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GMOs, Trade Policy, and Welfare in Rich and Poor Countries

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Abstract

The new agricultural biotechnologies that are generating genetically modified organisms (GMOs) are seen as exciting and valuable developments by some people, while others are objecting strongly to their use. Both environmental and food safety concerns have been raised by opponents of GM crops. That in turn is causing consumers and policy makers in numerous countries around the world to react and in some cases to over-react. A majority of people want at least to have labels on products that may contain GMOs, while the most extreme opponents (particularly in Western Europe) want to see GM crops totally excluded from production and consumption in their country. This paper first examines the ways in which the emergence of GMOs is generating policy reactions which, in extreme cases, may lead to trade disputes in the WTO. It then uses an empirical model of the global economy (the GTAP model) to quantify the effects on global production and trade patterns and national welfare of certain (non-European) countries adopting the new GMO technology in the context of different policy reactions in Western Europe. Specifically, the effects of an assumed degree of productivity growth in the maize and soybean sectors in selected countries are explored, and those results are then compared with what they would be if Western Europe chose to ban imports of those products from countries adopting GM technology. The effects of an alternative market-based shift in consumer preferences are then compared with this regulatory approach. The estimated implications for developing countries' participation in world agricultural and food trade, and for their economic welfare, are highlighted.

Key words: GMOs, trade policy, SPS Agreement, TBT Agreement, food safety

JEL codes: C68, D58, F13, O3, Q17, Q18

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Non-Technical Summary

The new agricultural biotechnologies that are generating genetically modified organisms (GMOs) are seen as exciting and valuable developments by many people who recognise the improvements in production efficiency that they offer. Others, however, are objecting strongly to their use. Both environmental and food safety concerns have been raised by opponents of GM crops. In response to these concerns, and to the general scientific uncertainty associated with the use of these new techniques, national regulations specifically addressing GMOs are being introduced or at least considered in many countries around the world. A majority of people want at least to have labels on products that may contain GMOs, while the most extreme opponents (particularly in Western Europe) want to see GM crops totally excluded from production and consumption in their country.

The right for a country to set its own environmental and food safety regulations at the national level is provided for in Article XX of the GATT. But members of the WTO have trade obligations under other GATT Articles (MFN, national treatment, customs transparency), and under other WTO agreements (most notably the SPS and TBT Agreements) that restrict the extent to which trade measures can be used against GMOs without risking a case coming before the WTO's Dispute Settlement Understanding (DSU).

This paper first examines the ways in which the emergence of GMOs could generate policy reactions, the most extreme of which may well lead to trade disputes in the WTO. It then uses an empirical model of the global economy (the GTAP model) to quantify the effects on national production and trade patterns and on national and global economic welfare of just North America, and then also some developing countries, adopting the new GMO technology. These estimates assume consumers are indifferent to whether crops contain GMOs. They are then compared with two other scenarios: one in which Western Europe bans the importation of products from countries adopting GMO technology, and another in which there is a partial switch by European consumers away from imports that 'may contain GMOs'. To be specific, the effects of an assumed degree of productivity growth in the maize and soybean sectors in selected countries are explored, and those results are then compared with what they would be if (a) Western Europe chose to ban imports of those products from countries adopting GM technology or (b) some of its consumers switched preferences away from imports.

Comparing the welfare effects of the latter alternative market-based approach with the regulatory approach of banning production and imports of GM products highlights the importance of developing countries gaining access to productivity-enhancing technologies and the

impact of Western European consumers' response to GMO labelling. In the scenarios presented, those developing countries that are net-exporters of GM-potential products and fortunate enough to benefit from this new technology in their domestic production, are clearly better off when consumers in Europe are left to make up their own minds about whether to avoid GMOs than when the government adopts a blanket ban. The results also suggest, however, that developing countries that do not gain access to GM technology may loose in terms of economic welfare if they cannot guarantee that their exports entering the Western European markets are GMO-free.

The final section of the paper discusses areas where future analytical work of this sort might focus, including examining the effects of a segregation of agricultural markets into GMO-inclusive and GMO-free lines.

1. Introduction

The use of modern biotechnology to create genetically modified organisms (GMOs) through agricultural production is seen as exciting and valuable by some people, while others are objecting strongly to their use. Concerns have been raised about the safety of consuming genetically modified foods, the environmental impact of growing genetically engineered plants, and the ethics related to using the technology *per se*. Scepticism toward genetic engineering has been particularly outspoken in Western Europe, and the development and use of genetically engineered products there has been stunted as a result. In contrast, farmers in North America and several large developing countries such as Argentina and China have adopted genetically modified crops as they have become available, and citizens there have generally accepted that development.

In Western Europe where food supplies are abundant and incomes are high, people can afford to be critical about the introduction of new agricultural technologies and production processes about which they are unsure. In developing economies, by contrast, the benefit/cost ratio is very different. Many food-insecure people in developing countries live in rural areas, earn a significant share of their income from agriculture, and meet a substantial share of their food needs from their own production. For them, increasing agricultural productivity and thereby real income is a high priority. And for the urban poor in those countries, anything that lowers the effective price of basic foods is highly desirable. Given the large value shares of agriculture in production and food in consumption in developing economies, GMO technology has the potential to generate significant economy-wide benefits that may well dwarf any costs that may be perceived in those countries in terms of environmental and food safety risks.

The extent to which developing countries can reap those potential net benefits from the new biotechnology is not independent of GMO policy actions by developed countries, however, for at least two reasons. One is that a ban on the use of the technology in a subset of rich countries will reduce directly the aggregate rich-country investment in GMO research and development, thereby reducing spillovers of that research to developing countries. The other is that if that subset of countries also bans imports of a GM product, the product’s international price will fall. That in turn will reduce the returns to and hence extent of GMO research in the other rich countries, which will further reduce the potential for technology spillovers to poorer countries. In this sense the potential benefits (and the perceived risks) of GMOs in developing countries depend to a considerable extent on how the controversy about transgenic crops, which is primarily between the European Union and the United States, is played out.

Given the US-EU differences, trade in agricultural biotech products is likely to become a controversial issue within the World Trade Organization. On the one hand, the US might accuse the EU of using this issue as an excuse for replacing price-support policies, which are being phased down following the Uruguay Round agreements, with technical barriers to trade. On the other hand, France and other European countries claim they have the right to adopt the precautionary principle given the scientific uncertainties associated with GM use -- an argument that may be strengthened if the Biosafety Protocol negotiated in Montreal in January 2000 is ratified by enough (50) countries to come into effect. Should a dispute settlement case be launched on the WTO-consistency of banning imports of GM products, along similar lines to the food-safety issue of the EU-US beef hormone case, a clean result is unlikely. The EU may keep bans in place pending not just the panel report but also the appeal process and possibly arbitration hearings -- the lifespan of which could be several years (witness the EU banana import regime cases).

Such an outcome may prove to be very harmful to agricultural-exporting countries, in particular those in Sub-Saharan Africa that are highly dependent on exporting crop products to Western Europe. Even if these countries were fortunate enough to benefit from the new technology in producing for their own consumption, they would risk having their products refused at the European borders solely because they were genetically modified. A market-based segregation of agricultural production into GMO-inclusive and GMO-free varieties, on the other hand, would allow for a broader choice of production methods, particularly if GMO-free products carry a price premium. This would, however, require the imposition of comprehensive testing, certification and labelling systems that can satisfy the requirements of importing countries. Such systems may prove to be very demanding financially and in terms of technical expertise, especially for developing countries.

This paper starts by providing a brief overview of the current status of transgenic crops in agriculture, and an exploration of the potential for GMOs in developing countries. Then the paper elaborates on ways in which the emergence of GMOs is prompting the development of national regulations and international agreements that could raise difficulties and potentially lead to trade disputes in the WTO. A major point of contention could be the requirement that scientific evidence is needed under the SPS Agreement to justify a trade restriction: many in Europe argue that the precautionary principle should operate where there is uncertainty as to the effects on health and/or the environment, even if there is no evidence yet of harm. An empirical model of the global economy (the GTAP model) is then used to analyse the possible effects on world production and trade patterns and on national economic welfare of selected (non-European) countries adopting genetically modified (GM) crops, first without and then with particular European policy and consumer responses. Specifically, the effects of an assumed degree of productivity growth in the maize and soybean sectors in selected countries are explored, and those results are then compared with what they would be if Western Europe chose to ban consumption and hence imports of those products from countries adopting GM technology. The effects of an alternative market-based shift in consumer preferences are then compared with this regulatory approach. The implications for developing countries' participation in world agricultural and food trade are discussed. Reference is also made to a parallel paper on GMO-driven rice and cotton productivity growth. The final section of the paper discusses the areas in which future research on the economics of GMOs and related national and international policy responses might focus. One obvious extension would be to explore the effects of a segregation of agricultural markets into GMO-inclusive and GMO-free lines. That is very much more complex in practice, and also to model, as it involves preserving the identity of the product (GMO or non-GMO) throughout the entire food supply chain. The associated cost structures and consumers' willingness-to-pay for upholding such a distinction would also need to be assumed. Another important aspect to analyse is the link between the extent to which different regulatory measures meet their intended objectives (e.g. food safety, environmental protection, or dissemination of information) on the one hand, and consumer responses on the other.

2. Genetic engineering in agriculture

Current status

The most recent research and development advances in modern biotechnology have introduced an ever-widening range of genetically engineered products to agriculture. While traditional biotechnology improves the quality and yields of plants and animals through, for example, selective breeding, genetic engineering[1] is a new biotechnology that enables direct

[1] Definitions of genetic engineering vary across countries and regulatory agencies. For the purpose of this paper a broad definition is used, in which a genetically modified organism is one that has been modified through the use of modern biotechnology, such as recombinant DNA techniques. In the following, the terms 'genetically engineered', 'genetically modified' and 'transgenic' will be used as synonyms.

manipulation of genetic material (inserting, removing or altering genes). In this way the new technology speeds up the development process, shaving years off R&D programs. Protagonists argue that genetic engineering entails a more-controlled transfer of genes because the transfer is limited to a single or just a few selected genes, whereas traditional breeding risks transferring unwanted genes together with the desired ones. Against that advantage, antagonists argue that the side effects in terms of potentially adverse impacts on the environment and human health are unknown. The ethicists among them also worry that there are seemingly no limits to the possibilities of gene transfers, even between plants and animals, which leads to discussions about whether limits to the use of this technology should be drawn based on ethics.

Genetic engineering techniques and their applications have developed rapidly since the introduction of the first genetically modified plants in the 1980s. In 1999 genetically modified crops occupied 40 million hectares of land – making up 3.4% of the world's total agricultural area[2] and representing a considerable expansion from less than 3 million hectares in 1996 (James 1997, 1999). Cultivation of transgenic crops has so far been most widespread in the production of soybeans and maize, accounting for 54% and 28% of total transgenic crop production in 1999, respectively (Table 1). Cotton and rapeseed each made up 9% of transgenic crop production in 1999.

