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Estimating the Economic Effects of GMOs: the Importance of Policy Choices and Preferences

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CIES POLICY DISCUSSION PAPER 0035

Estimating the Economic Effects of GMOs: the Importance of Policy Choices and Preferences

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ABSTRACT

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The new agricultural biotechnologies that are generating transgenic or genetically modified organisms (GMOs) are attracting an exceptionally large degree of opposition to their production and trade. Both environmental and food safety concerns have been raised by opponents to the development of transgenic crops. The vast majority of opponents want at least to have labels on products that may contain GMOs, while the most extreme of them (particularly in Western Europe) want to see GM crops totally excluded from production and consumption in their country. This extreme view contrasts with the more relaxed attitude towards the use of GMOs in pharmaceuticals, and swamps discussions of the positive attributes of the new technology. Also associated with that view is the idea that we should not try to measure the economic and other effects of GMOs because there is too much uncertainty surrounding the technology. We beg to differ with the latter sentiment, believing that without attempts to quantify the economic effects of GMOs, opinion formation and policy making would be even less well informed because it would have to depend even more on guesswork.

To illustrate the usefulness of quantitative models for informing GMO debates, the present paper draws on three recent studies by the authors that use existing empirical models of the global economy to examine what the effects of widespread adoption of genetically modified crop varieties in some (non-European) countries might be in light of different policy and consumer preference responses. Specifically, the effects of an assumed degree of GMO-induced productivity growth in selected countries for cotton, rice, and maize plus soybean are explored. In the latter case those results are compared with what they would be if (a) Western Europe chose to ban consumption and hence imports of those products from countries adopting GM technology or (b) some Western European consumers and intermediate users responded by boycotting imported GM crops. Then another global CGE model is introduced which distinguishes GM-inclusive from GM-free maize and soybean. It is used to explore the impact of increased preferences for GM-free food. The final section discusses areas where future empirical work of this sort might focus.

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1. Introduction

Virtually all new technologies, even when they unambiguously benefit the vast majority of society, are opposed by at least a few people. The new agricultural biotechnologies that are generating transgenic or genetically modified organisms (GMOs), however, are attracting an exceptionally large degree of opposition to their production and trade. Both environmental and food safety concerns have been raised by opponents to the development of transgenic or genetically modified crops. The vast majority of opponents want at least to have labels on products that may contain GMOs, while the most extreme of them (particularly in Western Europe) want to see GM crops totally excluded from production and consumption in their country.[1] This extreme view contrasts with the more relaxed attitude towards the use of the new biotechnologies in pharmaceuticals, and swamps discussions of the current and prospective positive attributes of GM crops. Also associated with that negative view is the idea that we should not try to measure the economic and other effects of GMOs because there is too much uncertainty surrounding the technology. We beg to differ with the latter sentiment, believing that without attempts to quantify the economic effects of GMOs, opinion formation and policy making would be even less well informed because it would have to depend even more on guesswork.

To illustrate the usefulness of quantitative models for informing GMO debates, the present paper draws on three recent studies by the authors that use two existing empirical models of the global economy to examine what the effects of widespread use of genetically modified crop varieties in some (non-European) countries might be in light of different some policy or consumer preference responses.[2] Specifically, the standard global, economy-wide GTAP model is used to explore the possible effects of an assumed degree of GMO-induced productivity growth in selected countries for cotton (least controversial because it is not a food), rice (next-least controversial because it is mostly consumed in developing countries), and maize plus soybean (most controversial because they are grown extensively in rich countries and are consumed by people there both directly and via animal products). In the maize/soybean case the results are compared with what they would be if (a) Western Europe chose to ban consumption and hence imports of those products from countries adopting GM technology or (b) some Western European consumers and intermediate users responded by boycotting imported GM crops. Then another global CGE model is introduced which distinguishes GM-inclusive from GM-free maize and soybean. It is used to explore the impact of increased preferences for GM-free food. The final section discusses areas where future empirical work of

[1] Whether import bans to achieve that would be consistent with other obligations members of the World Trade Organization may have is a moot point not discussed here, but see Anderson and Nielsen (2000).
[2] Nielsen and Anderson (2000b,c) and Nielsen, Robinson and Thierfelder (2000).

this sort might focus.

2. Estimating economic effects of GMO adoption

The apparent differences in preferences and views on environmental issues and consumers' right to know about food ingredients are unlikely to disappear in the foreseeable future. The extent to which that could lead to trade disputes depends heavily on the directions and magnitudes of the production, trade and welfare consequences of different responses to the technology by different countries. Theory alone is incapable of determining even the likely direction, let alone the magnitude, of some of the effects of those various responses to GMOs. Hence an empirical modelling approach is called for, to estimate the economy-wide impact of assumed GMO-induced productivity growth and any associated policy changes and consumer responses. What follows is a summary of some early attempts at doing that for cotton, rice, and maize and soybean.

The quantitative analyses described here all make used of global economy-wide CGE (computable general equilibrium) models and are based on the same global database known as GTAP (Global Trade Analysis Project).[3] The global CGE models capture 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.

Currently it is primarily cotton, maize and soybean that are benefiting most from GM-technology, although rice is considered to have a similar potential in the near future. Hence the scenarios analysed here assume that GM-driven productivity growth occurs only in the following GTAP sectors and for a subset of countries: plant-based fibres (of which cotton is by far the most important in the countries considered), paddy rice, coarse grain (grain other than wheat and rice, which is primarily maize in the countries considered) and oilseeds (primarily soybean in the countries considered). In order to appreciate the relative importance of these primary agricultural sectors and their related processing sectors to the economies of different regions, note from Table 1 that plant-based fibre production is of greatest importance to the agricultural sectors of China, India and the poor regions of East and South Asia and Sub-Saharan Africa. But cotton textile and clothing production is very important in the manufacturing sector of many developing countries, so any reduction in the price of the input cotton will impact on such countries. Note also that paddy rice production accounts for between one-sixth and one-quarter of agricultural production in the Asian economies and one-fifth in Sub-Saharan Africa, but is negligible in other regions. Coarse grains (particularly maize) and oilseeds (particularly soybean), by contrast, are of equal or greater importance to North American and Western European agriculture as they are to the farm sectors of most developing country regions. Also important to understand are the differing food consumption patterns across regions (Table 2) and the various regions' net trading situations in raw and processed forms and export dependence of these products (Table 3).

Detailed 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

[3] The Global Trade Analysis Project (GTAP) includes a multi-regional computable general equilibrium (CGE) model based on neo-classical perfectly competitive microeconomic theory and a unique global database for use with this and other CGE models. See Hertel (1997) for comprehensive documentation of the standard GTAP model and McDougall et al. 1998 for a description of the most recent GTAP database, whichin its full version comprises 50 sectors and 45 countries/regions and describes the global economic structures and trade flows of 1995.

(see e.g. OECD 1999 and Nelson et al. 1999). The quantitative studies reported in this paper are therefore necessarily based on no more than assumptions about what the use of genetically modified crops may do in selected sectors and regions. Even so, the analyses are able to highlight the principle economic and trade effects of the technology in different policy and consumer preference environments, and at the same time focus attention on the types of technological parameters needed to do such analysis with more precision.

2.1. Effects of GMO adoption using the GTAP model

This section presents five scenarios estimating the economic impact of adopting GM technology in the rice, cotton, and maize and soybean sectors in various countries/regions under different policy and consumer preference assumptions using the GTAP model. Although not much detailed information yet exists, available empirical evidence (e.g. USDA 1999 and James 1997, 1998) suggests that cultivating GM crops has general cost-reducing effects.[4] The scenarios analysed here are therefore based on a simplifying assumption that the effect of adopting GM crops can be captured by a Hicks-neutral technology shift, i.e. a uniform reduction in all primary factors and intermediate inputs to obtain the same level of production. For present purposes the GM-adopting sectors are assumed to experience a one-off increase in total factor productivity of 5%, thus lowering the supply price of the GM crop to that extent.[5] Assuming sufficiently elastic demand conditions, 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 consequently will be drawn into the affected sector. 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, however, 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 and soybean meal for livestock feed or cotton for textiles will benefit from lower input prices, which in turn will affect the market competitiveness of livestock or textile products.

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 restricted specifically because of the GMOs involved). To the extent that trade is not further restricted and not currently subject to binding quantitative restrictions, world market prices for these products will have a tendency to decline and thus benefit regions that are net importers of these products. For exporters, the lower price may or may not boost their trade volume, depending on price elasticities in foreign markets. Welfare in the exporting countries would go down for non-adopters but could also go down for some adopters if the adverse terms of trade change were to be sufficiently strong. Hence the need for empirical analysis[6].

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[4] Nelson et al. (1999), for example, 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%.

[5] Due to the absence of sufficiently detailed empirical data on the agronomic and hence economic impact of cultivating GM crops, the 5% productivity shock applied here represents an average shock (over both commodities and regions). Changing this shock (e.g. doubling it to 10%) generates near-linear changes (i.e. roughly a doubling) in the effects on price and quantity results reported below.

