use productivity estimates that are based on empirical micro-level data for the cotton sector and experimental data for the rice sector in China. They use the GTAP model, with baseline projections for 2010. This allows them to incorporate changes future changes in China that are important for its trade relations: China's accession to the WTO between 2002 and 2005; global phase out of the Multifiber Agreement by January 2005; and EU enlargement.

Huang et al. consider four policy scenarios. First they consider the effects of factor-biased productivity growth in cotton, based on empirical estimates. They find that the price of cotton declines by 10.9 percent. This affects trade in textiles because textile costs decline 0.27 percent. Output and exports of textiles increase 0.7 percent and 0.9 percent respectively.

When rice also benefits from a productivity gain due to GM technology, the price declines by 12 percent in 2010. The welfare effects of GM technology (in both cotton and rice) are substantial: annual income increases 5 billion US $ in 2010 or about 3.5 US $ per person.

Next, they consider the implications of a negative consumer response in China's major rice export markets, Japan, Korea, the enlarged EU, and South East Asia. They find that exports of GM rice from China drop substantially (however this is from a low base since rice exports are only 1.2 percent of production). There is a slight decline in output growth for China, however, the overall negative effect is small, most of the benefits of GM technology are realized within China.

Finally, they consider the effect of labeling GM rice, to be consistent with China's demand that GM soybean imports from the U.S. are labeled as such. They model the effect of labeling as an increase in the cost of services required for rice production, assuming a total increase in production costs due to labeling to be 3 percent. They find that labeling is costly in terms of welfare. The welfare loss to China is 1.3 billion US$ because labeling raises the domestic price of GM rice, hurting consumers.

Nielsen and Anderson (2001a)

Like both Anderson and Yao (2001) and Huang *et al.* (2002), , Nielsen and Anderson (2001a) use the GTAP model to evaluate the effect of GMO productivity increases in maize and soybean production. They include China in the set of countries that use GM technology and apply GM-driven productivity growth of 5 percent in coarse grain (excluding wheat and rice) and oilseeds to North America, Mexico, the Southern Cone region of Latin America, India, China, Rest of East Asia (excluding Japan and the East Asian newly industrialized countries, or NICs), and South Africa. Other countries are assumed to refrain from the use of GM crops in their production systems—the EU from choice and Sub-Sahara Africa because they are assumed not to be able to gain access to the technology.

Nielsen and Anderson focus on policy choices and consumer reactions to GM foods. The scenario first is a base case with no policy or consumer reactions to them. The others (scenarios 2 and 3) impose on this base case a policy or consumer response in Western Europe. In scenario 2, Western Europe not only refrains from using GM crops in its own domestic production systems, but the region is also assumed to reject imports of genetically modified oilseeds and coarse grains from GM-adopting regions. Scenario 3 considers the case in which consumers express their preferences through market mechanisms rather than through government regulation.

A 5% reduction in overall production costs in these sectors leads to increases in coarse grain production of between 0.4% and 2.1%, and increases in oilseed production of between 1.1% and 4.6%, in the GM-adopting regions. The production responses are generally larger for oilseeds as compared with coarse grain. This is because a larger share of oilseed production as compared with coarse grain production is destined for export markets in all the reported regions, and hence oilseed production is not limited to the same extent by domestic demand. Increased oilseed production leads to lower market prices and hence cheaper costs of production in the vegetable oils and fats sectors, expanding output there. This expansion is particularly marked in the Southern Cone region of South America, which exports a large share of production. In North America, maize is also used as livestock feed, and hence the lower feed prices lead to an expansion of the livestock and meat processing sectors there.

Due to the very large world market shares of oilseeds from North and South America and coarse grain from North America, the increased supply from these regions causes world prices for coarse grain and oilseeds to decline by 4.0% and 4.5%, respectively. As a consequence of the more intense competition from abroad, production of coarse grain and oilseeds declines in the non-adopting regions. This is particularly so in Western Europe, a major net importer of oilseeds, of which about half comes from North America. Cereal grain imports into Western Europe increase only slightly (0.1%), but the increased competition and lower price are enough to entail a 4.5% decline in Western European production. In the developing countries too, production of coarse grain and oilseeds is reduced slightly. The changes in India, however, are relatively small compared with e.g. China and the Southern Cone region. This is explained by the domestic market orientation of these sales.

Global economic welfare (as traditionally measured in terms of equivalent variations of income, ignoring any externalities) is boosted in this first scenario by US$9.9 billion per year, two-thirds of which are enjoyed by the adopting regions. All regions (both adopting and non-adopting) gain in terms of economic welfare except Sub-Saharan Africa (a non-adopter). Most of this gain stems directly from the technology boost. The net-exporting GM-adopters experience worsened terms of trade due to increased competition on world markets, but this adverse welfare effect is outweighed by the positive effect of the technological boost. Western Europe gains from the productivity increase in the other regions only in part because of cheaper imports; mostly it gains because increased competition from abroad shifts domestic resources out of relatively highly assisted segments of EU agriculture. The group of other high-income countries, among which are East Asian nations that are relatively large net importers of the GM-potential crops, benefits equally from lower import prices and a more efficient use of resources in domestic farm production.

Next, Nielsen and Anderson consider the scenario in which Western Europe not only refrains from using GM crops in its own domestic production systems, but the region is also assumed to reject imports of genetically modified oilseeds and coarse grain from GM-adopting regions. This assumes that the labelling requirements of the Biosafety Protocol (UNEP 2000) enable Western European importers to identify such shipments and that all oilseed and coarse grain exports from GM-adopting regions will be labelled "may contain GMOs". Under those conditions, the distinction between GM-inclusive and GM-free products is simplified to one that relates directly to the country of origin, and labelling costs are ignored.[13] This import-ban scenario reflects the most extreme application of the precautionary principle within the framework of the Biosafety Protocol.