To date genetic engineering in agriculture has mainly been used to modify crops so that they have improved *agronomic* traits such as tolerance of specific chemical herbicides and resistance to pests and diseases (Table 2). Development of plants with enhanced agronomic traits aims at increasing farmer profitability, typically by reducing input requirements and hence costs, i.e. an increase in factor productivity. Genetic modification can also be used to improve the final *quality* characteristics of a product for the benefit of the consumer, food processing industry or livestock producer. Such traits may include enhanced nutritional content, improved durability and better processing characteristics. This type of crop will typically sell at a higher market price since it is a different, better-quality product for which the buyer would be willing to pay a higher price. Most of these types of modification are still in the research pipeline.

The United States holds almost three-fourths of the total crop area devoted to genetically modified crops (Table 3). Other major GM-producers are Argentina, Canada and China. At the national level, the largest shares of genetically engineered crops in the total in 1999

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[2] Calculations are based on the FAOSTAT statistical database accessible at www.fao.org.

were found in Argentina (approximately 90% of the soybean crop), Canada (62% of the rapeseed crop) and the United States (55% of cotton, 50% of soybean and 33% of maize) (James 1999).

TABLE 1. **Distribution of transgenic crops by crop, 1996-1999**

	Soy-bean	Tobacco	Maize	Rapeseed	Cotton	Tomato	Potato	Total
	Distribution in percent							
1996	19	35	10	5	27	4	<1	100
1997	40	13	25	10	11	1	<1	100
1998	52	<1	30	9	9	<1	<1	100
1999	54	<1	28	9	9	<1	<1	100

Source: James (1997) for 1996 and 1997 data. James (1998) for 1998 data. James (1999) for 1999.

TABLE 2. **Distribution of transgenic crops by trait, 1998-1999**

	Herbicide tolerance	Insect resistance (*Bt**)	Insect resistance (*Bt**) and herbicide tolerance	Virus resistance and other	Total
	Distribution in percent				
1998	71	28	1	<1	100
1999	71	22	7	1	100

* *Bt* crops carry the gene from the soil bacterium *Bacillus thuringiensis,* which in turn produces a toxin against certain Lepidopteran insects. (USDA1999e)
Source: James (1999)

TABLE 3. **Distribution of transgenic crops by country, 1996-1999**

	USA	China	Canada	Argentina	Australia	Mexico	Spain	France	World	Global area Mill. hectares
	Distribution in percent									
1996	51	39	4	4	1	1	0	0	100	2.8
1997	64	14	10	11	<1	<1	0	0	100	12.8
1998	74	<1	10	15	<1	<1	<1	<1	100	27.8
1999	72	1	10	17	<1	<1	<1	<1	100	39.9

Source: James (1997) for 1996 and 1997 data. James (1998) for 1998 data. James (1999) for 1999 data.

Continued expansion in the use of transgenic crops will depend in part on the benefits obtained by farmers cultivating transgenic instead of conventional crops relative to the higher cost for transgenic seeds[3]. So far the improvements have been not so much in increased yields per hectare of the crops but rather by reducing costs of production (OECD 1999). Empirical data on the economic benefits of transgenic crops are still very limited, however. The effects vary from year to year and depend on a range of factors such as crop type, location, magnitude of pest attacks, disease occurrence and weed intensity. James (1997) mentions some examples of results that have been achieved to date: Leaf yield was 5-7% higher and insecticide-use 2-3% lower for virus tolerant tobacco in China; 70% of the insect resistant *Bt*-cotton in the United States in 1996 did not require any insecticide treatment and average yields increased by 7%; cultivation of herbicide tolerant soybeans in the US in 1996 lowered herbicide applications by 10-40%, provided more stable yields and a range of other agronomic and quality improvements. The latest study of the impact on yields and pesticide-use in American production of transgenic cotton and soybean by the USDA (1999a) controls for a number of factors such as pest infestation levels, crop rotations, soil and climate factors, etc. and this study also finds large variations in the effects. By surveying primarily studies conducted in the US, the OECD (1999) had difficulty finding firm evidence of higher profits for adopters compared to non-adopters: in these first learning years the increase in yields or decrease in chemical use seems to be offset by the technology fees paid by farmers for the new varieties. But the rapid adoption of GM crops suggests at least three points: (1) adoption depends critically on local farm characteristics such as regional location, current farming practices and farmer characteristics (degree of education, management skills and investment in technological advances), (2) non-profit considerations such as increased ease and flexibility in production provided by GM crops may play a large role, and (3) farmers understand that initial adopters of a successful new technology ultimately gain the most in the long run through learning and adapting.

Prospects for growing transgenic crops in developing countries

One of the main reasons for low crop yields currently being experienced in developing countries is the prevalence of biotic stresses caused by weeds, pests and diseases. The first generation of improved transgenic crops, into which a single trait such as herbicide tolerance or pesticide resistance has been introduced, can provide protection against several of these. “Combinations of traits and crops presently being field-tested in developing countries

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[3] As long as private companies uphold patents on their transgenic seeds they will be able to extract monopoly rents through price premiums or technology fees.

include virus-resistant melon, papaya, potato, squash, tomato, and sweet pepper; insect-resistant rice, soybean, and tomato; disease-resistant potato; and delayed-ripening chilli pepper." (James and Krattiger 1999, p.1). The development of more complex traits such as drought resistance, which is a trait controlled by several genes, is underway and highly relevant for tropical crops that are often growing under harsh natural and weather conditions and on poor-quality soils. Furthermore, the development of foods with enhanced nutritional value – such as the recent development of 'Golden Rice' that is enhanced with Vitamin A and iron -- may be a low-cost way of dealing with widespread malnutrition problems.

Today transgenic crops are mainly being developed and grown in industrial countries although the above data show that accelerated adoption is taking place in countries such as Argentina, Mexico, China and South Africa. Countries in South America that are already cultivating transgenic crops are expected to expand the area of available transgenic crops as well as develop new ones. According to James (1998, 1999), India and several Eastern European countries also have a number of transgenic crops in the pipeline ready for commercialisation. There are not many estimates of the potential productivity impact that widespread cultivation of transgenic crops may have in developing countries, but according to James and Krattiger (1999 p.1) "[a] World Bank panel has estimated that transgenic technology can increase rice production in Asia by 10 to 25 percent in the next decade."

Clearly, modern biotechnology is not the entire solution to the food supply constraints and food insecurity problems in the developing world, but it may well make a significant contribution if accompanied by appropriate policies. To date transgenic crops have been developed and commercialised by a few large private (multilateral) corporations based in industrial countries. As discussed earlier, there is an additional and more urgent need for productivity-enhancing crops specific to developing countries. In order for these to be made available and affordable for poor small-scale farmers, the public sector may need to subsidize investment in relevant research. Private biotechnology firms in developing countries will have enough difficulty reaping rewards from investing in transgenic research on crops that are sold in markets, let alone from developing improved subsistence crops. This means that additional public financial resources may need to be mobilized for research either within the public sector and/or in collaboration with private companies. As well, the risks of possible adverse effects on human and animal health, the environment and biodiversity need to be managed better, through boosting the capacity of developing countries to formulate and enforce relevant food safety and biosafety regulations. Other regulatory challenges associated with the introduction of modern biotechnological products include anti-trust legislation and the securing of intellectual property rights and farmers' rights. Management of intellectual property rights is crucial for encouraging private sector investment as well as enabling access to basic technologies and their applications. Developing countries will no doubt require financial and technical support from donor countries to develop their capacities to tackle these challenges of modern biotechnology.

3. National regulations

Given the novelty of commercial application of genetic engineering techniques, the regulatory frameworks around the world are in the process of being formulated and re-formulated in response to e.g. consumer reactions to these new products. Existing regulations differ substantially both in scope and stage of implementation, varying from very restrictive regulations in certain industrial countries to non-existent in certain developing countries.

The resistance of consumer and environmental groups in the European Union (EU) to genetically modified foods and to the use of GMOs in agricultural production has triggered the imposition of a *de facto* moratorium on the authorization of new releases of GMOs as of June 1999. This could be a prelude to a future EU ban on the cultivation of genetically modified crops and on imports of foods containing GMOs. Such a scenario would have an immediate impact on current exporters of genetically modified crops such as the United States, Canada and Argentina, and it would also affect the decisions made by other countries as to whether or not to pursue adoption of the new technology. Developing countries that have an export-oriented agricultural growth strategy and especially those that are highly dependent on access to the EU markets face a particularly difficult decision. Growing transgenic crops may substantially boost agricultural productivity, but these products risk facing trade restrictions or perhaps even being excluded from EU markets altogether. A less extreme scenario follows from the current EU regulation (1139/98) that requires mandatory labelling of products containing GMOs (whether domestically produced or imported), namely a segregation of genetically modified agricultural and food products from their conventional counterparts or, at the very least, rigorous testing systems. Even this second scenario would have substantial implications for international trade flows.

In the United States, permits for field-testing and release into the environment of transgenic crops must be obtained from the Animal and Plant Health Inspection Service (APHIS) of the USDA. For transgenic crops with which APHIS has experience, a notification system enables a more rapid permitting procedure (Nelson et al. 1999). By contrast, *all* deliberate releases of GMOs in the European Union – before the imposition of the current moratorium – were reviewed on a case-by-case basis and had to be approved at all steps from laboratory testing, to field testing and final marketing.

With regard to genetically modified *foods*, the United States Food and Drug Administration (FDA) does not distinguish between foods produced from genetically modified crops and foods produced from crops developed by other technologies. This means that genetically engineered foods and food ingredients must meet the same safety standards as other food products (Food and Drug Administration 1995). Furthermore, this implies that the FDA does not require labelling of genetically modified foods solely because they are genetically modified. Only if the transgenic food differs substantially from its conventional counterpart will a pre-market permit and labelling be required.

The EU, by contrast, requires labelling of all foodstuffs, additives and flavours containing 1% or more genetically engineered material (Regulations 1139/98 and 49/2000). This *de minimis* level takes into account the fact that a certain degree of co-mingling is unavoidable with common handling and transportation systems in the agri-food process and therefore does not require labelling of food ingredients that unintentionally contain GMOs if this level does not exceed 1%. Labelling in the EU is based on scientific evidence proving the presence of genetically engineered DNA or protein. There are loopholes in these labelling requirements, however. Processed foods whose ingredients have been genetically modified, but where the food production process has eliminated the external DNA or protein, do not need to be labelled because the genetically engineered material cannot be identified in the final product. Retail companies in individual countries within the EU, such as Denmark, are taking their labelling requirements one step further by requiring suppliers to label their products not only if GMO presence can be verified scientifically, but also if there is a possibility that the product could contain GMOs.

Regulatory changes are also taking place in other countries. South Korea, Japan, Australia, Mexico and New Zealand, for example, have recently decided to enact labelling requirement laws for transgenic foods. According to James (1998), many developing countries also are beginning to develop regulations related to genetically engineered products. Furthermore, operational field-testing regulations have been implemented in, for example, Argentina, Brazil, Mexico, Chile, Costa Rica, Cuba, India, the Philippines and Thailand.