[6] The GTAP model and database have been aggregated to 16 regions and 17 sectors as shown in Table 4 for all the scenarios in this section. Eight of the sectors are primary agricultural sectors and four are food-processing

Scenario 1: Selected regions adopt GM cotton

To model the effect of cotton farmers adopting GM seeds, Nielsen and Anderson (2000c) assume a 5% primary factor and intermediate input productivity shock applies to plant-based fibres crops in North America, the Southern Cone of Latin America, China, India, and the Rest of South Asia. The model results show that such a shock would induce rather large increases in plant-fibre production in the first two regions, and slightly smaller increases in China and Rest of South Asia (Table 5). This leads to the United States and developing Asia increasing their exports of plant-based fibres, which lowers the international indicator price of cotton by 4%. That in turn discourages cotton production in Africa where by assumption GMO technology is not adopted. But the cotton price fall also encourages the world's textile industry to expand. The resulting increase in textile and clothing production is largest in China, but it is close to zero in South Asia where exporters of the raw material evidently become relatively more internationally competitive than the textile industry there.

The decrease in price and increase in production of textiles and clothing are both very minor, however: Table 5 shows that the major importers of textiles and clothing, North America and Western Europe, hardly change the volume of their imports. This is because textile and clothing trade is still severely restricted by 'voluntary' export restraints on key exporters as part of the Multifibre Arrangement. As a result, the estimated welfare gains from this technological boost, shown in the lower part of Table 5, are relatively modest: just US$1.7 billion per year,[7] of which $350 million goes to North America alone.[7] If South Asia was unable to adopt GM cotton, Nielsen and Anderson (2000c) note that the global gain would fall to $1.2 billion, of which less than half would accrue to developing countries. Needless to say, if the restrictions on textile and clothing trade were removed so that that sector's output was produced in the most efficient locations (meaning much more in developing countries), the gains from GM cotton would be not only greater globally but the share of those gains enjoyed by developing countries also would be greater.[8]

Scenario 2: Selected regions adopt GM rice

The importance of rice production for the livelihoods of poor farmers and consumers in a large number of developing countries makes the introduction of even first-generation GMO technology, e.g. insect-resistant rice varieties, of great interest (let alone second-generation GMO technology that could enhance the nutritional attributes of rice, which is not considered in what follows). The rice scenario involves North America, the Southern Cone, China, East Asian NICs, the Rest of East Asia, India and the Rest of South Asia (but again not Africa, Europe or Japan) adopting productivity-enhancing GM rice seeds. Again the shock is assumed to increase primary factor and intermediate input productivity in the paddy rice sector by 5%.

First, note from Table 6 that Chinese and Indian paddy rice production increase by just 0.3% and the Rest of South Asia by even less, while the increase is around 2% for North America

sectors.

[7] This general equilibrium estimate of the annual gain of $350 million to North America in 1995 dollars for all plant-based fibres is comparable with that generated using a simpler partial equilibrium model for just cotton for the United States alone for 1996 of $240 million by Falck-Zepeda, Traxler and Nelson (2000).

[8] Estimates of those greater gains are to appear in the next revision of Nielsen and Anderson (2000c).

and the Rest of East Asia even though all experience the same assumed productivity increase. These differences are partly explained by the structures of intermediate use of paddy rice: 27% of paddy rice production in China is used to feed livestock and only about half of paddy rice production is further processed, whereas in the Rest of East Asia paddy rice is not used as livestock feed and almost all is processed. Chinese consumers spend an equal share of total food expenditure on processed and unprocessed rice, whereas consumers in the Rest of East Asia almost exclusively purchase processed rice while those in South Asia consume mostly unprocessed rice (Table 2). These different degrees of processing mean that the increased productivity in paddy rice production in the Rest of East Asia can result in much higher value-added than an identical increase in paddy rice productivity in China or South Asia. Moreover, India and the Rest of East Asia are major exporters of rice, so a foreign market for their increased production exists to the extent that demand for rice is price elastic and the average price of processed rice on world markets declines by about 3%. The domestic price of paddy rice within both East and South Asia declines by more: about 6-7%.

Second, as a net exporter of rice, non-adopting Sub-Saharan Africa in this scenario has to face a lower export price as a consequence of increased competition from GM-adopting, rice-exporting countries. This leads to a marked decline Sub-Saharan African exports and a rise in the region's imports of rice.

Third, in terms of economic welfare, the world economy is estimated to be better off by US$6.2 billion per year in 1995 dollars because of such a technology shock, assuming it has no external effects (lower part of Table 6).[9] Western Europe gains mostly because resources move out of producing highly protected rice there, while 'Other high-income' countries gain partly because Korea and Taiwan are assumed to adopt GM rice and partly because, as in Europe, non-adopting Australia shifts resources out of protected rice production. The only region in that table to lose is North America, and its loss is trivial. The welfare decomposition in Table 6 reveals that the reason for its loss is that the deterioration in the terms of trade, because of the fall in international rice prices outweighs the gain from productivity growth in this (to North America) relatively unimportant crop. All of Asia's adopting regions gain substantially. All gain from the technological improvement by similar amounts, but the Rest of Developing East Asia gains less overall because more resources are attracted to its relatively assisted rice sector.[10]

In this rice scenario, as in the previous cotton scenario, it is assumed that consumers are indifferent as to whether the product is free of GMOs, and hence genetically modified and conventional crops are produced side-by-side and traded in one co-mingled market. That is, there are assumed to be no restrictions on trade with genetically modified products, a point taken up below in the case of GM maize and soybean.

Scenario 3: Selected regions adopt GM maize and soybean

In modelling the adoption of GMOs in maize and soybean production, Nielsen and Anderson

[9] If South Asia did not adopt the new GM technology, the global gains would be reduced by more than one-quarter, to $4.5 billion p.a.

[10] East Asia's NICs also assist their rice industry, but they assist other farm sub-sectors even more so the expansion of rice by the latter does not reduce overall allocative efficiency in their farm sectors, unlike in Rest of East Asia.

(2000b) assume that GM-driven productivity growth of 5% occurs in two GTAP sectors: coarse grain (excluding wheat and rice) and oilseeds. The productivity shocks are applied to North America, Mexico, the Southern Cone region of Latin America, India, China, Rest of East Asia (excluding Japan and the East Asian NICs), and South Africa. Again the countries of Western Europe, Japan, Other Sub-Saharan Africa and elsewhere are assumed to refrain from the use of GM crops in their production systems.

The authors consider three maize/soybean scenario. The first or them (scenario 3) is a base case with no policy or consumer reactions to GMOs, as assumed above also for cotton and rice. The others (scenarios 4 and 5) impose on this base case a policy or consumer response in Western Europe. In scenario 4, Western Europe not only refrains from using GM crops in its own domestic production systems, but the region is also assumed to reject imports of genetically modified oilseeds and coarse grains from GM-adopting regions. Scenario 5 considers the case in which consumers express their preferences through market mechanisms rather than through government regulation.

Table 7 reports the results for scenario 3. A 5% reduction in overall production costs in these sectors leads to increases in coarse grain production of between 0.4% and 2.1%, and increases in oilseed production of between 1.1% and 4.6%, in the GM-adopting regions. The production responses are generally larger for oilseeds as compared with coarse grain. This is because a larger share of oilseed production as compared with coarse grain production is destined for export markets in all the reported regions, and hence oilseed production is not limited to the same extent by domestic demand, which is less price-elastic. Increased oilseed production leads to lower market prices and hence cheaper costs of production in the vegetable oils and fats sectors, expanding output there. This expansion is particularly marked in the Southern Cone region of South America where no less than one-fourth of this production is sold on foreign markets (Table 7a), thereby allowing for a larger production response to the reduced costs of production in this sector. In North America maize is also used as livestock feed, and hence the lower feed prices lead to an expansion of the livestock and meat processing sectors there.

Due to the very large world market shares of oilseeds from North and South America and coarse grain from North America (Table 7a), the increased supply from these regions causes world prices for coarse grain and oilseeds to decline by 4.0% and 4.5%, respectively. As a consequence of the more intense competition from abroad, production of coarse grain and oilseeds declines in the non-adopting regions. This is particularly so in Western Europe, a major net importer of oilseeds, of which about half comes from North America. Cereal grain imports into Western Europe increase only slightly (0.1%), but the increased competition and lower price are enough to entail a 4.5% decline in Western European production. In the developing countries too, production of coarse grain and oilseeds is reduced slightly. The changes in India, however, are relatively small compared with e.g. China and the Southern Cone region. This is explained by the domestic market orientation of these sales. That means India’s relatively small production increase causes rather substantial declines in domestic prices for these products, which in turn benefits the other agricultural sectors through vertical linkages. For example, 67% of intermediate demand for coarse grain and 37% of intermediate demand for oilseeds in India stems from the livestock sector, according to the GTAP database.

Global economic welfare (as traditionally measured in terms of equivalent variations of income, ignoring any externalities) is boosted in this first scenario by US$9.9 billion per year, two-thirds of which is enjoyed by the adopting regions (Table 7b). It is noteworthy that all regions (both adopting and non-adopting) gain in terms of economic welfare except Sub-Saharan Africa. Most of this gain stems directly from the technology boost. The net-exporting GM-adopters experience worsened terms of trade due to increased competition on world markets, but this adverse welfare effect is outweighed by the positive effect of the technological boost. Western Europe gains from the productivity increase in the other regions only in part because of cheaper imports; mostly it gains because increased competition from abroad shifts domestic resources out of relatively highly assisted segments of EU agriculture. The group of other high-income countries, among which are East Asian nations that are relatively large net importers of the GM-potential crops, benefits equally from lower import prices and a more efficient use of resources in domestic farm production.