A Western European ban on the imports of genetically modified coarse grain and oilseeds changes the situation in scenario 1 dramatically, especially for the oilseed sector in North America which is highly dependent on the EU market. The result of the European ban is not only a decline in total North American oilseed exports by almost 30%, but also a production decline of 10%, pulling resources such as land out of this sector. For coarse grain, by contrast, only 18% of North American production is exported and just 8% of those exports are destined for Western Europe. Therefore the ban does not affect North American production and exports of maize to the same extent as for soybean, although the downward pressure on the international price of maize nonetheless dampens significantly the production-enhancing effect of the technological boost. Similar effects are evident in the other GM adopting regions, except for India—once again because its production of these crops is virtually all sold domestically and so is not greatly affected by market developments abroad.

For Sub-Saharan Africa, which by assumption is unable to adopt the new GM technology, access to the Western European markets when other competitors are excluded expands. Oilseed exports from this region rise by enough to increase domestic production by 4%. Contrary to the Blair House Agreement, this study finds that Western Europe increases its own production of oilseeds, however, so the aggregate increase in its oilseed imports amounts to less than 1%. Its production of coarse grain also increases, but not by as much because of an initial high degree of self-sufficiency. Europe's shift from imported oilseeds and coarse grain to domestically produced products has implications further downstream. Given an imperfect degree of substitution in production between

[13] By distinguishing between GMO-inclusive and GMO-free products by country of origin, one concern may be that GM-adopting regions channel their exports to the country or region imposing the import ban (here Western Europe) through third countries that are indifferent as to the content of GMOs and that do not adopt GM technology in their own production systems. The possibility of such transshipments is abstracted from in this analysis.

domestic and imported intermediate inputs, the higher prices of domestically produced maize and soybean mean that livestock feed is slightly more expensive. (Half of intermediate demand for coarse grain in Western Europe stems from the livestock sector.) Inputs to other food processing industries, particularly the vegetable oils and fats sector, also are more expensive. As a consequence, production in these downstream sectors decline and competing imports increase.

Aggregate welfare implications of this scenario are substantially different from those of scenario 1. Western Europe now experiences a decline in aggregate economic welfare of US$4.3 billion per year instead of a boost of $2 billion. Consumer welfare in Western Europe is reduced in this scenario because, given that those consumers are assumed to be indifferent between GM-inclusive and GM-free products, the import ban restricts them from benefiting from lower international prices. Bear in mind, though, that in this as in the previous scenarios it is assumed citizens are indifferent to GMOs. To the extent that some Western Europeans in fact value a ban on GM products in their domestic markets that would partially offset the loss in economic welfare.

The key exporters of the GM products, Northern America, Southern Cone, and China, all show a smaller welfare gain in this scenario compared with the scenario in which there is no European policy response. Net importers of corn and soybeans (e.g. "Other high-income" which is mostly East Asia), by contrast, are slightly better off in this scenario than in scenario 1. Meanwhile, the countries in Sub-Saharan Africa are affected in a slightly positive instead of slightly negative way, gaining from better terms of trade. In particular, a higher price is obtained for their oilseed exports to Western European markets compared with scenario 1.

Two-thirds of the global gain from the new GM technology as measured in scenario 1 would be eroded by an import ban imposed by Western Europe: it falls from $9.9 billion per year to just $3.4 billion, with almost the entire erosion in economic welfare borne in Western Europe (assuming as before that consumers are indifferent between GM-free and GM-inclusive foods). The rest is borne by the net-exporting adopters (mainly North America and the Southern Cone region). Since the non-adopting regions generally purchase most of their imported coarse grain and oilseeds from the North American region, they benefit even more than in scenario 1 from lower import prices: their welfare is estimated to be greater by almost one-fifth in the case of a Western European import ban as compared with no European reaction.

As an alternative to a policy response, Nielsen and Anderson also consider a shift in European preferences away from imported coarse grain and oilseeds and in favour of domestically produced crops. The scenario is implemented as an exogenous 25% reduction in final consumer and intermediate demand for *all* imported oilseeds and coarse grain (that is, not only those which can be identified as coming from GM-adopting regions). Some European consumers and firms are assumed to choose to completely avoid products that are produced outside Western Europe. That import demand is shifted to domestically produced goods. Western European producers and suppliers are assumed to be able to signal—at no additional cost—that their products are GM-free by e.g.

labelling their products by country of origin. This is possible because it is assumed that no producers in Western Europe adopt GM crops (perhaps due to government regulation), and hence such a label would be perceived as a sufficient guarantee of the absence of GMOs.

Having consumers express their preferences through market mechanisms (which presumes labelling) rather than through a government-implemented import ban has a much less damaging effect on production in the GM-adopting countries. In particular, instead of declines in oilseed production as in scenario 2 there are slight increases in this scenario, and production responses in coarse grain are slightly larger. As expected, domestic oilseed production in Western Europe must increase somewhat to accommodate the shift in preferences, but not nearly to the same extent as in the previous scenario. Furthermore, there are in fact minor price reductions for agri-food products in Western Europe in part because (by assumption) the shift in preferences is only partial, and so some consumers and firms do benefit from lower import prices. In other words, in contrast to the previous scenario, a certain link between EU prices and world prices is retained here because we are dealing with only a partial reduction in import demand. The output growth in Sub-Saharan Africa in scenario 2, by taking the opportunity of serving European consumers and firms while other suppliers were excluded, is replaced in this scenario by declines: Sub-Saharan Africa loses export shares to the GM-adopting regions.

van Meijl and van Tongeren (2001)

Van Meijl and van Tongeren (2001), like Anderson and Yao (2001) and Nielsen and Anderson (2001a), use the GTAP model to evaluate the effect of a GM productivity shock. They consider the effects of GM technology in maize and soybeans. Unlike the other studies, van Meijl and van Tongeren have a different type of productivity shock for each crop. For maize, studies indicate that GM technology increases yield. They model this as a Hicks-neutral productivity growth at 5%, following Nielsen and Anderson (2001a). For soybeans, there is savings on inputs of chemicals and labor—this is modeled as a five percent chemical cum labor augmenting technical change in that sector. Also similar to previous studies, van Meijl and van Tongeren consider the effect of changes in consumer attitudes, modeled as an import ban.