4. International trade agreements

The Cartagena Protocol on Biosafety

Given the different national approaches to regulation of genetically modified products, future trade disputes are a distinct possibility (see e.g. Kelch et al. 1998). With the objective of ensuring safe transboundary movement of living modified organisms resulting from modern biotechnology, the Cartagena Protocol on Biosafety was finalized in Montreal on 29 January 2000. The Biosafety Protocol, if ratified by the parliaments of 50 signatories, will allow governments to decide whether or not to accept GMO imports and under what conditions, and reconfirms their rights to set their own domestic regulations. Most importantly, the Protocol stipulates that lack of scientific evidence regarding potential adverse effects of GMOs on biodiversity, taking also into account risks to human health, shall not prevent a signatory from taking action to restrict the import of such organisms in order to avoid or minimize risks (UNEP 2000). In essence, this reflects an acceptance of the guiding influence of the precautionary principle[4], i.e. “better safe than sorry”. In terms of documentation, the Protocol requires that GMOs intended for intentional introduction into the environment or for contained use clearly identifies them as living modified organisms. But for modified organisms intended for direct use as food or feed, or for further processing, the requirement is only a label stating that they “may contain” such organisms. No labelling requirements for processed foods such as cooking oil or meal were established. Hence the Protocol does not address growing demands by hard critics of biotech who call for labelling of products if genetic engineering techniques have been used at any stage in their production process regardless of whether or not this can be verified in the final product through testing.

The Cartagena Protocol on Biosafety is a part of the 1992 Convention on Biological Diversity to which in particular the United States is not a signatory. Nevertheless, it is expected that the US will abide to the rules of this Protocol so as to facilitate trade. However, there is an important aspect of the Protocol, which seems open to interpretation and hence potential dispute. This is the relationship between the Protocol and the WTO agreements. The text (UNEP 2000 p.1) states that the “Protocol shall not be interpreted as implying a change in the rights and obligations of a Party under any existing international agreements” while at the same time, the latter statement is “not intended to subordinate [the] Protocol to other international agreements.” Given the existing dispute settlement mechanism of the WTO, it is

[4] The precautionary principle implies that considerations of human health and the environment rank higher than possible economic benefits in circumstances where there is uncertainty about the outcome. Today this principle is used in certain international agreements concerning chemicals.

likely that potential disputes will be taken up in this forum. The Protocol has the objective of protecting and ensuring sustainable use of biological diversity whilst also taking into account risks to human health. Agreements within the WTO also acknowledge the rights of a country to protect its environment, ensure food safety and to inform consumers. But WTO members are also obliged to adhere to agreements that restrict the way trade-related measures are used to achieve these goals. Hence some of the current WTO agreements may prove to be in conflict with the rights to restrict trade in living modified organisms provided for in the Biosafety Protocol.

The WTO agreements and transgenic products

The overall goal of the WTO is to achieve effective use of the world's resources by reducing barriers to international trade. The WTO does, however, acknowledge the need of member states to apply and enforce trade-restricting measures in order to protect human, animal or plant health and life as well as public morals. That right for a country to set its own environmental and food safety regulations at the national level is provided for in Article XX of the GATT. Use of such measures must be consistent with the key principles of the WTO, however: non-discrimination among member states, 'national treatment' of imports once having entered the domestic market, and transparency of customs procedures[5].

Members of WTO also have trade obligations under other WTO agreements that restrict the extent to which trade measures can be used against GMOs without risking a case coming before the WTO's Dispute Settlement Body. More specifically related to food safety and animal and plant health are the Agreement on Sanitary and Phytosanitary measures (SPS) and the Agreement on Technical Barriers to Trade (TBT). These agreements allow member states to impose certain restrictions on trade if the purpose of the measure is to protect human, animal or plant life and health. The TBT agreement also covers technical measures aimed at protecting the environment and other objectives. At the same time the agreements aim at ensuring that applied measures and technical regulations do not pose unnecessary or arbitrary barriers to trade and that they are no more trade-restrictive than necessary to fulfil the legitimate objective (WTO 1998a, b).

Both the SPS and the TBT agreements encourage the use of international standards, guidelines and recommendations where they exist, such as in the realms of the Codex Alimen-

[5] The WTO TRIPs agreement that protects trade-related intellectual property rights is also very important in the context of the GMO debate, but it is not dealt with in this paper. For an overview of the TRIPs agreement see e.g. Watal (1999).

tarius. Currently there are no international standards for genetically modified products although the Biosafety Protocol explicitly notes that signatories "shall consider the need for and modalities of developing standards with regard to the identification, handling, packaging and transport practices, in consultation with other relevant international bodies." (UNEP 2000 p. 10, Article 18.3). International harmonization of regulatory approval procedures for genetically modified products is being discussed in several forums (see e.g. OECD 1998). The establishment of international standards for the production, regulation and labelling of these products may be helpful as a way of reducing future trade disputes. Nevertheless, under the SPS agreement a country may apply higher standards *only* if these can be justified by appropriate scientific risk assessments. In other words, the SPS agreement explicitly allows member states to set their own standards for food safety and animal and plant health, but at the same time requires that measures be based on scientific risk assessments. The TBT agreement is more flexible because member states can decide that international standards are inappropriate for a number of other reasons, such as national security interests (WTO 1998a). Hence determining which agreement a given trade measure is covered by is of key importance. The SPS agreement covers food safety measures and animal and plant health standards regardless of whether or not these are technical requirements. The TBT agreement, on the other hand, covers all technical regulations, voluntary standards and compliance procedures, except when these are sanitary and phytosanitary measures as defined in the SPS agreement (WTO 1998a).

The scientific requirement of the SPS agreement is important because it provides for a more objective approach to determining what is a justified trade restriction and what is hidden protectionism. On the other hand, the agreement may seem inadequate to tackle restrictions introduced on the basis of e.g. consumer sentiment in relation to food production methods such as genetic engineering. Official disputes about trade in genetically modified products have not yet materialized, but experience from earlier WTO panel dispute settlements with certain aspects comparable to the GMO debate give an indication as to how the existing rules may be applied. The SPS agreement was used in the beef hormone dispute between the US and the EU, for example. In short, the EU import ban on meat and meat products from hormone-fed livestock was found to be in conflict with the EU's WTO obligations, the main argument being that the EU could not present documented scientific risk assessment to justify the ban.

When scientific evidence is unavailable or insufficient so that a government considers that a final judgment about the safety of a product or process cannot be made, Article 5.7 of the SPS agreement explicitly allows WTO member states to take precautionary measures based on available pertinent information. Members are, however, obliged to seek additional information so that a more objective evaluation of the risks related to the relevant product or process can be made within a reasonable period of time. In this regard, the European Commission has requested a better clarification of the possibilities of using the precautionary principle within the framework of the WTO agreements (European Commission 1999). This is all the more relevant given the agreement in the Biosafety Protocol, which is the most explicit acceptance of the use of the precautionary principle in an international trade agreement relating to agri-food products to date. In an extreme form use of the precautionary principle may result in a ban on the use of genetic engineering in agricultural and food production until new scientific information is available, and this is allowed for within the Biosafety Protocol. The precautionary principle can be an understandable approach to uncertainties about genetically modified products, but there is a risk that when used in an international trade context, it can develop into protectionism against any new technology in e.g. agriculture. It would be extremely difficult to assess whether a measure is there for precautionary reasons or simply as a form of hidden protectionism.

Much of the concern about transgenic products is about their environmental impact. However, issues such as adverse effects of GMOs on biodiversity, wildlife and ecosystems are not covered by the SPS agreement. Nor is full coverage of potential trade barriers in this field provided for in the TBT agreement. A ban on the *production* of transgenic food in a country could, for example, be based on environmental concerns about the production process *per se*. An example of an attempt to extend such domestic environmental legislation *extra-territorially* is the US ban on imports of tuna fish products from Mexico because the fishing methods applied here did not live up to the 'dolphin-friendly' fishing method requirements stipulated in the American Marine Mammal Protection Act (see e.g. WTO 1998d). The GATT panel at the time ruled that the US could not ban Mexican tuna products "simply because Mexican regulations on *the way tuna was produced* did not satisfy US regulations." (but the US could apply its regulations on *the quality or content* of the tuna imported -- see WTO (1998d, p.1)).[6]

This conclusion is based on the way that the WTO agreements deal with the concepts of 'product' and 'process'. The existing trade agreements deal with regulations and standards concerning products as well as production processes and methods *if they affect the characteristics or safety of the product itself*. Standards for production processes that do *not* affect the final product are not covered by the existing agreements. In relation to genetically engi-

[6] See the paper by Howse and Regan (2000) for a critique of the product/process distinction in the WTO.

neered products, if the process itself alters the final product in a way so that there are adverse environmental or health effects associated with consumption, use or disposal of the product, restricting trade in this product would not violate existing WTO rules, *ceteris paribus*. If genetic engineering only concerns the production process and not the final characteristics of a transgenic product, domestic regulations that restrict the use of this method of production cannot be used to restrict imports of products produced by this method simply because the importing country finds it unacceptable by its own environmental, ethical or other norms, c.f. the tuna-dolphin case.

This discussion leads back to the role of scientific evidence. Some would argue that genetically modified products are different from conventional products *regardless* of whether or not this can be verified scientifically in the final product. One of the priorities of the European Commission in the upcoming WTO negotiations is indeed to obtain a clarification of the role of non-product-related processes and production methods within the WTO (European Commission 1999). If trade restrictions based on production methods are allowed, this can lead to the inclusion of a long list of non-tariff barriers not only in relation to biotechnology products but also related to labour standards, for example, to the potential detriment of especially developing countries.

Labelling of foods in relation to international trade is normally covered by the TBT agreement unless the label relates directly to food safety, in which case it is covered by the SPS agreement. The WTO's labelling rules encourage the use of international standards but, as discussed earlier, they do not yet exist for transgenic foods. Related to the discussion above about 'products' and 'processes', only labelling programs that concern production processes affecting the final product would be covered by the existing TBT agreement. Determining whether or not a genetic modification affects the final product will probably have to be done on a case-by-case basis, but if a labelling program is covered by the TBT agreement, it must not pose an unnecessary barrier to international trade.

Where labelling programs are not encompassed by the TBT agreement, which potentially may be the case for many transgenic products, the other agreements of the WTO will be applicable without exceptions (Tietje 1997). Article III concerning non-discrimination, for example, stipulates that member states may not discriminate between otherwise like goods on the basis of their country of origin. A key issue using this Article will be the interpretation of the concept of 'like goods' and whether the presence of genetically modified material is 'sufficient' to differentiate products. The Article seeks to avoid measures that are based on a false differentiation of products and this will probably have to be determined on a case-by-case basis.