Scenario 4: Selected regions adopt GM maize and soybean plus Western Europe bans imports of those products from GM-adopting regions

In this 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 coarse grain from GM-adopting regions. This assumes that the labelling requirements of the Biosafety Protocol (UNEP 2000) enable Western European importers to identify such shipments and that all oilseed and coarse grain exports from GM-adopting regions will be labelled “may contain GMOs”. Under those conditions the distinction between GM-inclusive and GM-free products is simplified to one that relates directly to the country of origin,[11] and labelling costs are ignored. This import ban scenario reflects the most extreme application of the precautionary principle within the framework of the Biosafety Protocol.

A Western European ban on the imports of genetically modified coarse grain and oilseeds changes the situation in scenario 3 rather dramatically, especially for the oilseed sector in North America which has been highly dependent on the EU market. The result of the European ban is not only a decline in total North American oilseed exports by almost 30%, but also a production decline of 10%, pulling resources such as land out of this sector (Table 8). For coarse grain, by contrast, only 18% of North American production is exported and just 8% of those exports are destined for Western Europe. Therefore the ban does not affect North American production and exports of maize to the same extent as for soybean, although the downward pressure on the international price of maize nonetheless dampens significantly the production-enhancing effect of the technological boost. Similar effects are evident in the other GM adopting regions, except for India – once again because its production of these particular crops is virtually all sold domestically and so is not greatly unaffected by market developments abroad.

For Sub-Saharan Africa, which by assumption is unable to adopt the new GM technology, access to the Western European markets when other competitors are excluded expands. Oilseed exports from this region rise dramatically, by enough to increase domestic production

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

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 coarse grain also increases, but not by as much because of an initial high degree of self-sufficiency. Europe's shift from imported oilseeds and coarse grain to domestically produced products has implications further downstream. Given an imperfect degree of substitution in production between domestic and imported intermediate inputs, the higher prices of domestically produced maize and soybean mean that livestock feed is slightly more expensive. (Half of intermediate demand for coarse grain in Western Europe stems from the livestock sector.) Inputs to other food processing industries, particularly the vegetable oils and fats sector, also are more expensive. As a consequence, production in these downstream sectors decline and competing imports increase.

Aggregate welfare implications of this scenario are substantially different from those of scenario 3. Western Europe now experiences a decline in aggregate economic welfare of US$4.3 billion per year instead of a boost of $2 billion (compare Tables 8b and 7b). Taking a closer look at the decomposition of the welfare changes reveals that adverse allocative efficiency effects explain the decline. Most significantly, EU 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 those consumers are assumed to be indifferent between GM-inclusive and GM-free products, the import ban restricts them from benefiting from lower international prices. Bear in mind, though, that in this as in the previous scenarios it is assumed citizens are indifferent to GMOs. To the extent that some Western Europeans in fact value a ban on GM products in their domestic markets, that would more or less than offset the above loss in economic welfare.

The key exporters of the GM products, North America, Southern Cone and China, all show a smaller gain in welfare in this as compared with the scenario in which there is no European policy response. Net importers of corn and soybean (e.g. 'Other high-income' which is mostly East Asia), by contrast, are slightly better off in this than in scenario 3. Meanwhile, the countries in Sub-Saharan Africa are affected in a slight positive instead of slight negative way, gaining from better terms of trade. In particular, a higher price is obtained for their oilseed exports to Western European markets in this as compared with scenario 3.

Two-thirds of the global gain from the new GM technology as measured in scenario 3 would be eroded by an import ban imposed by Western Europe: it falls from $9.9 billion per year to just $3.4 billion, with almost the entire erosion in economic welfare borne in Western Europe (assuming as before that consumers are indifferent between GM-free and GM-inclusive foods). The rest is borne by the net-exporting adopters (mainly North America and the Southern Cone region). Since the non-adopting regions generally purchase most of their imported coarse grain and oilseeds from the North American region, they benefit even more than in scenario 3 from lower import prices: their welfare is estimated to be greater by almost one-fifth in the case of a Western European import ban as compared with no European reaction.

Scenario 5: Selected regions adopt GM maize and soybean plus some Western Europeans' preferences shift against GM maize and soybean

As an alternative to a policy response, this scenario analyses the impact of a partial shift in

Western European preferences away from imported coarse grain and oilseeds and in favour of domestically produced crops.[12] The scenario is implemented as an exogenous 25% reduction in final consumer and intermediate demand for *all* imported oilseeds and coarse grain (that is, not only those which can be identified as coming from GM-adopting regions).[13] This can be interpreted as an illustration of incomplete information being 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 are assumed to choose to completely avoid products that are produced outside Western Europe. That import demand is shifted in favour of domestically produced goods. Western European producers and suppliers are assumed to be able to signal - at no additional cost – that their products are GM-free by e.g. labelling their products by country of origin. This is possible because it is assumed that no producers in Western Europe adopt GM crops (perhaps due to government regulation), and hence such a label would be perceived as a sufficient guarantee of the absence of GMOs.

As the results in Table 9 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 4 there are slight increases in this scenario, and production responses in coarse grain are slightly larger. 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) the shift in preferences is only partial, and so some consumers and firms do benefit from lower import prices. In other words, in contrast to the previous scenario, a certain link between EU prices and world prices is retained here because we are dealing with only a partial reduction in import demand. The output growth in Sub-Saharan Africa in scenario 4, by taking the opportunity of serving European consumers and firms while other suppliers were excluded, is replaced in this scenario by declines: Sub-Saharan Africa loses export share to the GM-adopting regions.

The numerical welfare results in this scenario are comparable with those of scenario 3 (the scenario without the import ban or the partial preference shift) for all regions except, of course, Western Europe. Furthermore, the estimated decline in economic welfare that Western Europe would experience if it banned maize and soybean imports is changed to a slight gain in this scenario (although recall that these welfare measures assume consumers are indifferent to whether a food contains GMOs). The dramatic worsening of resource allocative efficiency in the previous scenario is changed to a slight improvement in this one. This is because production in the lightly assisted oilseeds sector increases at the expense of production in all other (more heavily distorted) agri-food sectors in Western Europe.

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[12] See the technical appendix of Nielsen and Anderson (2000a), which describes how the exogenous preference shift is introduced into the GTAP model, a method adopted from Nielsen (1999).

[13] The size of this preference shift is arbitrary, and is simply used to illustrate the possible direction of effects of this type of preference shift as compared with the import ban scenario.

The welfare gains for North America are more similar in this scenario than in the previous one to those of scenario 3. But even in scenario 4 its gains are large, suggesting considerable flexibility in both domestic and foreign markets to respond to policy and consumer preference changes, plus the dominance of the benefits of the new technology for adopting countries. Given that the preference shift in scenario 5 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 coarse grain and oilseeds from just identifiable GMO-adopting regions were banned completely. Hence Sub-Saharan Africa slips back to a slight loss 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 a little below that when there is no preference shift: a gain of $8.5 billion per year compared with $9.9 billion in scenario 3, with Western Europe clearly bearing the bulk of this difference.

2.2. Effects of adopting GM maize and soybean using an alternative model

An alternative modelling framework is used in a recent analysis by Nielsen, Robinson and Thierfelder (2000), hereafter the NRT model, which draws on a model developed by Lewis, Robinson and Thierfelder (1999). It involves a more-aggregated multi-region computable general equilibrium (CGE) model consisting of just seven regions and ten sectors but is otherwise similar to the standard GTAP model with one important exception: the coarse grain and oilseed sectors of the NRT model have each been split into two. This split is in order to capture the production and trade effects of segregating maize and soybean markets into GM and non-GM lines of production as consumers in some parts of the world turn against GMOs. This segregation is introduced based on a notion that there may be a viable market for guaranteed GMO-free products alongside the new GMO-inclusive varieties if the GMO-critical consumers are willing to pay a price premium. Depending on the strength of opposition toward GM products in important markets and the costs of segregating agricultural markets, developing and developed countries alike may benefit from segregated agricultural markets, which will have different prices. Such a market development would be analogous to the niche markets for organic foods.

In the base data used for this model analysis, it is assumed that all regions initially produce some of both the GM and non-GM varieties of oilseeds and coarse grain (in contrast to the assumption in the preceding scenarios that only a subset of countries can or choose to develop GM crops). The assumed shares are as shown in Table 10, based on estimates provided in James (1999) and USDA (2000).Furthermore, the structures of production in terms of the composition of intermediate input and factor use in the GM and non-GM varieties are initially assumed to be identical, as are the destination structures of exports. In the NRT model the authors endogenize the decision of producers and consumers to use GM vs. non-GM varieties in production and final demand, respectively. The input-output choice is endogenized for four demanders of coarse grain and oilseeds: livestock, meat & dairy, vegetable oils & fats, and other processed food sectors. Intermediate demands for each composite crop (i.e. GM plus non-GM) are held fixed as proportions of output. In this way, the initial input-output coefficients remain fixed but, for oilseeds and coarse grain, a choice has been introduced between GM and non-GM varieties. Other intermediate input demands remain in fixed proportions to output. Similarly, final consumption of each composite GM-potential good is also fixed as a share of total demand, with an endogenous choice between GM and non-GM varieties. All other consumption shares remain fixed., and The choice between GM and non-GM varieties is determined by a CES function.[14]

Since the available estimates of agronomic and hence economic benefits to producers from cultivating GM crops are few and very diverse, NRT simply assume the GM oilseed and GM coarse grain sectors in all regions have a 10% higher level of primary factor productivity as compared with their non-GM (conventional) counterparts. (This shock is slightly different from the shock imposed in the above 5 GTAP scenarios: it is twice the size, but it concerns only primary factor use, not also intermediate input use.) They introduce this factor productivity shock in the GM sectors against a variety of base models, which differ in terms of substitution elasticities for GM and non-GM products in two of the most GM-critical regions, namely Western Europe and High IncomeAsia (mainly Japan). To start with, it is assumed that the elasticity of substitution between GM and non-GM varieties is high and equal in all regions. Then, in order to reflect the fact that citizens in Western Europe and High Income Asia are skeptical of the new GM varieties, the elasticities of substitution between the GM and non-GM varieties are gradually lowered so that GM and non-GM varieties are seen as increasingly poorer substitutes in production and consumption in these particular regions. Citizens in all other regions are basically indifferent, and hence the two crops remain highly substitutable in consumption and production there.