Their analysis differs from the other studies in two ways. First, they model spread of GM technology as an endogenous knowledge spillover linked to trade flows and country characteristics. They begin from the premise that knowledge is embodied in traded goods and that is how it travels between countries. "The international diffusion of these technologies is not perfect but dependent on trade linkages, absorption, capacity, size of farms and whether a technology is socially acceptable. If a production technology is not socially acceptable then a country is excluded from these potentially productivity gains that are already less than perfect." (p.2) For example, following a 5 percent productivity increase in North America (Hicks neutral for maize, factor-biased for soybeans), Argentina receives an increase a 70 percent productivity growth. The potential spillovers for developing countries are smaller because their farm size is too small and or education is too low to adopt GM technology profitably.

In contrast, Anderson and Yao (2001) note that a country must pay for research and development (R&D) to acquire GM technology. Since China has undertaken such (R&D), they consider the global effects of including China as a GM-adopter.

They also differ from other studies because they include the EU Common Agricultural Policy (CAP). The CAP shields EU farmers from world market price developments. So if world prices for grains decline, as a result of GM technology in the major exporters, the lower world prices do not necessarily trigger a substitution of EU demand towards imported varieties.

Acknowledging the similarity of their model to Nielsen and Anderson (2001a), they focus their discussion on the "new" information, endogenous international knowledge transfers. From the base scenario, GM adoption by North America (NAM), they show the potential knowledge spillovers (potential because social acceptance is not accounted for), shown as the percent productivity shock (NAM received 5%) they can apply to the GM sectors. Australia/New Zealand potentially receive full spillovers because their farm size and education level exceeds the threshold levels. Argentina and EU potentially receive 70% or 60%; they have relatively highly educated farmers (like NAM), but average farm size is lower. Potential spillovers to developing countries are smaller because they trade less chemical with NAM, their farm size is too small and/or education level is too low to adopt the new GM technologies profitably.

They discuss the effects of spillovers on production in the non-innovating countries. When North America innovates, and there are no spillovers, output of coarse grains and oilseeds expands in the innovating country and contracts in all other countries. With spillovers, other countries also get a part of the productivity increase. The knowledge receiving countries either do not see output decline as much or see an increase.

Next, they consider production and farm income impact of alternative EU policy responses to GMOs. With the CAP, the EU is isolated from the downward pressures on prices brought about by the global productivity boost. When the EU does not accept GMO production technologies, there is no internal productivity gain. Production and farm income do not change. They note that this contrasts to Nielsen and Anderson (2001) who find a sharp reduction in coarse grain output. They argue that Nielsen and Anderson do not represent the CAP so overstate the negative production effect of not adopting GM technology in the EU. However, van Meijl and Van Tongeren do not discuss the effect of GM technology on the program cost of the CAP. Depending on the nature of the productivity shock and price decline in GM-adopting countries, the CAP expenditures may become too expensive to maintain.[14]

[14] Burfisher, Robinson and Thierfelder (2002) analyzed a similar case of interdependent trade and domestic policy in Mexico, where the government sought to insulate corn producers from world market prices. When faced with cheap imports from the U.S. (due to tariff elimination as part of NAFTA), Mexico's program costs became exorbitant.

Nielsen, Robinson and Thierfelder (2001)

Nielsen, Robinson and Thierfelder (2001) also model the production and trade effects when countries adopt GM technology. The model (referred to as the NRT model) is more aggregated than the GTAP model used in Nielsen and Anderson (2001a) with seven regions and ten sectors, but has many features in common with the GTAP model.[15] The NRT model introduces GM varieties by segmenting the coarse grain and oilseed sectors into GM and non-GM lines of production. In contrast to the GTAP- based models, in which a country produces either the GM or non-GM variety exclusively, the NRT model allows a country to produce both varieties in response to market conditions. This segregation is introduced based on a notion that there may be a viable market for guaranteed GMO-free products alongside the new GMO-inclusive varieties if the GMO-critical consumers are willing to pay a price premium. Depending on the strength of opposition toward GM products in important markets and the costs of segregating agricultural markets, developing and developed countries alike may benefit from segregated agricultural markets, which will have different prices. Such a market development would be analogous to the niche markets for organic foods.

In the base data used for this model analysis, it is assumed that all regions initially produce some of both the GM and non-GM varieties of oilseeds and coarse grain. The assumed GM shares of production, based on estimates provided in James (1999) and USDA (2000), are just 10% in all but three regions. The exceptions are the Americas and developing Asian countries where it is assumed 40% of coarse grain and 60% of oilseeds (90% in South America) use GM technology.[16]

In the NRT model the decisions of producers and consumers to use GM versus non-GM varieties in production and final demand are endogenous. The input-output choice is also endogenous for four demanders of coarse grain and oilseeds: livestock, meat& dairy, vegetable oils & fats, and other processed food sectors. Intermediate demands for each composite group (i.e. GM plus non-GM) are held fixed as proportions of output. In this way, the initial input-output coefficients remain fixed, but for oilseeds and coarse grains, a choice has been introduced for GM and non-GM varieties. Other intermediate input demands remain in fixed proportions to output. Similarly, final consumption of each composite GM-potential good is also fixed as a share of total demand, with an endogenous choice between GM and non-GM varieties.