In response to the heated debate about transgenic crops and foods, markets for guaranteed non-GMO maize and soybeans have indeed begun to develop. Several large food companies around the world have already stated a non-GMO policy. Clearly, consumer demand and willingness-to-pay will determine the viability and size of this market, but producers of GMO-free products would be interested in labelling their products as such in order to distinguish them from GMO-inclusive products. Even if such labelling is based on voluntary decisions made by private companies, public authorities will often control the use of the label. Possible trade-distorting effects can thus be argued to be the responsibility of the state (i.e. the WTO member) and thus subject to WTO rules.

Presently there are examples of labelling programs for organic products, and these are typically voluntary, as non-GMO labelling probably also would be. The key requirements on the part of the WTO are that environmental measures such as organic labelling do not discriminate between domestic and foreign products. Market access must be predictable and competition undistorted. Subject to these requirements, "WTO rules place essentially no constraints on the policy choices available to a country to protect its own environment against damage either from domestic production or from the consumption of domestically produced or imported products." (WTO 1997a p.1).

Summarising, the emergence of GMOs in agricultural and food production introduces new issues to be dealt with within the WTO, only some of which the current rules are more or less suitable to tackle. The previous discussion of the existing WTO agreements and the new Biosafety Protocol hints to a number of potentially contentious issues:

(1) The aim of a national regulation: whether it is protection of the environment and/or human health will influence which WTO agreement or article a given regulation will fall under. The distinction may prove to be important in terms of interpreting the Biosafety Protocol and its relation to the WTO rules.

(2) The SPS requirement of scientific evidence: it now stands in sharp contrast to the Biosafety Protocol in which it is explicitly stated that lack of such evidence need not prevent importing countries from taking action.

(3) The product/process distinction: the Biosafety Protocol implicitly expresses a distinction between products based on their production process, i.e. with or without genetic engineering, unlike WTO rules on 'like products'.

(4) Mandatory labelling requirements of all GMO-inclusive products including processed foods: as long as they do not discriminate between foreign and domestic goods they will probably not violate existing WTO rules, even if they add significantly to trade costs.

5. Estimating economic effects of GMO adoption and policy reactions

Global modelling framework

This section examines empirically the production, trade and welfare effects of GM crop adoption by selected regions, first without and then with specific policy and consumer responses. This is done using an applied analytical framework involving a global economy-wide model and database known as GTAP (Global Trade Analysis Project)- [7]. Being a general equilibrium model, GTAP describes both the vertical and horizontal linkages between all product markets both within the model's individual countries and regions as well as between countries and regions via their bilateral trade flows. The most recent database available for the model is for 1995, and it comprises 50 sectors and 45 countries and regions (Version 4 -- see McDougall et al. 1998). For the purpose of the present analysis the database is aggregated to 16 regions and 17 sectors, shown in Table 4. The regional detail highlights the attention to be given to the main participants in the GMO debate and the key groups of developing countries, while the sectoral detail focuses on the primary agricultural sectors involved in the GMO debate and their related processing industries. That includes not only maize and soybean for the present paper but also rice and cotton, which are analysed in Nielsen and Anderson (2000).

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[7] The GTAP (Global Trade Analysis Project) model is a multi-regional, static, applied general equilibrium model based on neo-classical microeconomic theory. Markets are characterised by perfect competition, the technology of the profit-maximizing producers exhibit constant returns to scale, and substitution between intermediate inputs is possible. The behaviour of the utility-maximising consumers is captured in a non-homothetic private demand system. Capital and labour are perfectly mobile between sectors, whilst the total supply of each factor of production is fixed within each region. Land is limited to use in the primary agricultural sectors and shifts among these are determined by transformation elasticities. International trade is has an Armington specification (Armington 1969), which means that products are differentiated by country of origin. This enables a detailed specification of the gross bilateral trade flows, including intra-industry trade, rather than simply net trade. Macro closure of the model is achieved by ensuring equilibrium between global savings and investment. The GTAP model is documented fully in Hertel (1997).

TABLE 4. **Regions and sectors in the empirical model analysis**

Regions		Sectors	
1. Australia & New Zealand	11. Rest of Latin America	1. Paddy rice	11. Meat and dairy products
2. Japan	12. Western Europe	2. Wheat	12. Vegetable oils and fats
3. Other high-income Asia	13. Central Europe and FSU	3. Cereal grains	13. Processed rice
4. China	14. South Africa	4. Vegetables, fruits & nuts	14. Other processed food
5. Rest of East Asia	15. Sub-Saharan Africa	5. Oilseeds	15. Textiles and clothing
6. India	16. Middle East and North Africa	6. Plant-based fibres	16. Other manufactures
7. Rest of South Asia		7. Other crops	17. Services
8. North America		8. Livestock	
9. Mexico		9. Forestry and fishing	
10. Southern Cone		10. Energy and minerals	

Scenarios

Of the foods it is primarily maize and soybean that are currently benefiting most from GM-technology. Hence the scenarios analysed here assume that GM-driven productivity growth occurs only in the following GTAP sectors: cereal grains (excluding wheat and rice) and oilseeds. We assume these crops exhibit improved agronomic traits, which reduce their costs of production. Appendix 1 provides a brief overview of the production, consumption and trade structures for key markets for these and other products showing GM potential.

The empirical information about the impact of GMO technology in terms of reduced chemical use, higher yields and other agronomic improvements is at this stage quite limited. The scenarios analysed here are therefore based on an assumed productivity growth resulting from widespread use of genetically modified crops in selected sectors and regions. It is assumed that the effect of adopting GM crops can be captured by a Hicks-neutral technology shift, i.e. a uniform reduction in all inputs to obtain the same level of production (i.e. a total factor productivity (TFP) shock). Available empirical evidence (e.g. USDA 1999d and James 1997, 1998) suggests that there are agronomic benefits associated with cultivating GM crops other than the target characteristic, and that these have general cost-reducing effects. This suggests that the Hicks-neutral description of the technology shift (at least as applied in this context) may not be as crude as it may initially seem.

The available estimates of economic benefits to producers from cultivating GM crops are very scattered and highly diverse (see e.g. OECD 1999 for an overview of available estimates). Nelson et al. (1999) suggest that glyphosate-resistant soybeans may generate a total production cost reduction of 5%, and their scenarios have *Bt* corn increasing yields by between 1.8% and 8.1%. For present purposes the GM-adopting sectors are assumed to experience a one-off increase in total factor productivity of 5%. Such a downward shift in the unit cost function lowers the supply price of the GM crop. Assuming adequate demand conditions (domestically and/or abroad) the cost-reducing technology will lead to increased production and higher returns to the factors of production employed in the GM-adopting sector. Labour, capital and land will consequently be drawn into the affected sector. However, if demand conditions are weak or unresponsive to the initial price fall, the supply price might decline so much as to reduce farm profitability and factor payments even for the adopters of the new technology. As suppliers of inputs and buyers of agricultural products, other sectors will also be affected by the use of genetic engineering in GM-potential sectors through vertical linkages. Input suppliers will initially experience lower demand because the production process in the GM sector has become more efficient. To the extent that the production of GM crops increases, the demand for inputs by producers of those crops may actually rise despite the input-reducing technology. Demanders of primary agricultural products such as grains for livestock feed will benefit from lower prices, which in turn will affect the market competitiveness of livestock products.

The other sectors of the economy may also be affected through horizontal linkages. Primary crops and livestock are typically complementary in food processing. Cheaper genetically modified crops have the potential of initiating an expansion of food production and there may also be substitution effects. Applying genetic engineering techniques to wheat breeding is apparently more complex compared with e.g. maize. As long as this is the case, the price of wheat will be high relative to other more easily manipulated grains, and to the extent that substitutions in production are possible, the food processing industry may shift to the cheaper GM intermediate inputs. Widespread use of GM products can furthermore be expected to affect the price and allocation of mobile factors of production and in this way also affect the other sectors of the economy.

The widespread adoption of GM varieties in certain regions will affect international trade flows depending on how traded the crop in question is and whether or not this trade is left to take place freely (or rather, without further restrictions related specifically to their GM-characteristic). To the extent that trade is not further restricted and not currently subject to binding tariff quotas, world market prices for these products will have a tendency to decline and thus benefit net importers. For exporters, the lower price may enable an expansion of the trade volume depending on the price elasticities in foreign markets.

Four scenarios are considered below. The first scenario examines the implications of widespread adoption of GM maize and soybeans in North America, which as mentioned above, is assumed to imply a 5% productivity growth in these sectors. The results of this experiment may be interpreted as an indication of North America's 'first mover advantage' in the sense that consumers everywhere are assumed not to be opposed and regulations are assumed not to restrict the production and trade in GM products by North America.

The second scenario then expands the GM-driven productivity growth to the other current and potential biotech front-runners: Mexico, the Southern Cone region of Latin America, India, China, East Asia's other lower-income countries, and South Africa. The countries of Western Europe and elsewhere are assumed to refrain completely from the use of GM crops in their production systems. For the EU this may be interpreted as an extension of the *de facto* moratorium that has been in place there since June 1999. Most notably among the developing countries, Sub-Saharan Africa is assumed to be unable to take advantage of the new technology. In this second scenario, as with the first, consumers are assumed not to be concerned about the introduction of GM crops in the agric-food system, and hence genetically modified and conventional crops are produced side-by-side and traded in one co-mingled market.

In the third scenario, 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 cereal grains from GM-adopting regions. It is assumed that the labelling requirements of the Biosafety Protocol enable Western European importers to identify such shipments and that basically all oilseed and cereal grain exports from GM-adopting regions will be labelled "may contain GMOs". Hence the distinction between GM and GM-free products is simplified to one that relates directly to the country of origin[8]. Furthermore, given the formulation of the labelling requirement in the Biosafety Protocol ("may include GMOs") it would not be very costly for producers to place such a label on their products sold to sensitive markets. Specifically, it would not require a costly identity reservation system (which could increase the price of the labelled product by 5%-15% -- see Buckwell et

[8] 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. Such a transshipment affect is *not* generated in this model. In the GTAP model bilateral export flows are determined directly by the bilateral import flows, which in turn are determined by a nested Armington-CES (Constant Elasticity of Substitution) specification. This means that the sourcing of imports (and hence also the determination of bilateral export flows) occurs at the border. It is thus a composite import good that enters the domestic market, which then combines with domestically produced goods to satisfy domestic demand. In this way a GMO-indifferent, non-adopting country may increase its imports of the cheaper GMO products at the expense of its own production, but the country will still only export its own GMO-free products to Western Europe. However, a non-GM adopting region that imports GM primary products will typically use these in its food processing industry and then export these products to other regions, including Western Europe. Both in practice and in this model such trade is not traced. Once again, for the hard critic of GM technology a complete segregation of production is the only way of avoiding GMOs completely.

al. 1999). This import ban scenario reflects the most extreme application of the precautionary principle within the framework of the Biosafety Protocol.