What results should we expect?

As in the 5 GTAP scenarios above, the more-effective GM production process will initially cause labour, land, and capital to leave the GM sectors because lower (cost-driven) GM product prices will result in lower returns to factors of production. To the extent that demand (domestically or abroad) is very responsive to this price reduction, this cost-reducing technology may potentially lead to increased production and hence higher returns to factors. Suppliers of inputs and buyers of agricultural products also will be affected by the use of genetic engineering in GM-potential sectors through vertical (or backward) linkages. To the extent that the production of GM crops increases, the demand for inputs by producers of those crops may rise. Demanders of primary agricultural products, e.g. livestock producers using grains and oilseeds for livestock feed, will benefit from lower prices, which in turn will affect the market competitiveness of these sectors.

The other sectors of the economy may also be affected through horizontal (or forward) 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. For example, since applying genetic engineering techniques to wheat breeding is apparently more complex compared with maize, the price of wheat will be high relative to other more easily manipulated grains. 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.

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[14] See Nielsen, Robinson and Thierfelder (2000) for a formal description of how the endogenous choice between GM and non-GM varieties is incorporated into the model.

In terms of price effects, there is both a direct and an indirect effect of segregating the markets. Due directly to the output-enhancing productivity effect, countries adopting GM crops should gain from lower cost-driven prices. The more receptive a country is to the productivity-enhancing technology, the greater the gains. There is also an indirect effect, which will depend on the degree of substitutability between GM and non-GM products. When substitutability is high, the price of non-GM crops will decline along with the prices of GM-crops. The lower the degree of substitutability, the weaker will be this effect, and the larger should be the price wedge between GM and non-GM crops. The net effect of these direct and indirect effects on particular countries is theoretically ambiguous, again underscoring the need for empirical analysis.

The widespread adoption of GM varieties in certain regions will affect international trade flows depending on how traded the crop in question is and the preferences for GM versus non-GM in foreign markets. World market prices for GM products will have a tendency to decline and thus benefit net importers to the extent that they are indifferent between GM and non-GM products. For exporters, the lower price may enable an expansion of the trade volume depending on the price elasticities and preferences in foreign markets. In markets where citizens are critical of GM ingredients in their food production systems, consumers will not fully benefit from the lower prices on GM crops. Furthermore, resources will be retained in the relatively less productive non-GM sectors in these regions. However, as is the case with organic food production, this would simply be a reflection of consumer preferences and hence not welfare-reducing (so long as an appropriate welfare measure is used).

What production and trade results emerge from the NRT empirical analysis?

The expected increase in production of the genetically modified crops is borne out in the empirical results for all regions of the NRT model as a direct consequence of the assumed increase in factor productivity. Due to the relative decline in productivity in the non-GM sectors, production of conventional coarse grain and oilseeds declines. Attention here focuses on the effects on overall trade and bilateral trade patterns for selected regions as citizens in High Income Asia and Western Europe become increasingly critical of GM crops, and hence these crops become correspondingly worse substitutes in production in these two regions. First, the results for North America and Western Europe are commented on briefly because the countries in these regions are currently the most outspoken participants in the GMO debate. But focus then turns to examining the effects on bilateral trade flows of selected developing country regions to provide an indication as to whether they are able to take advantage of the segregation of oilseed and coarse grain markets in the light of the GMO-critical stance taken in Western Europe and High Income Asia. Three developing country regions are in focus: South America, Sub-Saharan Africa, and Low-Income Asia.

As expected, the North American region is very sensitive to changes in preferences toward GMOs because it is the world’s largest exporter of both oilseeds and coarse grain, and it is particularly dependent on the GM-critical markets for these exports. Total exports of the GM varieties decline as GM and non-GM substitutability worsens in the GM-critical regions, and this is particularly so for oilseeds because almost 80% of North American oilseeds exports are initially sold in these markets, whereas the share is less than 60% for coarse grain. In response to the changing preferences, exports of the non-GM varieties are boosted. These changes are reflected in North America's production results. Western Europe is an important *importer* of oilseeds. At the extreme, where Western Europeans are unconcerned about the GM or non-GM status of crops used in production, imports increase dramatically as the lower world market prices are exploited. As substitutability is reduced, GM-imports and production plunge while non-GM imports and production increase. Note that the reduction of total GM oilseed imports occurs at a slower rate than for total GM cereal grain imports. This is due to the initial high dependence on oilseed imports from regions that are intensive users of GM varieties. Furthermore, as the Western European market becomes more difficult to penetrate, the import prices on GM products faced by Europeans decline. This tendency works against the effect of the preference shift. (See Nielsen, Robinson and Thierfelder (2000) for more-detailed results.)

What about the trade results for the three developing country regions? Starting with oilseed exports from South America and Sub-Saharan Africa, Figures 1 and 2 show that the initial increase in total GM oilseed exports from these regions due to the factor productivity shock is reduced as preferences in High Income Asia and Western Europe turn against GMOs. (The vertical axis refers to the new level as a percentage of the base level before the TFP shock.) Exports are directed away from the GM critical regions and spread evenly over the other importing regions. Of South America's total oilseed exports, 84% are initially sold on GM critical markets as compared with 58% of oilseed exports from Sub-Saharan Africa. As seen in Figures 1 and 2, the adjustment in total GM oilseed exports is therefore relatively larger for South America. As expected, Figures 3 and 4 show the exports of non-GM oilseeds from these two regions generally being diverted toward the GM-critical regions and away from other regions. A noteworthy exception is that non-GM oilseed exports to North America also increase marginally as the *other* High Income countries become more critical of GMOs. Production of non-GM products increases mainly to serve the markets in Western Europe and High Income Asia as citizens there become increasingly critical of GMOs, but given a high yet not perfect substitutability between the two varieties in the other regions, there is scope for selling both varieties in these markets as well.

Both South America and Sub-Saharan Africa depend on imports for 8-9% of their total cereal grain absorption. However, in terms of sources, South America depends almost entirely on North America for its imports, while imports into Sub-Saharan Africa come from North America (50%), Western Europe (16%), and the Rest of World (28%). Because citizens of South America and Sub-Saharan Africa are assumed to be uncritical of GMO content, *total* GM cereal grain imports increase as preferences in Western Europe and High Income Asia turn against GMOs. This is because GM exports are now increasingly directed to non-critical markets (i.e. *fewer* markets), and so the import price declines even further than the price decline due to the factor productivity shock. Imports of GM crops from the GM critical countries of course decline drastically as production of GM crops in these regions declines. For the non-GM varieties, imports from the GM-critical regions increase marginally as substitutability in those regions worsens. Given competition from increased supplies of GM crops, prices of non-GM crops also fall, and so South America and Sub-Saharan Africa also face declining prices on non-GM imports from the GM-critical regions as preferences shift.

Low Income Asia is a net importer of both oilseeds and cereal grains. Most of these imports (89% of oilseeds and 83% of cereal grains) come from North and South America. Figures 9 and 10 show that total imports of GM crops into this region increase slightly as preferences turn against GMOs in Western Europe and High Income Asia. Once again, this is because the redirection of GM export crops means increased supplies on fewer markets and hence prices decline even further. The flow of non-GM imports into Low Income Asia is relatively unaffected by the preference changes in the GM-critical regions because the bulk of oilseed imports initially comes from the Americas. In terms of bilateral flows, there are marginal increases in non-GM imports from Western Europe since imports from these regions must compete with GM crops in a GM-indifferent market.

How large are the price wedges between GM and non-GM varieties?

The bilateral trade results above show that trade diversion is significant. As preferences in High Income Asia and Western Europe turn against GM varieties, trade of GM-varieties expands in the GM-indifferent markets, while non-GM sales decline in those markets. At the same time, non-GM exports are redirected toward the GM-critical regions. In other words, markets adjust to accommodate the differences in tastes across countries. This favorable outcome is driven by the price differential that results between the two crop varieties. The price wedges that arise as a consequence of the different levels of factor productivity in GM and non-GM crop production are between 4.0% and 6.6% (when GM/non-GM substitutability is high in all regions), varying across crops and regions. Figures 13 and 14 show how the ratios of non-GM to GM prices in different regions develop as substitutability between the two varieties worsens in the GM-critical regions. In the GM critical regions, the price ratio increases as citizens there become increasingly skeptical. This tendency is weakest for cereal grains in Western Europe because this region is not as strongly engaged in international trade in this crop as it is in oilseeds. In North America, the price wedge is generally small, and it declines as GM and non-GM substitutability worsens in the other High Income countries. Given that North America is the world's largest producer and exporter of both crops, the high degree of substitutability between GM and non-GM crops in this region means that prices of *both* varieties decline – the GM price declines due to the productivity shock, while the non-GM price declines because of increased competition in the GM-indifferent markets. Furthermore, in an effort to retain access to the GM critical markets, North American production of non-GM varieties increases as citizens of the GM critical regions become increasingly skeptical of GMOs.