Since the available estimates of agronomic and hence economic benefits to producers from cultivating GM crops are few and very diverse, NRT simply assume the GM oilseed and GM coarse grain sectors in all regions have a 10% higher level of primary factor productivity as compared with their non-GM (conventional) counterparts. This shock is slightly different from the shock imposed in the three GTAP model

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[15] The NRT model is implemented in the GAMS software and is solved in levels rather than in log differentials (as in the GTAP model software).

[16] The numbers for South America reflect GM use in Argentina. For Brazil, the adoption rate is much lower.

scenarios: it is twice the size, but it is applied only to primary factor inputs and not to intermediate input use.

A shift in consumer preference for the GM-variety is modeled as a change in the substitution elasticities for GM and non-GM products in two of the most GM-critical regions, Western Europe and High-income Asia. As consumers perceive GM and non-GM varieties as bad substitutes, the GM-variety must sell at more of a discount to induce consumers to purchase it. To incorporate this preference change, the factor productivity shock in the GM sectors is performed against a variety of base models, which differ in terms of substitution elasticities for GM and non-GM products in the two most GM-critical regions. Initially, it is assumed that the elasticity of substitution between GM and non-GM varieties is high and equal in all regions. Then, in order to reflect the fact that citizens in Western Europe and High-income Asia are skeptical of the new GM varieties, the elasticities of substitution between the GM and non-GM varieties are gradually lowered so that GM and non-GM varieties are seen as increasingly poorer substitutes in production and consumption in these particular regions.[17] Citizens in all other regions are assumed to be indifferent, and hence the two crops remain highly substitutable in consumption and production there.

In all scenarios, output of GM varieties increases and output of non-GM varieties declines, due to the productivity shock to the GM varieties. However, the magnitude of the change depends on consumer preferences in Western Europe and Japan, two important export markets for the GM producing regions. For example, the North America region is very sensitive to changes in preferences toward GMOs because it is the world's largest exporter of both oilseeds and coarse grains, and it is particularly dependent on the GM-critical markets for these exports. Total exports of the GM varieties decline as GM and non-GM substitutability worsens in the GM-critical regions, especially for oilseeds because almost 80% of North American oilseeds exports are initially sold in these markets.

In response to the changing preferences, exports of the non-GM varieties increase. These changes are reflected in North America's production results. Western Europe is an important importer of oilseeds. At the extreme, where Western Europeans are unconcerned about the GM or non-GM status of crops used in production, imports increase dramatically in response to lower world market prices. As substitutability is reduced, GM-imports and production plunge while non-GM imports and production increase.

The consumer preference shift also affects developing countries. For example, GM-oilseed exports from South America (an extensive GM adopter) and Sub-Saharan Africa (a region with a low share of GM varieties in total production) initially increase due to the factor productivity shock. Total GM-oilseed exports decline following as preferences in High-income Asia and Western Europe turn against GMOs. Furthermore, GM-exports are redirected from the GM critical regions and spread evenly over the other

[17] NRT use elasticity of substitution values ranging from 0.5 to 5.0. The purpose is to show the impact of GM technology for different preferences. It is difficult to find empirical estimates in the literature.

importing regions. Of South America's total oilseed exports, 84% are initially sold on GM critical markets as compared with 58% of oilseed exports from Sub-Saharan Africa. The adjustment in total GM oilseed exports is therefore relatively larger for South America. As expected, the exports of non-GM oilseeds from these two regions are generally being diverted toward the GM-critical regions and away from other regions.

Both South America and Sub-Saharan Africa depend on imports for almost one-tenth of their total cereal grain absorption. However, in terms of sources, South America depends almost entirely on North America for its imports, while imports into Sub-Saharan Africa come from North America (50%), Western Europe (16%), and the Rest of World (28%). Because citizens of South America and Sub-Saharan Africa are assumed to be uncritical of GMO content, *total* GM cereal grain imports increase as preferences in Western Europe and High-income Asia turn against GMOs. This is because GM exports are now increasingly directed to non-critical markets (i.e. *fewer* markets), and so the import price declines even further than the price decline due to the factor productivity shock. Imports of GM crops from the GM critical countries of course decline drastically as production of GM crops in these regions declines. For the non-GM varieties, imports from the GM-critical regions increase marginally as substitutability in those regions worsens and they respond by producing more of the non-GM variety. Given competition from increased supplies of GM crops, prices of non-GM crops also fall, and so South America and Sub-Saharan Africa also face declining prices on non-GM imports from the GM-critical regions as preferences shift.

Low-income Asia is a net importer of both oilseeds and cereal grains. Most of these imports (89% of oilseeds and 83% of cereal grains) come from North and South America. Total imports of GM crops into this region increase slightly as preferences turn against GMOs in Western Europe and High-income Asia. Once again, this is because the redirection of GM export crops means increased supplies on fewer markets and hence prices decline even further.