In the event that this is found to be in conflict with the WTO rules, the Western European import ban may have to be lifted. The final scenario therefore considers the case in which consumers express their preferences through market mechanisms rather than through government regulation. The scenario analyses the impact of a shift in Western European preferences away from imported cereal grains and oilseeds and in favour of domestically produced crops[9]. This is implemented as an exogenous 25% reduction in final consumer and intermediate demand for all imported oilseeds and cereal grains, i.e. not only those which can be identified as coming from GM adopting regions. This can be interpreted as an illustration of the incomplete information provided about imported products (still assuming that GM crops are not cultivated in Western Europe), if a label only states that the product "may contain GMOs". Such a label does not resolve the information problem facing the most critical Western European consumers who want to be able to distinguish between GMO-inclusive and GMO-free products. Thus some European consumers and firms chose to completely avoid products that are produced outside of Western Europe. In response, this demand is shifted in favour of domestically produced goods. Western European producers and suppliers are assumed to be able to signal - at no (significant) additional cost – that their products are GM-free by e.g. labelling the products indicating the country of production. 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 GM-free products.

6. Empirical results

Scenario 1: North America adopts GM cereal grains and oilseeds

A 5% reduction in overall production costs in the cereal grains and oilseed sectors leads to a 3% increase in cereal grains production and an almost 7% increase in oilseed production in North America (Table 5). The difference in production response is explained by the fact that a larger share of oilseed production as compared with cereal grains is destined for export markets (37% versus 18% -- see Table A4 in Appendix 1) and hence not limited to the same extent by domestic demand which is less price-elastic. Increased oilseed production leads to lower market prices and hence cheaper costs of production in the North American

[9] Appendix 2 describes how the exogenous preference shift is introduced into the GTAP model, a method adopted from Nielsen (1999).

vegetable oils and fats sector, which expands output by 1.7%. In North America cereal grains are also used as livestock feed, and hence the lower grain prices lead to an expansion of the livestock and meat processing sectors.

Due to the relatively large share of North American products on world markets, the increased supply causes world prices for cereal grains and oilseeds to decline, in this case by 2.5% and 1.6%, respectively. As a consequence of the more intense competition from abroad, production of cereal grains and oilseeds declines in all other regions. This is particularly so in Western Europe, a major net importer of oilseeds (Table A3 in Appendix 1), of which 47% initially 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 3.5% decline in Western European production. In the developing countries too, production of cereal grains and oilseeds is reduced slightly. Oilseeds account for as much as 14% of the Indian agricultural production value (Table A1 in Appendix 1) but because this production is almost exclusively oriented toward domestic sales and there are virtually no imports of oilseeds, the lower international market price for these products hardly affects this production.

As reported in Table 6, global welfare (measured in terms of equivalent variations of income) is boosted by $5.5 billion per year by the new technology, half of which is enjoyed by the adopting region. Welfare effects in North America of them getting a head start in the cultivation of genetically modified crops are rather modest – amounting to an increase of just 0.04% of initial welfare – and this is because of the relatively minor share of these products in total national production. Most of the remaining global welfare gains go to Western Europe and the other high-income countries rather than developing countries though. Notice in particular that Western Europe gains from North America’s technological boost only in part because of cheaper imports; mostly it is because this triggers a shift of domestic resources out of relatively protected and supported sectors of EU agriculture, as is clear from the welfare decomposition in Table 6. The group of other high-income countries, of which the Asian nations 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 production.

TABLE 5. **Scenario 1: N. America adopts GM cereal grains and oilseeds, selected results, % changes**

	North America	Southern Cone	China	India	South Africa	Western Europe	Sub-Saharan Africa
Production							
Cereal grains	3.1	-1.9	-1.9	-0.0	-8.6	-3.5	-1.6
Oilseeds	6.6	-2.3	-2.6	-0.2	-6.0	-7.1	-0.8
Livestock	0.8	-0.0	-0.0	-0.0	-0.1	-0.2	-0.1
Meat & dairy	0.5	0.0	-0.1	-0.1	0.0	-0.1	-0.1
Veg.oils,fats	1.7	-0.2	-0.5	-0.5	-0.6	-0.2	-0.6
Other foods	0.2	0.0	-0.0	-0.1	-0.0	-0.1	0.0
Market prices							
Cereal grains	-5.2	-0.5	-0.5	-0.2	-0.7	-0.4	-0.3
Oilseeds	-4.9	-0.7	-0.6	-0.2	-0.6	-0.8	-0.2
Livestock	-1.6	-0.3	-0.2	-0.2	-0.2	-0.2	-0.2
Meat & dairy	-0.9	-0.2	-0.2	-0.1	-0.2	-0.1	-0.1
Veg.oils,fats	-2.2	-0.4	-0.4	-0.1	-0.1	-0.3	-0.1
Other foods	-0.2	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
Exports*							
Cereal grains	13.8	-13.9	-18.3	-14.7	-16.7	-9.1	-13.7
Oilseeds	15.5	-15.4	-18.1	-17.2	-16.4	-13.5	-18.2
Livestock	8.4	-1.1	-3.1	-2.7	-1.6	-1.0	-1.3
Meat & dairy	4.4	-0.3	-1.1	-0.9	0.1	-0.4	-0.3
Veg.oils,fats	11.3	-0.8	-5.7	-4.7	-5.7	-1.6	-2.1
Other foods	0.5	0.0	-0.5	-0.6	-0.4	-0.4	0.0
Imports*							
Cereal grains	-2.2	5.9	15.3	4.9	4.5	0.1	7.2
Oilseeds	-4.1	3.1	13.9	16.8	0.8	1.9	2.1
Livestock	-2.5	1.0	0.9	0.6	1.5	0.1	0.5
Meat & dairy	-1.7	0.0	0.8	0.1	0.3	-0.0	0.1
Veg.oils,fats	-4.5	-0.2	1.2	1.4	0.4	0.1	2.0
Other foods	-0.2	-0.1	0.1	0.3	0.1	0.0	-0.1

*Includes intra-regional trade.

TABLE 6. **Scenario 1: North America adopts GM cereal grains and oilseeds, selected welfare results**

	Equivalent Variation (EV)	Decomposition of welfare results, contribution of (US$ million):		
	US$ million pa	Allocative Efficiency Effects	Terms of Trade effects	Technical Change
North America	2,762	-211	-838	3,781
Southern Cone	-124	-37	-82	0
China	64	22	44	0
India	6	14	-7	0
South Africa	-4	-3	-1	0
Western Europe	1,421	1,265	157	0
Sub-Saharan Africa	-9	-2	-8	0
Other high-income	1,040	511	542	0
Other developing and transition econs.	385	203	191	0
WORLD	5,542	1,761	0	3,781

Scenario 2: Several regions adopt GM cereal grains and oilseeds

In this scenario the analysis is expanded to include the Southern Cone, China, the Rest of East Asia, India, Mexico and South Africa as adopters of GM varieties in the cereal grains and oilseed sectors. Table 7 reports the results of this experiment for selected regions with Western Europe and Sub-Saharan Africa as non-adopters and the other reported regions as adopters of the new technology. The increased competition on world markets means that, compared with the base case, the increase in production in North America is less marked than in the first scenario, where North America had the benefit of being the front-runner. Competition comes especially from the Southern Cone region, where production of oilseeds increases by almost 5% and exports by 10.5%. As a result, international market prices fall more sharply, by 4.0% for cereal grains and 4.5% for oilseeds.

Once again the changes in India are relatively small compared with e.g. China and the Southern Cone region and this is explained by the domestic market orientation of these sales. As a consequence the relatively small production increase causes rather substantial declines in market prices for these products. This in turn benefits the other agricultural sectors through vertical linkages. For example, 67% of intermediate demand for cereal grains and 37% of intermediate demand for oilseeds in India stems from the livestock sector.

All regions (both adopting and non-adopting) gain in welfare except, notably, Sub-Saharan Africa (Table 8). 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. At the national/regional level India experiences the largest relative gains equal to a 0.4% increase in aggregate economic welfare ($1.3 billion). The world economy as a whole is nearly twice as well off in this scenario as in the previous one in which just North America adopts: by $9.9 billion instead of $5.5 billion per year. Most of this gain stems directly from the technology boost in the various regions. And in this case it is the developing countries that enjoy about half the gains, with those adopting the new technology gaining most.

TABLE 7. **Scenario 2: Several regions adopt GM cereal grains & oilseeds, selected results, % changes**

	North America	Southern Cone	China	India	South Africa	Western Europe	Sub-Saharan Africa
Production							
Cereal grains	2.1	1.6	1.0	0.4	3.8	-4.5	-2.3
Oilseeds	3.6	4.6	1.8	1.1	3.0	-11.2	-1.3
Livestock	0.8	-0.0	0.1	0.4	-0.1	-0.2	-0.1
Meat & dairy	0.5	0.0	0.1	1.3	0.1	-0.1	-0.1
Veg.oils,fats	1.1	4.5	1.4	0.0	-2.3	-0.9	-1.2
Other foods	0.2	0.1	0.4	1.5	-0.0	-0.1	0.0
Market prices							
Cereal grains	-5.5	-5.5	-5.6	-6.7	-4.9	-0.5	-0.4
Oilseeds	-5.5	-5.3	-5.6	-6.5	-5.0	-1.2	-0.3
Livestock	-1.8	-0.3	-0.4	-1.4	-0.2	-0.3	-0.3
Meat & dairy	-1.0	-0.2	-0.3	-1.0	-0.2	-0.2	-0.2
Veg.oils,fats	-2.4	-3.1	-2.6	-1.0	-0.5	-0.5	-0.2
Other foods	-0.3	-0.2	-0.5	-1.0	-0.1	-0.1	-0.2
*Exports**							
Cereal grains	8.5	13.3	16.8	37.3	7.3	-11.5	-20
Oilseeds	8.5	10.5	8.2	21.5	7.9	-20.5	-26.5
Livestock	8.9	-2.0	-3.3	9.4	-2.3	-1.1	-1.5
Meat & dairy	4.8	-0.9	-0.9	5.8	0.3	-0.5	-0.2
Veg.oils,fats	5.8	14.3	5.6	-3.8	-7.6	-4.9	-5.3
Other foods	0.2	0.1	1.6	7.6	-0.5	-0.6	0.1
*Imports**							
Cereal grains	-1.6	-4.6	-4.2	-20.5	-1.9	0.1	11.3
Oilseeds	-2.6	-9.2	-1.6	-8.6	-0.9	2.5	16.5
Livestock	-2.1	1.3	0.9	-5.2	1.9	0.2	0.5
Meat & dairy	-1.9	0.2	0.8	-1.7	0.3	-0.0	0.1
Veg.oils,fats	-3.7	-3.6	-1.7	3.1	2.9	1.3	3.4
Other foods	0	-0.1	-0.6	-3.1	0.2	0.1	-0.1

*Includes intra-regional trade.