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

What are the effects on economic welfare in the different regions?

Global economic welfare (i.e. absorbtion) increases by US$12 billion per year when GM coarse grain and oilseed production processes experience a 10% factor productivity increase with the assumed regional shares of GM and non-GM varieties. As preferences in Western Europe and High Income Asia turn against GM varieties, this increase is reduced to $11 billion. As Figure 15 shows, South America, North America, and Low Income Asia are the main beneficiaries of the factor productivity increase. This is because all of them are assumed to be intense adopters of the productivity-increasing crop varieties. North America gains as the major producer and exporter of both crops. The total absorption gain in this region is reduced, but only by 5% relative to the high substitutability experiment, as a consequence of changing preferences in its important export markets in Western Europe and High Income Asia. However, the ‘costs’ of the preference changes are borne mainly by the GM-critical regions themselves, with the gains made in High Income Asia (in terms of lower import prices) basically disappearing. In Western Europe, the initial boost in total absorption is cut in half. In particular, the increases in total absorption in *all* the developing country regions are *not* affected by the preference changes in the GM-critical regions. Low Income Asia is the major beneficiary in absolute terms, being both a net importer of the two crops and basically indifferent as to GM content. Hence the region benefits from substantially lower import prices on GM crops. Despite the high dependence on the GM critical regions for its exports of oilseeds, the increase in total absorption in South America is unaffected by the preference changes there because bilateral trade flows adjust well – trade diversion offsets the effects of demand shifts in the GM-critical regions. In Sub-Saharan Africa the gains are small in absolute terms, mainly due to the small share of these particular crops in production and trade, but they are also unaffected by preference changes in GM-critical regions.

3. Conclusions

Lessons

What have we learned? First, the potential economic welfare gains from adopting GMO technology in even just a subset of producing countries for these crops is non-trivial. In the cases considered in the first three scenarios using the GTAP model it amounts to an estimated $1.7 billion per year for cotton, $6.2 billion for rice, and $9.9 billion for coarse grain and oilseeds. Moreover, in all three cases developing countries would receive a sizeable share and possibly the majority of those gains (more so the more of them that are capable of introducing the new GM technology). The size of these gains, especially for developing countries, are such that policy makers should not ignore them when considering policy responses to appease opponents of GMO technology.

Second, scenarios 3 to 5 show that the most extreme use of trade provisions by Western Europe, namely an import ban on GM crops, would be very costly in terms of economic welfare for the region itself – a cost which governments in the region need to weigh against the perceived benefits to voters of adopting the precautionary principle in that way. Imposing a ban prevents European consumers and intermediate demanders from gaining from lower import prices, domestic production of corn and soybean would be forced to rise at the expense of other farm production, and hence overall allocative efficiency in the region would be worsened. In the case modelled the GM-adopting regions still enjoy welfare gains due to the dominating positive effect of the assumed productivity boost embodied in the GM crops, but those gains are reduced by the import ban as compared with the scenario in which GM crops are traded freely. 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 slightly in gross terms from retaining access to the GMO-free markets when others are excluded. Whether they gain in net terms would depend on the cost of compliance with European regulations.

Third, even if many consumers in Western Europe are concerned about GMOs, the results of the market-based partial preference shift experiment (scenario 5) suggest that letting consumers express that preference through the market reduces the welfare gains from the new technology much less than if (as in scenario 4) a ban on GMOs is imposed in Europe. The results also suggest, however, that developing countries that do not gain access to GM technology may be slightly worse off 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.

Fourth, the NRT model results suggest that global markets are able to adjust to such segregation in the sense that non-GM exports are diverted to the GMO-critical regions, while GM-exports are diverted to the indifferent regions. Price differentials are significant, but tempered by commodity arbitrage. In particular, in certain GMO-favourable regions, the prices of the non-GM varieties also decline because of the high degree of substitutability between the GM and non-GM varieties in domestic use and increased production to supply critical consumers. In the GMO-critical regions, the price differentials reflect minor increases in supply of the non-GM products and marked declines in supply of GMO varieties. An important aspect of these results is that developing countries are also responsive to these GM preferences, and redirect their trade flows among partners accordingly. But this favourable outcome would require the relative price premium on the non-GM products to be sufficient not only to outweigh the productivity growth foregone by not adopting GMOs but also to cover the potentially significant costs of compliance. Recall that the above analyses bravely assume that labelling would enable costless identification of the GM status of any product.

And fifth, large though the estimated welfare gains from the adoption of GM technology are, they are dwarfed by the welfare gains that could result from liberalizing global markets for farm products and textiles and clothing (recently estimated at around $180 billion per year *even after* the Uruguay Round is fully implemented in 2005 – see Anderson et al. (2000)). Should opposition to GMOs lead to the erection of further barriers to farm trade, that would simply add to the welfare cost of restrictive trade policies.

Qualifications and areas for further research

The 'realism' of the above quantitative results is of course limited by the lack of empirical data and incomplete knowledge of the effects of GM crops. The analysis has had to be based on no more than assumptions about the productivity impact of introducing genetically modified crops in the agricultural production system. To do better, more data needs to be made available about the nature and size of the productivity gains likely to be made in specific sectors of different countries.

It needs to be kept in mind, too, that the above welfare analysis ignores any of the alleged negative welfare consequences of introducing GMOs, for example due to externalities affecting the natural environment. But it also ignores the positive welfare consequences that could flow from GM technology, such as reduced pesticide use.

The above analyses rely on simplifying assumptions about the productivity impact of adopting GM crops, namely, that it affects each primary factor and intermediate input by the same amount. But it is a reduction in pesticide and herbicide use that is the main cost-reducing impact of using the first-generation GM crops (see, e.g., Pray et al. 2000). This suggests the above results, which may be exaggerating the factor re-allocation effects, need to be amended to take that into account.

In the analysis using the NRT model, the segregation of production and marketing of GM and non-GM varieties of coarse grain and oilseeds is assumed only to bear the cost of the relative productivity difference. This assumption captures the cost of having to preserve the identity of the crop throughout the production and marketing chains, as well as any testing and labelling requirements at national borders. Experience from identity preservation of specialty crops reveals that this can potentially increase the price of such products by between 5 and 15% (Buckwell et al. 1999). Runge and Jackson (1999) argue that in a free market, and in the absence of unsympathetic policy reactions, such a cost-price premium will fall on the GM-free products (as now happens with organic food). Whether consumers in Western Europe and elsewhere are in fact willing to pay such a premium is a moot point. Moreover, consumers may demand supplies of *processed* foods that are guaranteed free from genetically modified organisms. To the extent that testing methods and accompanying labelling systems cannot deliver this guarantee, it will be necessary to trace GMO ingredients through feed use and further processing to the final processed food product. This would in turn mean – both in reality and in empirical modelling – that processed foods would also have to be identified as either GMO-inclusive or GMO-free.

Each of the global models used above assumes perfect competition in all markets, and neither separates out the (relatively tiny) markets for agricultural research and for crop seeds. However, GMO technology is raising the incentive for vertical integration of firms involved in producing the biotechnology, the germplasm, the seeds, and some of the chemical inputs such as pesticides (Lindner 2000). Also, if GM crops are to be marketed separately from conventional crops, that may alter merger/acquisition incentives for grain-marketing firms in terms of horizontal integration, and in terms of their involvement in the feed-livestock complex. Less likely is that firms in either of these sectors might also be attracted to vertically integrate into food retailing if enough supermarket chains chose to not stock GM foods. Changes to firm concentration ratios in those sectors could well alter the extent to which they can capture monopolistic rents within the food chain, thereby altering the size of the gains from this technology enjoyed by farmers and final consumers. More-complex modelling would be needed to estimate the distributional and overall welfare consequences of such possibilities.

Finally, the above type of models could also be used to explore the possible economic effects of second-generation GMO technologies such as nutritional enhancement of foods. Being able to produce rice rich in vitamin A and iron could be a huge boon to the health of literally billions of poor consumers, for example. Whether a country's farmers choose to adopt such crops depends on the extent to which consumer resistance eases (or changes to enthusiasm) or trade barriers to GM products and on the responses of producers in other countries. Quantitative economic modelling has the potential to help food producers to assess their prospects under these and other (including more optimistic) conceivable circumstances.