The bilateral trade results summarized above show that, while trade diversion is significant, markets can adjust to accommodate the differences in tastes across countries. This favorable outcome is driven by the price differential that results between the two crop varieties. The price wedges that arise as a consequence of the different levels of factor productivity in GM and non-GM crop production are between 4.0% and 6.6%, varying across crops and regions. In the GM critical regions, the non-GM/GM price ratio increases as citizens there become increasingly skeptical. In North America, the price wedge is generally small, and it declines as GM and non-GM substitutability worsens in the other high-income countries. Given that North America is the world's largest producer and exporter of both crops, when there is high substitutability in all regions, prices of *both* varieties decline – the GM price declines due to the productivity shock, while the non-GM price declines because of increased competition in the GM-indifferent markets. In an effort to retain access to the GM critical markets, North American production of non-GM varieties increases as citizens of the GM critical regions become increasingly skeptical of GMOs.

With the exception of oilseeds in South America, the price wedges in the developing countries are *unaffected* by the preference changes in the Western Europe and High-income Asia. Thus it is the productivity differential that determines the price wedge in developing countries, not preference shifts in the GM critical regions. When developing countries are indifferent to the GM content of agricultural products (whether produced domestically or imported) and obtain most of their imports from countries that are extensive adopters of GM crops, they gain substantially from lower import prices.

Global economic welfare (i.e. absorption) is estimated by the NRT model to increase by US$12 billion per year when GM coarse grain and oilseed production processes experience a 10% primary factor productivity increase, given the assumed regional shares of GM and non-GM varieties. As preferences in Western Europe and High-income Asia turn against GM varieties, this increase is reduced to $11 billion. South America, North America, and Low-income Asia are the main beneficiaries of the factor productivity increase, because they all are assumed to be intense adopters of the productivity-increasing crop varieties. North America gains as the major producer and exporter of both crops. The total absorption gain in this region is reduced, but only by 5% relative to the high substitutability experiment, as a consequence of changing preferences in its important export markets in Western Europe and High-income Asia.

As with the import ban and preference shift scenarios in Nielsen and Anderson, these results also show that the 'costs' of the preference changes are borne mainly by the GM-critical regions themselves, with the gains made in High-income Asia (in terms of lower import prices) basically disappearing. In Western Europe, the initial boost in total absorption is cut in half. In particular, the increases in total absorption in *all* the developing country regions are *not* affected by the preference changes in the GM-critical regions. Low-income Asia is the major beneficiary in absolute terms, being both a net importer of the two crops and basically indifferent as to GM content. Hence the region benefits from substantially lower import prices on GM crops. Despite the high dependence on the GM critical regions for its exports of oilseeds, the increase in total absorption in South America is unaffected by the preference changes there because bilateral trade flows adjust well—trade diversion offsets the effects of demand shifts in the GM-critical regions. In Sub-Saharan Africa the gains are small in absolute terms, mainly due to the small share of these particular crops in production and trade, but they are also unaffected by preference changes in GM-critical regions.

Nielsen, Thierfelder and Robinson (2001)

Nielsen, Thierfelder and Robinson expand on the previous paper in two ways. First, they segment both the farm and processed food sectors. In the earlier paper, the processed food sectors had an endogenous choice between GM and non-GM intermediate inputs and used a combination of both. Here, non-GM processed foods use only non-GM farm products as intermediate inputs, and similarly for GM varieties. The assumption is that there is full market segmentation, with identity preservation through the processing chain, from the intermediate input to the final product. Second, they expand the treatment of consumer preferences to include a structural shift—regardless of the price differential, some consumers turn against GM foods and their consumption share declines. They find that this specification of changes in consumer preferences has a dramatic impact on the gains from adoption of GM technology.

In their specification, the GM-adopting cereal grains and oilseed sectors are assumed to make more productive use of the primary factors of production as compared with the non-GM sectors, following the treatment in the NRT model. In addition, there is some evidence that cultivating GM varieties substantially reduces the use of chemical pesticides and herbicides (e.g. Pray et al. 2001). Based on this work, the use of chemicals in the GM oilseed and GM cereal grain production is reduced by 30%.[18]

The starting point for the consumer preference experiments is that food products come in two varieties, distinguished by their method of production: GM and non-GM. The model has a representative consumer who views these two varieties as imperfect substitutes. Three different consumer response scenarios are examined. In the base case, consumers in all countries are relatively indifferent with respect to the introduction of GM techniques in food production, and so find GM and non-GM food varieties to be highly substitutable.

The next two scenarios attempt to capture the fact that citizens in Western Europe and High-income Asia dislike the idea of genetically modified foods. In the second scenario this dislike is captured by lowering the elasticities of substitution between the GM and non-GM varieties for consumers in these two regions, precisely as in the NRT model. Citizens in all other regions are basically indifferent, and hence the two varieties remain fairly substitutable in consumption.

In some countries, irrespective of how cheap these products may become (relative to non-GM foods), some consumers may simply not want to consume GM foods. In the third scenario, consumers are assumed to change the ratio of GM to non-GM foods demanded at initial prices—a structural shift in their expenditure pattern. Consumers spend the same amount on consumption of food, but the composition is changed in favor of non-GM varieties, even with no change in prices. In the scenario, the GM share of foods in consumption in Western Europe and High-income Asia is reduced to 2%.