TABLE 8. **Scenario 2: Several regions adopt GM cereal grains and oilseeds, selected welfare results**

	Equivalent Variation (EV) US$ million pa	Decomposition of welfare results, contribution of (US$ million): Alloctive Efficiency Effects	Terms of Trade effects	Technical Change
North America	2,624	-137	-1,008	3,746
Southern Cone	826	120	-223	923
China	839	113	66	672
India	1,265	182	-9	1,094
South Africa	35	4	3	27
Western Europe	2,010	1,755	253	0
Sub-Saharan Africa	-9	-2	-9	0
Other high-income	1,186	554	641	0
Other developing and transition econs.	1,085	167	286	646
WORLD	9,859	2,756	0	7,108

Scenario 3: Western Europe bans the imports of GM cereal grains and oilseeds

A Western European ban on the imports of genetically modified cereal grains and oilseeds changes the situation rather dramatically, especially for the oilseed sector in North America, which as mentioned above, is initially highly dependent on this export 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 despite the introduction of the new productivity enhancing technology (Table 9). For cereal grains, by contrast, only 18% of North American production is exported (Table A4 in Appendix 1) and just 8% of those exports are destined for Western Europe. Therefore the ban does not affect North American production and exports of cereal grains to the same extent as for oilseeds, although the production-enhancing effect of the technological boost is nonetheless dampened significantly by the downward pressure on the international price of maize. Similar effects are evident in the other GM adopting regions, except for India (once again because its production of these particular crops is largely unaffected by world market developments).

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 dramatically, by enough to increase domestic production by 4%. Western Europe increases its own production of oilseeds, however, so the aggregate increase in oilseed imports amounts to less than 1%. Its production of cereal grains also increases, but not as dramatically because of an initial high degree of self-sufficiency. The shift from imported oilseeds and cereal grains to domestically produced products has implications further downstream. Given an imperfect degree of substitution in production between domestic and imported intermediate inputs, the higher prices on domestically produced grains and oilseeds mean that livestock feed is slightly more expensive (half of intermediate demand for cereal grains in Western Europe stems from the livestock sector). Inputs to the 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 as compared with scenario 2 are substantially different. Western Europe now experiences a decline in aggregate welfare of US$4.3 billion per year (Table 10) instead of a boost of $2 billion (Table 8). Taking a closer look at the decomposition of the welfare changes reveals that adverse allocative efficiency effects explain the decline. Most significantly, resources are forced into producing oilseeds, of which a substantial amount was previously imported. Consumer welfare in Western Europe is reduced in this scenario because, given that they are assumed to be indifferent between GM and GM-free crops, the import ban restricts them from benefiting from lower international prices. All other regions show a gain in welfare and this is particularly so for India, which in addition to being a GM adopter is also screened from the price developments on international markets for these particular GM crops. As non-adopters, the countries in Sub-Saharan Africa are hardly affected, gaining only very slightly from better terms of trade. In particular a higher price is obtained for their oilseed exports to Western European markets.

Globally, two-thirds of the gains from the new GM technology as measured in scenario 2 are eroded by the import ban in Western Europe: they fall from $9.9 billion per year to just $3.4 billion (assuming as before that consumers are indifferent between GM-free and GM-inclusive food). Almost the entire erosion in economic welfare is borne in the Western Europe, although the net-exporting adopters (mainly North America and the Southern Cone region) do gain less in overall economic welfare in this scenario as compared with the previous one. Since the non-adopting regions generally purchase most of their imported cereal grains and oilseeds from the North American region they continue to benefit from lower import prices, relatively unaffected by the Western European import ban.

TABLE 9. **Scenario 3: Several regions adopt GM technology but WEU bans imports of GM cereal grains and oilseeds, selected results, % changes**

	North America	Southern Cone	China	India	South Africa	Western Europe	Sub-Saharan Africa
Production							
Cereal grains	0.9	0.0	0.8	0.4	2.4	5.3	-2.2
Oilseeds	-10.2	-3.6	-0.8	0.8	-11.4	66.4	4.4
Livestock	1.2	0.3	0.2	0.4	0.2	-0.8	0.0
Meat & dairy	0.8	0.3	0.2	1.4	0.2	-0.5	-0.0
Veg.oils,fats	2.4	8.1	1.6	0.1	-2.4	-3.4	0.0
Other foods	0.3	0.4	0.5	1.6	0.1	-0.5	-0.1
Market prices							
Cereal grains	-6.2	-6.0	-5.6	-6.7	-4.9	0.8	-0.0
Oilseeds	-7.4	-6.8	-6.0	-6.5	-5.9	5.8	0.4
Livestock	-2.2	-0.7	-0.4	-1.4	-0.2	0.5	0.1
Meat & dairy	-1.3	-0.4	-0.3	-1.0	-0.2	0.3	0.1
Veg.oils,fats	-3.3	-4.0	-2.7	-1.0	-0.6	2.0	0.0
Other foods	-0.4	-0.3	-0.5	-1.0	-0.1	0.1	0.0
Exports*							
Cereal grains	0.3	-2.9	5.0	23.4	4.2	15.9	-13.1
Oilseeds	-28.8	-69.2	-18.4	-8.7	-41.2	167.2	105.0
Livestock	13.7	4.0	-1.4	12.6	2.2	-3.8	-1.8
Meat & dairy	7.5	2.1	0.1	7.1	2.6	-1.4	0.3
Veg.oils,fats	14.4	26.2	7.0	1.3	-4.1	-15.0	5.8
Other foods	1.5	1.9	2.0	8.0	0.4	-1.4	-0.6
Imports*							
Cereal grains	-1.9	-5.3	-2.8	-20	-1.2	3.3	13.4
Oilseeds	-5.6	-21.9	3.0	-3.7	-0.7	0.6	22.5
Livestock	-3.2	0.1	0.1	-5.9	0.9	0.9	0.5
Meat & dairy	-2.8	-0.5	0.8	-1.8	-0.1	-0.2	-0.0
Veg.oils,fats	-7.7	-5.5	-1.7	4.0	3.6	5.5	2.4
Other foods	-0.6	-0.6	-0.8	-2.8	0.0	0.1	0.2

*Includes intra-regional trade.

TABLE 10. **Scenario 3: WEU bans imports of GM cereal grains and oilseeds, selected welfare results**

	Equivalent Variation (EV)	Decomposition of welfare results, contribution of (US$ million):		
	US$ million pa	Allocative Efficiency Effects	Terms of Trade effects	Technical Change
North America	2,299	27	-1,372	3,641
Southern Cone	663	71	-303	893
China	804	74	70	669
India	1,277	190	-3	1,092
South Africa	38	3	8	27
Western Europe	-4,334	-4,601	257	0
Sub-Saharan Africa	42	5	38	0
Other high-income	1,371	592	782	0
Other developing and transition econs.	1,258	98	523	645
WORLD	3,419	-3,541	0	6,966

Scenario 4: Western European preferences shift against GM cereal grains and oilseeds

In this scenario it is assumed that there is no import ban but that some Western European consumers have a strong bias against genetically modified crops. Given the essentially incomplete information embodied in the "May contain GMOs" label, recall that preferences in this scenario are assumed to shift away from imported cereal grains and oilseeds in general, not only from declared GMO-producing regions. As the results in Table 11 reveal, having consumers express their preferences through market mechanisms 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 3 there are slight increases, and production responses in cereal grains are slightly greater. Once again the changes are less marked for India and in part also for China, which are less affected by international market changes for these products. 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) three out of four consumers and firms make use of the lower import prices. The output growth in Sub-Saharan Africa in scenario 3, by increasing oilseed production to serve European consumers and firms, is replaced in this scenario by agricultural production declines; Sub-Saharan Africa loses export shares to GM adopting regions.

The welfare results in this scenario (Table 12) are comparable with those of scenario 2, i.e. the scenario without the import ban or the preference shift, for all regions, except, of course, for Western Europe. Furthermore, the decline in economic welfare that Western Europe experienced when banning cereal grain and oilseed imports is changed to a slight gain in this scenario (although recall that scenario 3 assumes consumers are indifferent to whether a food contains GMOs). Most importantly, the dramatic worsening of resource allocative efficiency in the previous scenario is changed to a slight improvement in this one. Given that the preference shift in this scenario is based on the assumption that non-adopters outside Western Europe cannot guarantee that their exports to this region are GMO-free, Sub-Saharan Africa cannot benefit from the same kind of 'preferential' access the region obtained in the previous scenario, where cereal grains and oilseeds from identifiable GMO-adopting regions were banned completely. Hence Sub-Saharan Africa does not gain in this scenario due to a net worsening of its terms of trade and the absence of productivity gains from genetic engineering techniques. Globally, welfare in this case is only slightly below that when there is no preference shift: a gain of $8.5 billion per year compared with $9.9 billion in scenario 2, with Western Europe clearly bearing the bulk of this reduction.

TABLE 11. **Scenario 4: Several regions adopt GM technology but WEU preferences shift against them, percentage changes, selected results**

	North America	Southern Cone	China	India	South Africa	Western Europe	Sub-Saharan Africa
Production							
Cereal grains	1.8	1.3	1.0	0.4	3.4	-2.0	-2.6
Oilseeds	1.0	2.8	1.1	1	0.0	8.7	-1.6
Livestock	0.9	0.0	0.2	0.4	-0.0	-0.4	-0.1
Meat & dairy	0.6	0.1	0.1	1.3	0.1	-0.2	-0.0
Veg.oils,fats	1.2	5.0	1.4	-0.0	-2.4	-1.1	-1.2
Other foods	0.2	0.2	0.4	1.5	-0.0	-0.2	0.1
Market prices							
Cereal grains	-5.7	-5.6	-5.6	-6.7	-4.9	-0.2	-0.4
Oilseeds	-5.9	-5.6	-5.7	-6.5	-5.2	0.1	-0.3
Livestock	-1.9	-0.4	-0.4	-1.4	-0.2	-0.1	-0.3
Meat & dairy	-1.1	-0.2	-0.3	-1.0	-0.2	-0.1	-0.2
Veg.oils,fats	-2.6	-3.3	-2.6	-1.0	-0.5	-0.4	-0.2
Other foods	-0.3	-0.2	-0.5	-1.0	-0.1	-0.1	-0.2
Exports*							
Cereal grains	6.6	9.7	13.9	34.1	6.5	-29.7	-24.1
Oilseeds	1.4	-4.5	2.1	14.1	-1.9	-41.5	-32.4
Livestock	9.8	-0.9	-3.0	10.0	-1.5	-1.8	-1.2
Meat & dairy	5.3	-0.4	-0.8	6.0	0.7	-0.7	0.1
Veg.oils,fats	6.7	15.8	5.5	-4.0	-7.6	-5.8	-4.9
Other foods	0.4	0.4	1.7	7.6	-0.4	-0.7	0.1
Imports*							
Cereal grains	-1.7	-4.8	-3.9	-20.4	-1.7	-23.6	11.5
Oilseeds	-2.9	-9.6	-0.7	-7.4	-0.9	-17.7	17.3
Livestock	-2.3	1.1	0.8	-5.3	1.7	0.4	0.2
Meat & dairy	-2.1	0.1	0.8	-1.7	0.3	-0.1	-0.0
Veg.oils,fats	-4.2	-3.8	-1.5	3.4	3.1	1.5	3.4
Other foods	-0.1	-0.2	-0.6	-3	0.2	0.1	-0.1

*Includes intra-regional trade.