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Table 1. Agricultural and food production structures in selected regions, 1995

	Japan	China	Rest of East Asia	India	Rest of South Asia	North Amer-ica	South-ern Cone	Western Europe	South Africa	Rest of Sub-Saharan Africa
Share of GM-potential crop in 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
Coarse grain	0.6	5.6	4.8	4.4	4.1	18.5	5.1	5.3	4.7	2.8
Oil seeds	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
Share of GM-related food production in total value of food production (percent)										
Vegetable Oils& fats	11.8	11.3	13.4	6.1	6.9	32.8	30.7	36.7	35.3	7.0
Processed rice	7.8	22.0	27.0	3.8	8.3	0.3	3.4	0.4	0.0	7.9
Other foods	79.9	58.5	49.1	67.9	66.4	62.9	59.4	56.7	62.1	73.6

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

Table 2. Food consumption structures in selected regions, 1995

	Japan	China	Rest of East Asia	India	Rest of South Asia	North Amer-ica	South-ern Cone	Western Europe	South Africa	Rest of Sub-Saharan Africa
Structure of selected foods in total food consumption (percent)										
Paddy rice	0.0	7.2	1.4	17.9	15.7	0.0	0.5	0.0	0.0	17.6
Proc. Rice	6.3	7.1	19.5	0.0	1.0	0.2	3.9	0.6	0.1	2.2
Coarse grain	0.0	2.6	1.8	4.9	3.9	0.1	0.5	0.1	0.3	2.5
Oilseeds	0.0	0.1	0.8	6.7	5.4	0.1	0.8	0.1	0.1	3.0
Veg. oil, fats	0.1	3.3	3.3	5.6	8.2	0.7	3.5	3.5	1.9	3.2
Livestock	1.0	23.6	6.3	19.8	15.6	1.3	3.7	3.2	3.1	13.0
Meat, dairy	11.7	3.5	9.5	1.3	2.6	25.6	26.2	32.6	29.3	3.2
Fish	2.4	6.1	11.8	5.3	5.3	1.1	1.4	2.1	0.0	4.6
Share of food in total value of private household consumption (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 3. Exports of selected products by selected regions[b], 1995

(a) Net exports by region as a % of world exports of selected products

	Japan	China	Rest of East Asia	India	Rest of South Asia	North America	Southern Cone	Western Europe	South Africa	Rest of Sub-Saharan Africa
Paddy rice (1)[a]	0.4	0.3	7.4	19.2	4.0	37.6	-1.8	-30.7	0.1	-7.3
Coarse grain (16)[a]	-19.3	-6.2	-3.5	0.1	-0.1	56.2	2.6	-2.3	0.5	-0.7
Oilseeds (13)[a]	-18.1	3.0	-3.7	1.1	-0.4	54.8	11.2	-39.5	-0.3	1.3
Plant fibres (10,817)	-7.0	-12.1	-16.1	-1.3	-1.1	33.2	-1.0	-15.4	-0.5	10.7
Veg. oil, fats (20)[a]	-2.7	-10.2	26.8	-2.0	-6.0	2.8	14.9	-4.5	-1.3	-0.9
Processed rice (6)[a]	0.2	-7.9	18.0	19.0	1.1	8.3	-0.7	-4.5	-2.4	-11.3
Other foods (181)[a]	-12.4	1.4	3.1	0.9	0.1	-0.5	5.0	3.6	0.4	-0.1
Tex&clothing (314)[a]	-5.4	8.7	3.6	2.6	2.4	-12.1	-0.5	-10.1	-0.1	-0.4

(b) Exports by region as a percent of their total production of selected products

	Japan	China	Rest of East Asia	India	Rest of South Asia	North America	Southern Cone	Western Europe	South Africa	Rest of Sub-Saharan Africa
Paddy rice	0.0	0.0	0.4	0.6	0.4	22.1	0.1	17.1	27.2	0.0
Coarse grain	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
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

[a] The value of world exports in US$ billions is shown in parentheses.
[b] For space reasons regions 1, 3, 9, 11, 13, and 16 of Table 4 are omitted from this table.

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

Table 4. Regions and sectors used in the five GTAP model analyses in Section 2.1

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

[a] Hong Kong, Singapore, South Korea and Taiwan

Table 5. Scenario 1: Effects of selected regions[a] adopting GM cotton

(a) Effects on production, domestic prices and trade (percentage changes)

	North America	Japan	China	India	Rest of South Asia	Western Europe	Sub-Saharan Africa
Production							
Plant-based fibres	5.4	-5.7	3.8	1.1	3.4	-6.3	-5.5
Textiles & clothing	0.1	-0.3	2.7	0.0	-0.2	-0.4	-0.1
Market prices							
Plant-based fibres	-4.8	-0.4	-5.4	-5.9	-5.2	-0.7	-0.6
Textiles & clothing	-0.2	-0.0	-0.5	-0.1	-0.1	-0.0	-0.1
Exports[b]							
Plant-based fibres	13.4	-17.3	18.8	31.1	17.7	-10.7	-14.7
Textiles & clothing	0.2	-1.2	4.1	-0.3	-0.4	-0.7	0.2
Imports[b]							
Plant-based fibres	-2.5	0.1	-4.6	-13.1	-5.3	-1.1	4.4
Textiles & clothing	-0.0	1.3	-0.5	0.6	0.3	0.1	0.3

(b) Effects on regional economic welfare

	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	350	6	-130	462
Western Europe	140	91	37	0
Japan	107	24	70	0
Other high-income[c]	19	-4	21	0
China	389	57	0	375
India	416	33	-4	385
Rest of South Asia	136	14	-3	123
Sub-Saharan Africa	-5	14	-21	0
Other developing and transition economies	177	-4	31	150
WORLD	1727	230	0	1497

[a] North America, Southern Cone, China and South Asia. For space reasons, results numerous regions of Table 4 are omitted from this table.
[b] Includes intra-regional trade.
[c] Newly industrialized Asia, Australia and New Zealand.

Source: Nielsen and Anderson's (2000c) GTAP model results.

Table 6. Scenario 2: Effects of selected regions[a] adopting GM rice

(a) Effects on production, domestic prices and trade (percentage changes)

	North America	China	Rest of East Asia	India	Rest of South Asia	Western Europe	Sub-Saharan Africa
Production							
Paddy rice	1.8	0.3	2.0	0.3	0.1	-11.5	-0.3
Processed rice	-5.2	0.3	2.4	6.8	-3.1	-1.5	-3.7
Domestic prices							
Paddy rice	-5.5	-6.0	-6.7	-7.2	-7.1	-0.9	-0.1
Processed rice	-0.3	-2.7	-4.5	-3.9	-1.8	-0.4	-0.2
Exports[b]							
Paddy rice	10.8	33.6	22.5	28.8	31.7	-23.7	-25.9
Processed rice	-10.2	4.1	10.7	6.8	-5.2	-3.9	-11.6
Imports[b]							
Paddy rice	-0.9	-0.1	-8.9	-25.5	-22.4	-0.3	22.2
Processed rice	9.2	5.5	-5.4	4.4	-1.6	0.0	8.0

(b) Effects on regional economic welfare

	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	-30	8	-126	76
Western Europe	295	284	14	0
Other high-income[c]	1427	180	124	1122
China	1715	226	24	1489
Rest of East Asia	804	-232	-87	1120
India	1178	140	-46	1088
Rest of South Asia	389	53	5	328
Sub-Saharan Africa	21	5	15	0
Other developing and transition economies	422	101	77	241
WORLD	6220	765	0	5466

[a] North America, China, Rest of East Asia, India, and Rest of South Asia. For space reasons, results for numerous regions in Table 4 are omitted from this table.
[b] Includes intra-regional trade.
[c] Japan, newly industrialized Asia, Australia and New Zealand.

Source: Nielsen and Anderson's (2000c) GTAP model results.

Table 7. Scenario 3: Effects of selected regions[a] adopting GM maize and soybean

(a) Effects on production, domestic prices and trade (percentage changes)

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

(b) Effects on regional economic welfare

	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	2,624	-137	-1,008	3,746
Southern Cone	826	120	-223	923
China	839	113	66	672
India	1,265	182	-9	1,094
Western Europe	2,010	1,755	253	0
Sub-Saharan Africa	-9	-2	-9	0
Other high-income[c]	1,186	554	641	0
Other developing and transition econs.	1,120	171	289	673
WORLD	9,859	2,756	0	7,108

[a] North America, Mexico, Southern Cone, China, Rest of East Asia, India, and South Africa. For space reasons, results for numerous regions in Table 4 are omitted from this table.

[b] Includes intra-regional trade.

[c] Japan, newly industrialized Asia, Australia and New Zealand.

Source: Nielsen and Anderson's (2000b) GTAP model results.

Table 8. Scenario 4: Effects of selected regions[a] adopting GM maize and soybean *plus* Western Europe bans imports of those products from GM-adopting regions

(a) Effects on production, domestic prices and trade (percentage changes)

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

Table 8. Scenario 4: continued

(b) Effects on regional economic welfare

	Equivalent Variation (EV)	Decomposition of welfare results (US$ million pa):		
	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
Western Europe	-4,334	-4,601	257	0
Sub-Saharan Africa	42	5	38	0
Other high-income[c]	1,371	592	782	0
Other developing and transition econs.	1,296	101	531	672
WORLD	3,419	-3,541	0	6,966

[a] North America, Mexico, Southern Cone, China, Rest of East Asia, India, and South Africa. For space reasons, results for numerous regions in Table 4 are omitted from this table.
[b] Includes intra-regional trade.
[c] Japan, newly industrialized Asia, Australia and New Zealand.

Source: Nielsen and Anderson's (2000b) GTAP model results.