In general, the results are very similar to the NRT model when the changes in consumer preferences are treated the same in the two models—as a decrease in the elasticity of substitution—and will not be discussed further here. In the final scenario, where consumers in Western Europe and High-income Asia turn against genetically

[18] The assumed savings in intermediate costs are not as important as the assumptions about overall productivity improvements. At this point, both should be seen as educated guesses based on scanty and preliminary evidence. The increase in factor productivity and the reduced need for chemicals in the GM cereal grain and oilseed sectors will cause the cost-driven prices of these crops to decline. The magnitude of this price decline in the different sectors and regions will differ, depending on the shares of primary production factors and chemicals in total production costs. In sectors and regions where these costs make up a large share of total costs, the impact of the productivity shock in terms of lower supply prices will be greater than in sectors and regions where the share is smaller. Intermediate users of GM inputs (the GM livestock and GM processed food producers) will benefit from lower input prices.

modified foods, the resulting changes are much more dramatic compared with assuming only reduced price sensitivity. The price of GM varieties in the GMO-critical countries declines further because of the almost complete rejection of these products, whereas the price of non-GM foods increases. This leads to substantially larger price wedges in the GM-critical regions as compared with the previous scenarios. The larger price wedges between GM and non-GM primary crops follow through the entire food processing chain. The price increase for non-GM foods is, however, moderated by the fact that there are markets for non-GM products in all regions in the model, so consumers are not closing themselves off to necessary goods, nor are they required to produce all the non-GM goods themselves. The model allows all countries to produce both varieties and hence supply both GMO-indifferent and GMO-critical consumers.[19]

Total U.S. GM cereal grain and oilseed exports fall by no less than –17% and –33%, respectively. Instead, exports of the non-GM varieties increase by 10% and 16%, respectively. These changes are a direct reaction to the relative prices obtainable on their key export markets, namely High-income Asia and Western Europe. The prices of GM cereal grains and oilseeds on these markets plummets and the prices of non-GM varieties increase slightly. The price decline for GM cereal grains in Western Europe is not as large as for oilseeds because this region is less dependent on imports of these crops, relatively speaking.

For Low-income Asia and South America, exports of GM oilseeds decline, similar to the export response in the U.S. However, exports of GM cereal grains still expand. These countries are less dependent on GM-critical regions for cereal grains than is the U.S. For example, South America sends 92 % of its cereal grain exports to the Cairns Group.

Changing consumer attitudes in Western Europe and High-income Asia also affect Sub-Saharan Africa's trade patterns. While that region is not an intense GM-adopter, it does have strong trade ties to Western Europe. Its imports of GM processed products declines, despite the fact that it is not a GM-critical region. Instead, its major import source changes its production patterns and therefore the structure of its exports.

Imports of GM cereal grain and oilseeds into Western Europe and High-income Asia decline substantially (between –57% and –71%). These decreases in quantities are accompanied by import price declines in the order of –21% to –26%. Conversely, imports of non-GM crops increase substantially, at slightly higher prices. The sourcing of these non-GM crop imports is spread across all regions, because in the model all regions are assumed to be able to produce both varieties and to be able to credibly verify this characteristic to importers. Clearly, this is a simplification of reality, and one can easily imagine that for some regions, living up to the principles of identity preservation and verifying this is very costly, thereby putting them at a cost disadvantage. Such effects are not captured in this model. The increases in non-GM cereal grain and oilseed imports are supplemented by increases in own production in both High-income Asia and Western Europe.

[19] The underlying assumption is that there is labeling and successful market segmentation.

In the structural shift experiment, the production of GM oilseeds in the U.S. declines by –15%, in spite of the factor productivity gain and the reduced chemical requirements. The direction of the effect is the opposite of that in the first two scenarios. Because the U.S. is so highly dependent on exporting to the GM-critical markets, a structural change in consumer preferences has much more of an impact on this region's trading opportunities compared with the reduced price sensitivity experiment.

An interesting question is whether these changing preferences in Western Europe and High-income Asia can open opportunities for developing countries to export non-GM varieties of cereal grains and oilseeds to these regions. Sub-Saharan Africa has some production of oilseeds, for example, and although exports of these crops do not account for a significant share of total production value at present, they might if niche markets for non-GM crops develop in Western Europe. Similarly, Low-income Asian countries might look into expanding their production of e.g. non-GM oilseeds if nearby niche markets in High-income Asian countries develop.

Although the differences are very small, comparing production results from the three scenarios indicates that pursuing niche markets might be beneficial if the price premiums obtainable for non-GM varieties are large enough to outweigh the relative decline in productivity and any identity preservation and labeling costs. But even more significant in value terms for these countries are exports of processed foods, i.e. vegetable oils and fats, meat and dairy products, and other processed foods. For a region like Sub-Saharan Africa, with strong ties to Western Europe, changing consumer attitudes toward GM foods may be an important determinant of future decisions regarding genetic engineering in food production. Production of GM processed food products expands in the first two scenarios, but declines in the structural shift third scenario. In the third scenario, the increase in demand for non-GM processed foods in the EU determines the pattern of production

5. Conclusion

The world trade models surveyed differ in country and sector focus. They also incorporate different assumptions about how GM technology affects markets, with alternative treatments of market segmentation. One set of models assumes country specialization in either GM or non-GM commodities, while others assume countries can produce both and separate them in the supply chain. None of the models incorporate labeling and market segmentation costs, given the lack of good data at this point as to what those costs might be.[20] The models also differ in terms of the assumed productivity gains associated with adoption of GM technology—again, there is as yet little quantitative information available.[21] The models also vary in how they specify shifts in consumer attitudes toward GM commodities, which reflects different views about how

[20] The issue comes town to the cost of segmenting which are unknown. Empirical work needs to be done to estimate these costs.
[21] Marra, Pardey, and Alston (2002) make some effort to generalize from the individual studies at the farm-level in the U.S.

these changes are going to play out in various countries. Finally, the models differ in how they capture the dissemination of the GM technology across countries, again reflecting different views about how the process might occur in the future.

At this point, it is impossible to make critical judgments about the relative validity of the different models. They are essentially prospective views, based on some empirical evidence (largely from partial studies) and educated speculation about how these trends might evolve in the future. As better information becomes available, the models will evolve to incorporate it.