TABLE 12. **Scenario 4: WEU preferences shift against them, selected welfare results**

	Equivalent Variation (EV) US$ million pa	Decomposition of welfare results, contribution of (US$ million): Allocative Efficiency Effects	Terms of Trade effects	Technical Change
North America	2,554	-100	-1,092	3,726
Southern Cone	785	109	-246	917
China	834	106	69	672
India	1,267	184	-9	1,093
South Africa	35	4	4	27
Western Europe	715	393	319	0
Sub-Saharan Africa	-5	0	-7	0
Other high-income	1,233	567	674	0
Other developing and transition econs.	1,085	164	289	646
WORLD	8,503	1,428	0	7,081

7. Conclusions and areas for further research

The differences in perception regarding the benefits and risks of the applications of modern biotechnology have already resulted in very different approaches to regulating the cultivation of genetically modified crops and the marketing of their products in Western Europe on the one hand and North America on the other. This in turn has led to the declaration of the Biosafety Protocol, which is essentially a compromise between these views. Moreover, it is yet to be seen whether the stipulations of this Protocol are consistent with the WTO rules when carried out in practise. The empirical analysis performed here shows that the most extreme use of its provisions, namely an import ban on GM crops, would have a substantial adverse impact on world production and trade flows not only for the GM-potential crops but also for other related downstream food products. To the extent that some developing and other countries do not adopt GM crops (by choice or otherwise) and they can verify this at the Western European borders, our results suggest it is possible they could gain from retaining access to the GMO-free markets when others are excluded. If European consumers are not worried about GMOs, it is at their expense that non-adopting foreign producers gain. If those consumers ARE worried, on the other hand, the results of the market-based preference shift experiment (scenario 4) suggest that letting consumers express that preference through the market gives markedly greater welfare gains for net-exporting, GM-adopting developing countries. The results also suggest, however, that developing countries that do not gain access to GM technology may loose in terms of economic welfare if they cannot guarantee that their exports entering the Western European markets are GMO-free. For these countries, a complete segregation of GMO-inclusive and GMO-free markets may be a way in which they could reap benefits from selling ‘conventional’ products to GM-critical consumers in industrialised countries to the extent that the relative price premium on these products is sufficient to outweigh the relative decline in productivity.

The empirical analysis will be able to be enhanced once more data become available. The analysis has had to be based on assumptions about the productivity impact of introducing genetically modified crops in the agricultural production system, in the absence of informed views on the size (and factor-bias, if any) of the probable productivity impact for specific sectors in different countries. The policy response analysed here– a Western European ban on imports of identifiable GM-crops -- is simply hypothetical. But even some developing countries (e.g., Sri Lanka) have already taken that step, so it is not necessarily an unrealistic policy reaction. This scenario assumed that GM-producing regions could at a negligible extra cost place a “may contain GMOs” label on their products and that this would be sufficient for Western European importers to identify and reject such shipments. However, in the case of non-adopting countries, they presumably would face testing requirements at Western European borders. The costs of those procedures may be non-trivial, especially for smaller developing countries. It is conceivable that providing a better guarantee of food safety and/or providing relevant and desired information about the new technology, e.g. via labelling, may effectively stimulate consumer demand. Since the GMO debate will continue to centre on the concept of “the consumer’s right to know”, it is important for analysts to understand how consumers react to different attempts to satisfy that demand.

Something else that will be easier to do, once more is learned about the externalities associated with production and consumption of GMOs, is identifying the optimal policy measures for offsetting those externalities. The effects of their adoption will then be better able to be estimated for comparing with the effects of cruder instruments such as import bans.

The GM-inclusive and GM-free distinction in the present empirical analysis was based on country of origin – either a country adopts GM crops or it does not. Ideally, the model should explicitly describe the markets for GM and GM-free products separately within each national market and in the international market. Such a differentiation has not been possible in the time made available to prepare this paper, but it is clearly an important area of future research. In order to be able to make such a distinction, consumer preferences for the two types of products should be assessed and then incorporated into the model. To do so requires deciding whether there are in fact two different demand systems and whether they will be relevant in the longer run.

Splitting the two markets in the model would open up possibilities for in-depth analysis of identity preservation and labelling systems. Identity preservation requires that production and marketing channels be segregated completely. In the model this would require establishing linkages all the way from crop to animal feed and final processed food. To the extent that a GMO-free line of production is expected to develop, one must evaluate which price premia such products can be expected to uphold. Consumer preferences may e.g. be incorporated endogenously by linking consumption decisions (GM versus non-GM) to income levels and hence obtaining an implicit measure of willingness-to-pay.

Another aspect of the GMO debate is the increasing concentration of market power in the seed and chemical supplying industries due to biotechnology-driven consolidation in the agri-food industry. This suggests that an investigation of the extent to which modelling the seed-supplying markets as imperfectly competitive would be relevant. In practice this may not be very significant, however, not least because over time more forms will enter this high-tech activity and in any case seed involves a relatively small share of the total cost of crop production.

The applied model used in this paper, although rich in terms of regional coverage and agricultural sector detail, is limited particularly in terms of its simple representation of agents in the economies. There is only one representative household in each country/region, and therefore one cannot draw conclusions about the welfare effects on food-producing and food-consuming households separately. Judging from other empirical analyses, such as the partial equilibrium analysis of Moschini et al. (2000), which calculates measures of crop producer and consumer surplus, this can be a useful distinction.

Finally, there is obviously scope to look at the market effects of GMOs in other product areas. Of particular importance to developing countries are the prospects for vitamin A-supplemented rice and for input cost-reducing cotton varieties. Neither of these is as likely to generate food safety concerns and both offer great prospects for boosting economic welfare in developing countries (Nielsen and Anderson forthcoming 2000). Yet there is the distinct possibility that the extreme reactions against GMOs in some rich countries will thwart the production, dissemination and adoption of GM seeds for all products, not just the ones of concern to rich-country consumers. A less-emotive, more-informed debate is clearly called for so that such opportunities to boost the well-being of potentially billions of poor people are not diminished.

Appendix 1. Production, consumption and trade structures of selected regions

In order to appreciate the relative importance of the different primary agricultural sectors (some or all of which may in the future benefit from genetic engineering techniques) and their related processing sectors to the economies of different regions, Tables A1-A4 provide a few descriptive economic indicators. Table A1 shows that the cereal grains sector, which is dominated by maize production, accounts for almost one fifth of North American agricultural production but only about 5% or less of agricultural production in most other regions. Oilseed production, which includes soybeans, is also rather heavily represented in North American production relative to other regions except South Asia for which oilseeds constitute 13-14% of agricultural production value. Table A1 further shows that paddy rice production accounts for 17-26% of agricultural production in the Asian economies and 20% in Sub-Saharan Africa, and is basically negligible in the other regions. Plant-based fibre production is relatively most important in the low and middle-income Asian agricultural sectors. The residual ‘other processed foods’ sector accounts for the largest share of total food processing in all regions. Meat and dairy production accounts for roughly a third of total processed food production in North and South America, Western Europe and South Africa.

What about the existing trading patterns for these products in their primary and processed forms? Table A3 shows that most international trade in GM-related products (measured in terms of the value of global exports and presented in parentheses in the far left column) takes place in the category ‘other food products’ (and textiles and clothing for GM cotton). Among the primary products there is a fair amount of trade in cereal grains, oilseeds and plant-based fibres and hardly any trade in paddy rice. North America is a major net exporter of cereal grains, oilseeds and plant-based fibres, whilst Western Europe is a major net importer of oilseeds. Keeping in mind the relative importance of the individual products in domestic production, it is worth noting that North America exports a substantial share of its cereal grains and oilseeds (Table A4). In particular, almost 40% of North American oilseed exports are sold in Western Europe (not shown in table).

TABLE A1. **Agricultural and food production structures in selected regions, 1995**

	Japan	China	Rest of East Asia	India	Rest of South Asia	North Amer.	South. Cone	West. Europe	South Africa	Sub-Sahar. Africa
Share of GM-potential crop in primary agricultural production value (percent)										
Paddy rice	25.9	16.8	26.1	18.1	18.1	0.4	3.5	0.2	0.1	19.8
Wheat	1.2	4.3	0.0	8.8	8.1	5.6	4.5	5.1	0.6	4.3
Cereal grains	0.6	5.6	4.8	4.4	4.1	18.5	5.1	5.3	4.7	2.8
Veg. And fruits	37.9	26.9	20.6	5.8	9.9	12.0	23.6	17.6	27.3	17.7
Oilseeds	0.1	2.0	2.9	13.9	12.9	7.1	8.0	1.5	0.9	6.4
Plant fibres	0.1	4.2	4.3	6.4	6.7	3.4	2.1	0.5	0.8	4.9
Other crops	4.2	6.9	20.8	16.9	16.9	7.6	22.5	15.3	19.6	26.7
Livestock	30.0	33.3	20.5	25.6	23.4	45.5	30.8	54.4	46.0	17.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Share of GM-related food production in total value of processed food production (percent)										
Meat & dairy	11.8	11.3	13.4	6.1	6.9	32.8	30.7	36.7	35.3	7.0
Vegetable oils& fats	0.4	8.1	10.6	22.1	18.5	4.0	6.5	6.2	2.6	11.5
Processed rice	7.8	22.0	27.0	3.8	8.3	0.3	3.4	0.4	0.0	7.9
Other proc. Foods	79.9	58.5	49.1	67.9	66.4	62.9	59.4	56.7	62.1	73.6
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Source: GTAP database, Version 4, McDougall et al. (1998)

TABLE A2**. Food consumption structures in selected regions, 1995**

	Japan	China	Rest of East Asia	India	Rest of South Asia	North Amer.	South. Cone	West. Europe	South Africa	Sub-Sahar. Africa
Structure of food consumption expenditure (percent)										
Paddy rice	0.0	7.2	1.4	17.9	15.7	0.0	0.5	0.0	0.0	17.6
Wheat	0.0	2.2	0.2	8.2	8.0	0.0	0.2	0.2	0.2	4.0
Cereal grns	0.0	2.6	1.8	4.9	3.9	0.1	0.5	0.1	0.3	2.5
Veg& fruits	8.6	18.2	11.9	4.9	8.7	5.4	9.7	6.4	6.8	15.2
Oilseeds	0.0	0.1	0.8	6.7	5.4	0.1	0.8	0.1	0.1	3.0
Plant fibres	0.0	0.0	0.8	3.2	3.1	0.0	0.8	0.0	0.0	1.3
Other crops	0.4	4.4	1.9	7.8	7.0	2.6	2.8	3.5	2.1	8.5
Livestock	1.0	23.6	6.3	19.8	15.6	1.3	3.7	3.2	3.1	13.0
For& fish	2.4	6.1	11.8	5.3	5.3	1.1	1.4	2.1	0.0	4.6
Meat,dairy	11.7	3.5	9.5	1.3	2.6	25.6	26.2	32.6	29.3	3.2
Veg.oil,fats	0.1	3.3	3.3	5.6	8.2	0.7	3.5	3.5	1.9	3.2
Proc. Rice	6.3	7.1	19.5	0.0	1.0	0.2	3.9	0.6	0.1	2.2
Other foods	69.6	21.6	30.9	14.2	15.5	63.0	46.2	47.7	56.0	21.6
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Share of food consumption in total value of private consumption expenditure (percent)										
	16.1	49.1	33.9	47.0	46.4	8.0	25.3	13.1	23.9	45.0

Source: GTAP database, Version 4, McDougall et al. (1998).