Table 9. Scenario 5: Effects of selected regions[a] adopting GM maize and soybean *plus* partial shift of Western European preferences away from imports of GM products

(a) Effects on production, domestic prices and trade (percentage changes)

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

Table 9. Scenario 5: continued

(b) Effects on regional economic welfare

	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
Western Europe	715	393	319	0
Sub-Saharan Africa	-5	0	-7	0
Other high-income[c]	1,233	567	674	0
Other developing and transition econs.	1,120	168	293	673
WORLD	8,503	1,428	0	7,081

[a] North America, Mexico, Southern Cone, China, Rest of East Asia, India, and South Africa. For space reasons, results for numerous regions in Table 4 are omitted from this table.
[b] Includes intra-regional trade.
[c] Japan, newly industrialized Asia, Australia and New Zealand.

Source: Nielsen and Anderson's (2000b) GTAP model results.

Table 10. Assumed initial shares of GM crop varieties used in the NRT model

(% of total GM-potential-crop production)

	High-income Asia[a]	Low-income Asia	North America	South America	Western Europe	Sub-Saharan Africa	Rest of World
GM coarse grain	10	40	40	40	10	10	10
GM oilseeds	15	60	60	90	10	10	10

[a] Includes Japan, East Asia's NICs, Australia and New Zealand.

Source: Nielsen, Robinson and Thierfelder (2000), based on James (1999) and USDA (2000).

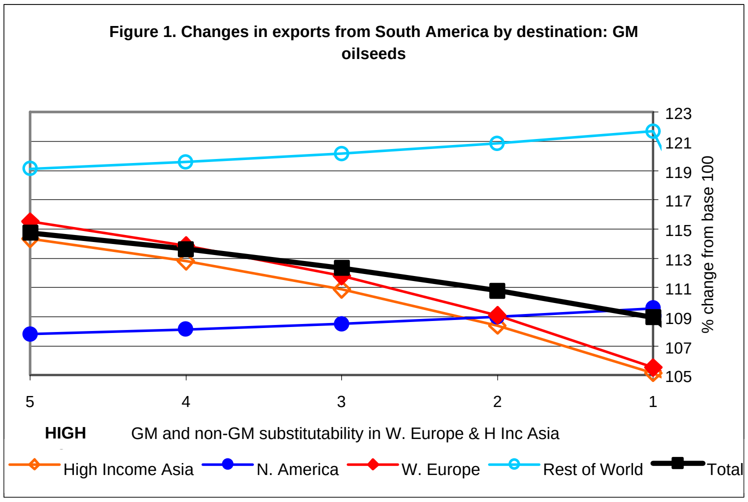


Figure 1. Changes in exports from South America by destination: GM oilseeds
% change from base 100
HIGH
GM and non-GM substitutability in W. Europe & H Inc Asia
High Income Asia
N. America
W. Europe
Rest of World
Total

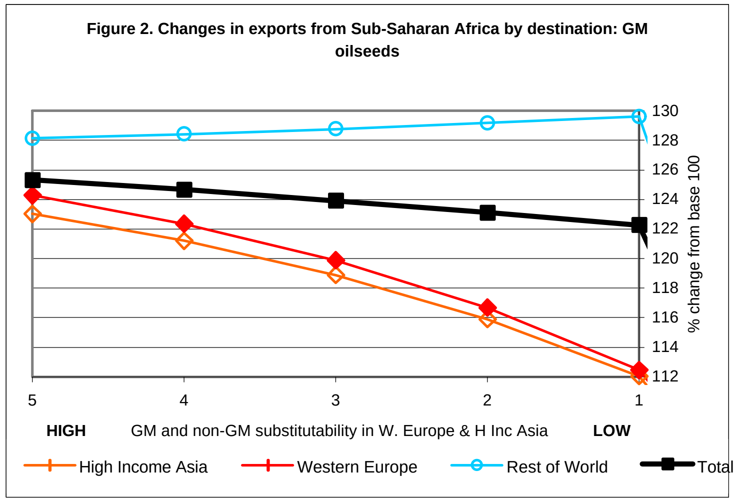


Figure 2. Changes in exports from Sub-Saharan Africa by destination: GM oilseeds
% change from base 100
HIGH
GM and non-GM substitutability in W. Europe & H Inc Asia
LOW
High Income Asia
Western Europe
Rest of World
Total

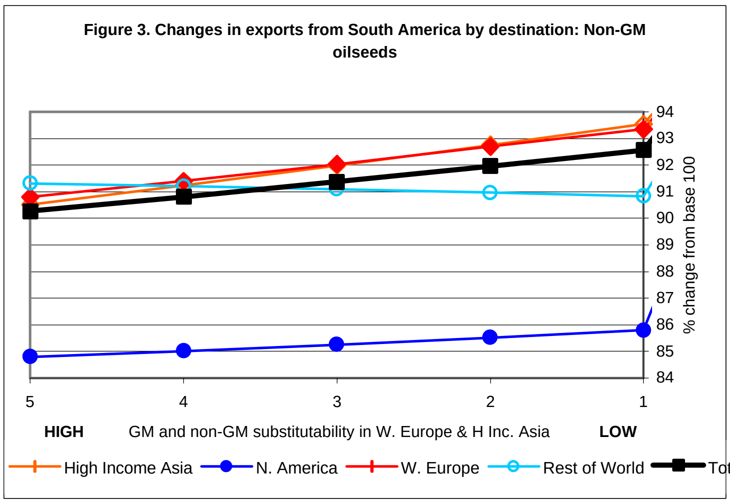


Figure 3. Changes in exports from South America by destination: Non-GM oilseeds
% change from base 100
HIGH
GM and non-GM substitutability in W. Europe & H Inc. Asia
LOW
High Income Asia
N. America
W. Europe
Rest of World

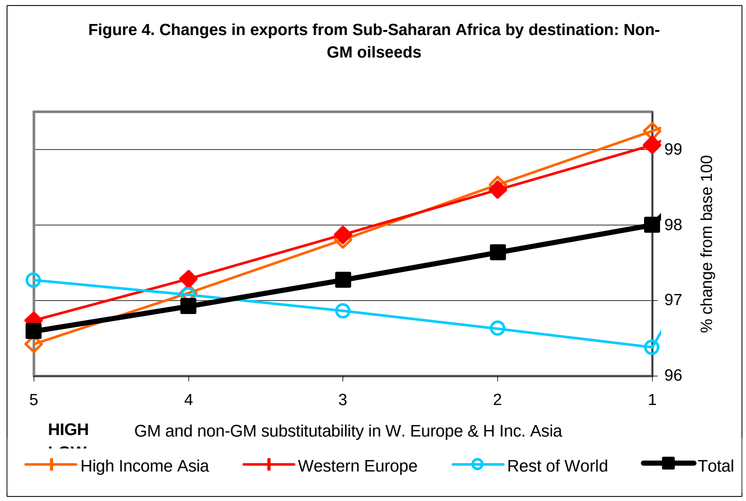


Figure 4. Changes in exports from Sub-Saharan Africa by destination: Non-GM oilseeds
% change from base 100
HIGH
GM and non-GM substitutability in W. Europe & H Inc. Asia
High Income Asia
Western Europe
Rest of World
Total

Figure 5. Changes in imports into South America by source: GM coarse grains

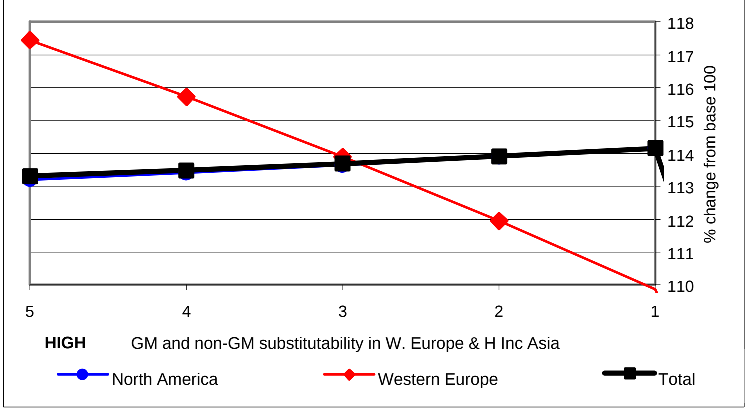


Figure 6. Changes in imports into Sub-Saharan Africa by source: GM coarse grains

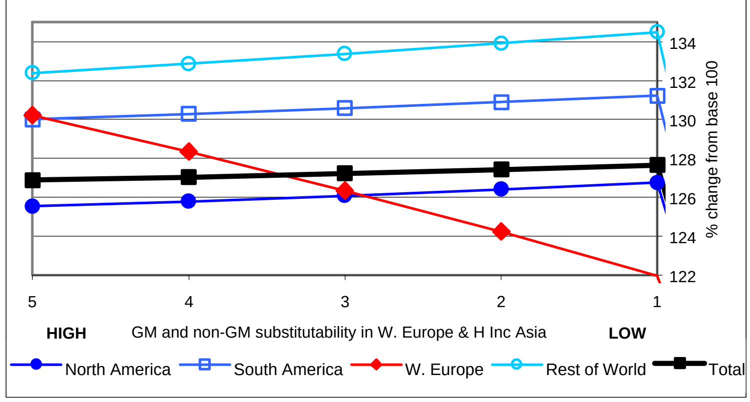


Figure 7. Changes in imports into South America by source: Non-GM coarse grains

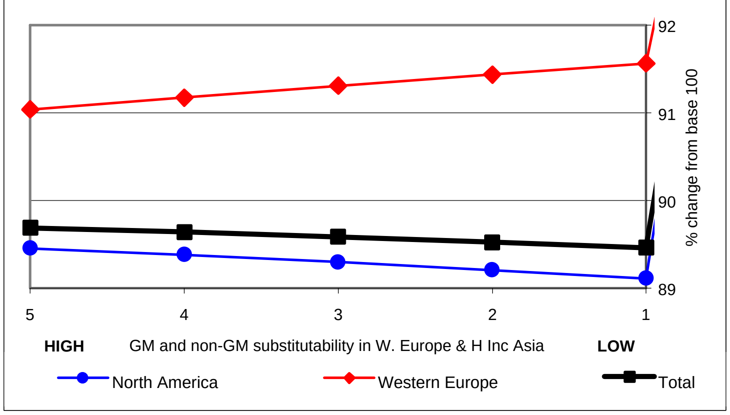


Figure 8. Changes in imports into Sub-Saharan Africa by source: Non-GM coarse grains