There are a few robust results from the various studies:

- In general, adopters of the more productive GM technologies gain, while non-adopters or GM-critical regions either do not gain at all or only gain some (through changes in world prices), depending on how strongly they segment their markets. In particular, developing countries will benefit if they can adopt the new technologies, and get mixed results if they are non-adopters.
- Assuming that the costs of labeling and market segmentation are not large, world markets can adjust relatively easily to the introduction of the new technologies. The price changes and changes in production and trade flows, while significant, are not dramatic.
- Developing countries are more sensitive to the issue, given their higher shares of agriculture in national product and of food in household consumption. Large developing countries, like India and China, gain from the new technology and are not much affected by changes in trade regime, since their domestic markets are large. Countries in Sub-Saharan Africa, on the other hand, are very dependent on EU markets and would potentially be strongly affected by EU trade restrictions, although they do not currently export significant amounts of potential GM commodities (e.g., maize and soybeans).

In terms of future research, there are a number of knowledge gaps that require detailed study. Issues that are particularly important to any analysis of the impacts of the new technologies on trade and on developing countries include:

- What are the potential benefits of the next generation of GM goods, which might incorporate improved nutritional content (e.g., golden rice) or adaptability to particular climate conditions (e.g., drought tolerance)? This is especially important for developing countries.
- What are the productivity and cost gains from available and potential GM technologies? The historical record is short and the existing partial studies, which have been used to provide parameters for world trade models, are already out of date.
- What are the likely outcomes of the policy debates regarding labeling requirements and market segmentation?
- What are the actual and potential costs associated with labeling requirements, identify preservation, and segmentation of domestic and world markets for GM

and non-GM products? Knowledge of these costs is crucial to analyzing the potential spread of GM technologies.

- What are the implications of different intellectual property right (IPR) regimes for the dissemination of the new technologies and for the distribution of the benefits? Again, this is a crucial issue for analyzing potential spread of GM technologies.
- What will be the nature of consumer attitudes about commodities that incorporate gm technologies? What will be the impact on market demand? Results from the existing world trade models indicate the importance of this knowledge gap.
- What will be the impact of these new technologies on market structure and degree of international competition? Will the new market structure follow the pattern of the pharmaceutical industry, with an oligopolistic structure requiring a period of protected monopoly markets in order to recoup on large, up-front research costs?
- How will the institutions of the world trading system, including the WTO, adapt to the evolution of these new technologies?
- Given these trends, is there a need for various new forms of "special and differential treatment" for developing countries in the world trading system?

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Appendix: Summary of Computable General Equilibrium Models

Article	Model Framework and Key Assumptions	Scenarios	Key findings
Anderson and Yao (2001)	• GTAP model (base 1995) projected to 2005 with no agricultural biotechnology adoption (because GM technology is still at the early and experimental stage and will take years until it is adopted commercially on a large scale). • Segment market by country (each country produces only GM or non-GM variety). • GM technology is represented as a Hicks-neutral technology shift; an increase in total factor productivity of 5% for rice, cotton, maize, and soybean.	• Selected countries (North America, the Southern Cone of South America, and South East Asia) first without and then with China adopt GM technology in rice. • Selected countries first without and then with China adopt GM technology in cotton. • Selected countries first without and then with China adopt GM technology in maize and soybeans. • Ban on imports of Chinese food products	• When other countries adopt GM rice, output growth depresses the price of rice in their own countries by up to 5% and in all other regions to a small extent. When China is included, its output growth reduces the price of rice in China, but China is not sufficiently large to have an effect on world market prices. • China is a net importer of cotton and a net exporter of textiles and apparel. When other countries adopt GM cotton, their output growth depresses prices in their own countries 5-6 % and other countries to a small extent. When China also adopts GM cotton, it dampens the global price of cotton. There is also a large increase in China's production of textiles and cotton. When the U.S. and EU also remove VERs on China's exports of textile and apparel, China's exports and production of these products increase and China becomes a net importer of cotton, despite the productivity increase in cotton production. • When other countries adopt GM maize and soybeans, output increases and prices fall. If China joins the GM-adopting group, its production and exports increase rather than fall; prices in China decline 5 %. • If both the EU and Northeast Asia ban Chinese food products, China's gain from GM adoption would be reduced by 4/5.

Article	Model Framework and Key Assumptions	Scenarios	Key findings
Huang *et al.* (2002)	• GTAP model with baseline projection for 2001-2010 (the impact of alternative biotechnology scenarios is assessed relative to the baseline projection for 2010. • Policy changes included in the baseline: China's WTo accession,; global phase out of the Multifiber Agreement; EU enlargement with Central Europe. • Update GTAP data for the Chinese economy to 2001. • GM technology is represented by a factor biased productivity shock in the Chinese cotton and rice sectors.	• GM productivity gains in cotton. • GM productivity gains in both cotton and rice. • Import ban on GM rice by China's main trading partners (enlarged EU, Japan,Korea, and South East Asia). • Labeling requirements for imported soybeans and domestic rice (modeled as an increase in the cost of services required for rice production, a 3 % increase in production costs through labeling).	• GM technology in Bt cotton reduces the supply price by 10.9%. This yields a 0.27% reduction in textile costs. Textile output and exports increase 0.7% and 0.9%, respectively. • GM technology in rice reduces the supply price by 12%. • The use of GM technology in both cotton and rice yields a welfare gain of 5 billion US$ in 2010, about 3.5US$ per person. • A trade ban on GM rice reduces China's exports substantially. However, although output growth in the rice sectors is somewhat dampened, the overall negative effect on China is small. The largest gains are realized within China. • Labeling GM rice is costly in terms of welfare because it raises the cost of rice and hurts consumers.
Van Meijl and van Tongeren (2001)	• GTAP model supplemented to include endogenous technology spillover. • Segment market by country (each country produces only GM or non-GM variety). • GM technology is differs by sector: 5% Hicks neutral productivity growth in maize, 5% chemical and labor augmenting technological change in soybeans. • EU Common Agricultural Policy (CAP) insulates the price of grain in the EU from world price shocks.	• Base – GM technology is adopted in North America • Scenario 1 + endogenous international knowledge spillovers • Scenario 2 + CAP implementation • Scenario 3 + social acceptability of GMO production technology (so EU does not benefit from productivity shock) • Scenario 4 + EU ban on GMO imports	• Australia-New Zealand potentially receive full spillovers because their farm size and education levels exceed the threshold levels; Argentina and EU potentially receive about 60-70% of the productivity growth; potential spillover in developing countries is smaller. • The CAP changes the EU's production response to GMOs (without taking social acceptance into account). Coarse grain output increases by 2.9% rather than decreases by –0.2%, indicating that the EU is isolated from the downward pressure on world prices brought about by the global productivity boost. • When consumers in the EU find GMO technology socially unacceptable (scenario 4), production and farm income do not change because the CAP insulates farmers from productivity improvements in other regions. • If the EU completely rejects consumption of products produced with GMO technology (import ban, scenario 5), production and farm income increase dramatically (oilseed output increases nearly 20%, farm income from soybeans increases 24%)