TABLE A3. **Net exports as a percent of world exports, selected products and regions, 1995 (Value of world exports are shown in billion US$ in parentheses)**

	Japan	China	Rest of East Asia	India	Rest of South Asia	North Amer.	South. Cone	West. Europe	South Africa	Sub-Sahar. Africa
Paddy rice (1)	0.4	0.3	7.4	19.2	4.0	37.6	-1.8	-30.7	0.1	-7.3
Wheat (17)	-5.9	-11.2	-8.1	0.5	-4.9	47.9	0.1	5.9	-1.0	-3.4
Cereal grains (16)	-19.3	-6.2	-3.5	0.1	-0.1	56.2	2.6	-2.3	0.5	-0.7
Oilseeds (13)	-18.1	3.0	-3.7	1.1	-0.4	54.8	11.2	-39.5	-0.3	1.3
Plant fibres (11)	-7.0	-12.1	-16.1	-1.3	-1.1	33.2	-1.0	-15.4	-0.5	10.7
Other crops (55)	-9.8	-0.7	16.4	1.7	0.2	-12.0	8.0	-26.2	0.0	12.0
Livestock (26)	-6.3	0.4	-1.2	-1.3	-0.2	6.0	1.3	-7.9	0.5	0.8
Meat & dairy (81)	-12.8	1.1	0.0	0.0	-0.4	7.1	2.7	3.3	-0.2	-1.0
Veg.oil,fats (20)	-2.7	-10.2	26.8	-2.0	-6.0	2.8	14.9	-4.5	-1.3	-0.9
Proc. Rice (6)	0.2	-7.9	18.0	19.0	1.1	8.3	-0.7	-4.5	-2.4	-11.3
Other foods (181)	-12.4	1.4	3.1	0.9	0.1	-0.5	5.0	3.6	0.4	-0.1
Tex&clothing (314)	-5.4	8.7	3.6	2.6	2.4	-12.1	-0.5	-10.1	-0.1	-0.4

Source: GTAP database, Version 4, McDougall et al. (1998)

TABLE A4. **Exports as a percent of total production, selected products and regions, 1995**

	Japan	China	Rest of East Asia	India	Rest of South Asia	North Amer.	South. Cone	West. Europe	South Africa	Sub-Sahar. Africa
Paddy rice	0.0	0.0	0.4	0.6	0.4	22.1	0.1	17.1	27.2	0.0
Wheat	0.3	0.0	18.9	0.7	0.0	54.3	12.2	31.3	0.0	0.2
Cereal grains	1.9	1.1	2.2	0.2	0.0	18.2	10.5	26.9	43.9	5.6
Oilseeds	0.8	9.2	4.4	0.9	0.7	36.9	13.1	26.8	29.2	4.3
Plant fibres	7.8	0.8	1.0	0.6	9.8	39.1	18.1	54.4	31.8	36.2
Other crops	2.5	11.5	53.7	6.3	10.5	15.1	14.5	23.4	16.6	35.3
Livestock	0.3	2.1	2.0	0.1	0.6	3.5	1.4	6.6	4.2	1.9
Meat & dairy	0.2	8.7	20.5	9.5	0.7	5.6	6.2	18.1	2.3	13.9
Veg.oil,fats	1.0	2.9	47.2	4.5	1.1	8.2	25.6	11.9	4.8	9.4
Proc. rice	0.2	0.2	15.5	97.1	54.0	40.4	3.1	23.5	56.3	0.2
Other foods	0.3	9.2	21.3	10.7	11.0	5.8	9.5	17.9	9.8	16.7
Tex&clothing	4.6	35.4	44.3	17.1	43.6	7.6	2.6	35.0	12.9	11.8

Source: GTAP database, Version 4, McDougall et al. (1998)

Appendix 2. Incorporating a preference shift into the GTAP model (Scenario 4)

Scenario 4 analyses a preference shift in Western Europe in favour of domestically produced oilseeds and cereal grains at the expense of imported oilseeds and cereal grains. In the model a preference shift parameter is added to the behavioural relations of producers and households. The GTAP model has a set of equations that describe the individual producing sector's demand for domestically and imported intermediate goods, respectively. This set of equations is given below, for a producing sector j:

$$(1)\ qfm(i,j,s) = qf(i,j,s) - \Phi_D(i) * [pfm(i,j,s) - pf(i,j,s)] + ffm(i,j,s)$$

$$(2)\ qfd(i,j,s) = qf(i,j,s) - \Phi_D(i) * [pfd(i,j,s) - pf(i,j,s)] + ffd(i,j,s)$$

$$(3)\ pf(i,j,s) = FMSHR(i,j,s) * pfm(i,j,s) + [1 - FMSHR(i,j,s)] * pfd(i,j,s)$$

A sector j in region s uses intermediate input i. This intermediate input can either be imported or produced domestically. Equations (1) and (2) determine sector j's demand for imported intermediates $qfm(i,j,s)$ and domestically produced intermediates $qfd(i,j,s)$, respectively. Both these demands are determined by the overall demand for intermediates $qf(i,j,s)$, irrespective of the country of origin. This is the first term of the right hand side of both equations (1) and (2) and may be termed the expansion effect. There is also a substitution effect – the second term in equations (1) and (2) – which determined the split of demand for intermediates between domestic and imported goods. This effect is a combination of the elasticity of substitution $\Phi_D(i)$ for the individual input and, in equation (1), the difference between the import price $pfm(i,j,s)$ and the composite input price $pf(i,j,s)$. In equation (2) it is the difference between the domestic price $pfd(i,j,s)$ and the composite input price $pf(i,j,s)$ that is relevant. The composite price $pf(i,j,s)$ is determined in part by the share of imports in the sectors' total use of input i in the production of commodity j, given by $FMSHR(i,j,s)$. Note that the equations in the GTAP model – and thereby also equations (1), (2) and (3) above – describe the relative changes. That is, equation (1) describes the relative change in demand for imported intermediates as a function of the relative change in the overall demand for intermediates and the difference between the relative price changes.

Compared to the original GTAP model equations, equations (1) and (2) include the preference shift parameters $ffm(i,j,s)$ and $ffd(i,j,s)$. A value of $ffm(i,j,s)$ = -25 thus represents a 25% reduction in demand for imported input i in sector j in region s. Correspondingly, a value of *ffd(i,j,s)* = 25 represents a 25% increase in demand for the domestic intermediate good *i*. Similarly the model includes behavioural relations for the representative household, which consists of private households:

$$(4)\ qpm(i,s) = qp(i,s) - \Phi_D(i) * [ppm(i,s) - pp(i,s)] + fpm(i,s)$$

$$(5)\ qpd(i,s) = qp(i,s) - \Phi_D(i) * [ppd(i,s) - pp(i,s)] + fpd(i,j,s)$$

$$(6)\ pp(i,s) = PMSHR(i,s) * ppm(i,s) + [1 - PMSHR(i,s)] * ppd(i,s)$$

and the public sector:

$$(7)\ qgm(i,s) = qg(i,s) - \Phi_D(i) * [pgm(i,s) - pg(i,s)] + fgm(i,s)$$

$$(8)\ qgd(i,s) = qg(i,s) - \Phi_D(i) * [pgd(i,s) - pg(i,s)] + fgd(i,j,s)$$

$$(9)\ pg(i,s) = GMSHR(i,s) * pgm(i,s) + [1 - GMSHR(i,s)] * pgd(i,s)$$

These behavioural relations have only two dimensions and contain preference shift parameters in the same way as equations (1) and (2).

In scenario 4 it is assumed that there is a shift of preferences in Western European away from imported oilseeds and cereal grains equivalent to 25% of the total value of imports. But a 25% reduction in demand for imported products is not equal to a 25% increase in the demand for domestically produced foods, because the share of domestic and imported goods in total use typically are different. Producers of vegetable oils and fats in Western Europe, for example, purchased oilseeds from foreign sources equal to a value of USD 4,160 million in 1995. By assuming unitary prices, a 25% reduction of this demand would be equivalent to USD 1,040 million. This amounts to 36% of the processing sector's purchases of *domestic* oilseeds. If the sector's demand for oilseeds is to be directed away from imported goods, i.e. *ffm(oilseeds, vegetable oils and fats, WEU)* = -25, and in favour of domestic production, the parameter *ffd(oilseeds, vegetable oils and fats, WEU)* has to be set equal to 36. All of the model's preference shift parameters are calculated in a similar manner. The table below provides the values of the resulting preference shift parameters. As hinted above the values reflect the initial split between imported and domestic intermediates in production and the split between imported and domestic consumer goods.

TABLE A5. **Exogenous values of the preference shift parameters in scenario 4**

Parameter	Value	Parameter	Value
ffm(cereal grains, cereal grains, WEU)	-25.0	ffm(oilseeds, oilseeds, WEU)	-25.0
ffd(cereal grains, cereal grains, WEU)	+2.7	ffd(oilseeds, oilseeds, WEU)	+270.2
ffm(cereal grains, livestock, WEU)	-25.0	ffm(oilseeds, livestock, WEU)	-25.0
ffd(cereal grains, livestock, WEU)	+1.1	ffd(oilseeds, livestock, WEU)	+5.6
ffm(cereal grains, meat and dairy, WEU)	-25.0	ffm(oilseeds, meat and dairy, WEU)	-25.0
ffd(cereal grains, meat and dairy, WEU)	+10.2	ffd(oilseeds, meat and dairy, WEU)	+1609.7
ffm(cereal grains, other foods, WEU)	-25.0	ffm(oilseeds, veg. Oils and fats, WEU)	-25.0
ffd(cereal grains, other foods, WEU)	+32.9	ffd(oilseeds, veg. Oils and fats, WEU)	+36.3
		ffm(oilseeds, other foods, WEU)	-25.0
		ffd(oilseeds, other foods, WEU)	+20.9
fpm(cereal grains, WEU)	-25.0	fpm(oilseeds, WEU)	-25.0
fpd(cereal grains, WEU)	+28.4	fpd(oilseeds, WEU)	+964.1
fgm(cereal grains, WEU)	-25.0	fgm(oilseeds, WEU)	-25.0
fgd(cereal grains, WEU)	+1.8	fgd(oilseeds, WEU)	+142.2

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