Article	Model Framework and Key Assumptions	Scenarios	Key findings
Nielsen and Anderson (20001a)	• GTAP model • Productivity growth from GM technology in maize and soybeans is modeled as a 5% total factor productivity gain. • Segment market by country (each country produces only GM or non-GM variety)	• GM technology is adopted in coarse grains (excluding wheat and rice) and oilseeds in North America, Mexico, the Southern Cone of Latin America, India, China, Rest of East Asia (excluding Japan and the East Asian NICs), and South Africa. Other countries are assumed to refrain from using GM crops in their production systems. • GM technology is adopted and the EU bans imports of GM products. • GM technology is adopted and there is a partial shift in EU preferences away from imported coarse grain and oilseeds and in favour of domestically produced crops. The scenario is implemented as an exogenous 25% reduction in final consumer and intermediate demand for *all* imported oilseeds and coarse grain (that is, not only those which can be identified as coming from GM-adopting regions)	• A 5% reduction in overall production costs in coarse grains and oilseeds increase coarse grain production between 0.4 and 2.1% and increases oilseed production between 1.1 and 4.6 % in the GM-adopting regions. World prices for coarse grains and oilseeds decline by 4.0 and 4.5% respectively. • An EU ban on imports of GM coarse grain and oilseed (identified as such by country of origin), means North American oilseed production declines by 10 % and exports by almost 30%. The changes in coarse grain are less dramatic because North America is not as dependent on exports to the EU. For Sub-Saharan Africa, which by assumption is unable to adopt the new GM technology, access to EU markets when other competitors are excluded expands. Oilseed exports from this region rise enough to increase domestic production by 4%. The EU experiences a decline in aggregate welfare of 43 billion U.S. dollars per year, rather than an increase of 2 billion, as it did in the first scenario. • When EU consumers shift away from all imported oilseeds and coarse grains (that is not only those which can be identified as coming from GM-adopting regions), the results are much less dramatic as the case of the import ban from GM-adopting regions. Output of oilseeds expand slightly in this scenario. In contrast to scenario 2, Sub-Saharan Africa loses export share to the GM-adopting regions and therefore its output declines.

Article	Model Framework and Key Assumptions	Scenarios	Key findings
Nielsen, Robinson, and Thierfelder (2001)	• GAMS based model, using data from GTAP. • All regions produce some of both the GM and non-GM varieties of each product; in North America, South America, and Low-income Asia, 40% of coarse grain and 60% of oilseed (90% for South America) production use GM technology. • Producers who use GM potential agriculture as an intermediate good (e.g. livestock, meat & dairy, vegetable oils & fats, and other processed food sectors) and direct consumers of GM potential crops have an endogenous decision over the GM and non-GM variety; the choice between GM and non-GM is determined by a CES function. • GM productivity shock is a 10% increase in primary factor productivity.	• The factor productivity shock in the GM sectors is performed against a variety of base models which differ in terms of the substitution elasticities for GM and non-GM products in the two most GM-critical. Initially, it is assumed that the elasticity of substitution between GM and non-GM varieties is high and equal in all regions. Then, the elasticities of substitution between the GM and non-GM varieties are seen as increasingly poorer substitutes in production and consumption. Consumers in other regions are assumed to be indifferent so the two crops remain highly substitutable	• In all scenarios, output of GM varieties increases and output of non-GM varieties declines, due to the productivity shock in the GM varieties. • The North America region is very sensitive to changes in preferences towards GMOs because it is the world's largest exporter of both oilseeds and coarse grains and it is particularly dependent on GM-critical markets for these products. Total exports of the GM varieties decline as GM and non-GM substitutability worsens in the GM-critical regions, and this is particularly so for oilseeds because almost 80% of North American oilseeds exports are initially sold in these markets. • GM oilseed exports from South America (an extensive GM adopter) and Sub-Saharan Africa (a regions with a low share of GM varieties in total production) initially increase due to the factor productivity shock. As preferences shift, total GM-oilseed exports decline and GM-exports are redirected from the GM-critical regions and are spread evenly over all other importing regions. • Low-income Asia is a net importer of both oilseeds and cereal grains. Most of these imports come from North and South America. Total imports of GM crops into this region increases slightly as preferences turn against GMOs in the EU and High-income Asia. •

Article	Model Framework and Key Assumptions	Scenarios	Key findings
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