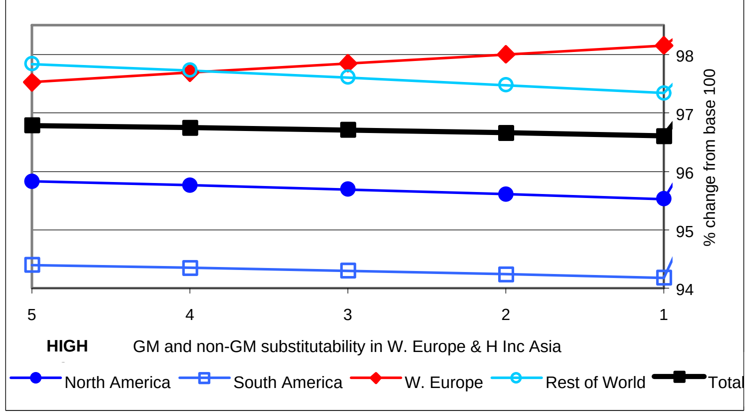


Figure 9. Changes in imports into Low Income Asia by source: GM oilseeds

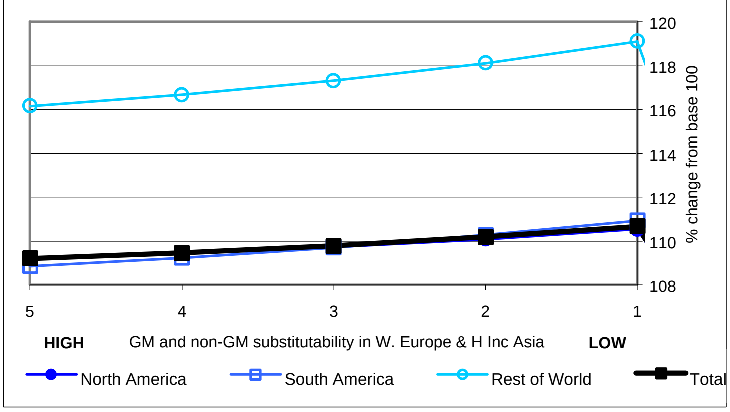


Figure 10. Changes in imports into Low Income Asia by source: GM coarse grains

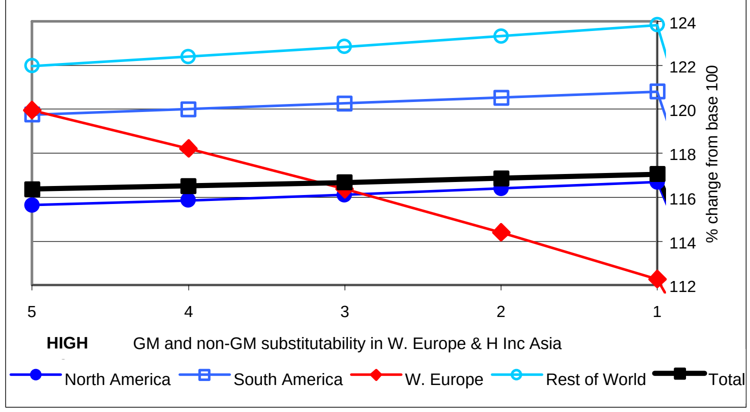


Figure 11. Changes in imports into Low Income Asia by source: Non-GM oilseeds

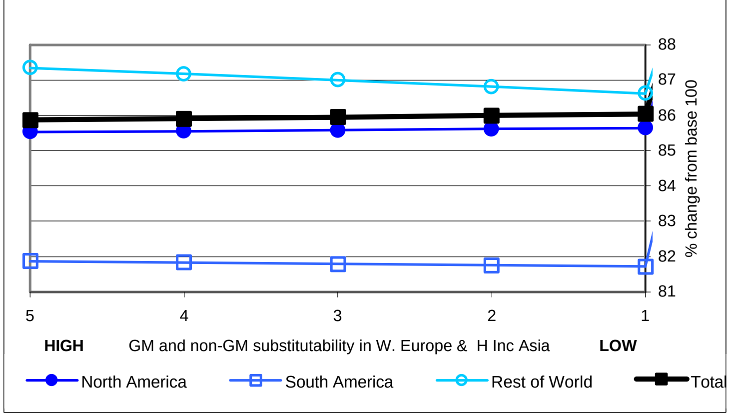


Figure 12. Changes in imports into Low Income Aisa by source: Non-GM coarse grains

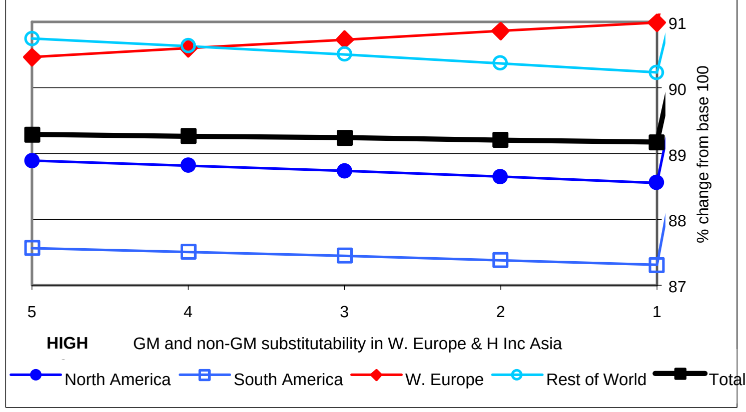


Figure 13. Ratio of non-GM to GM prices of oilseeds

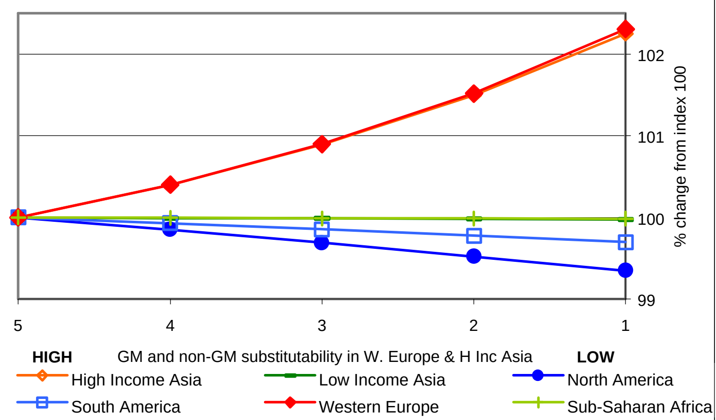


Figure 14. Ratio of non-GM to GM prices of coarse grains

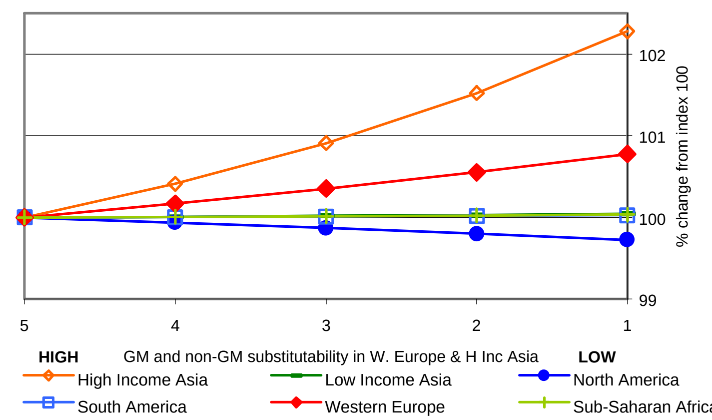
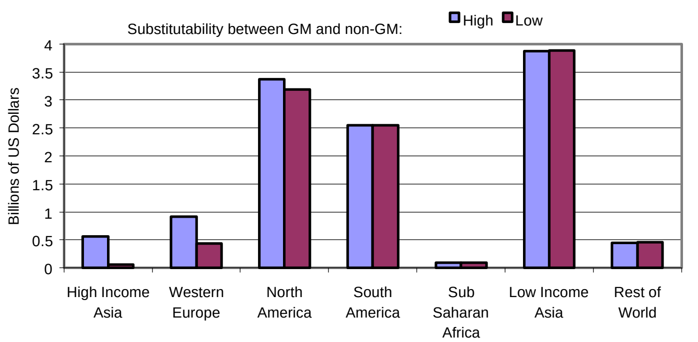


Figure 15. Changes in total absorption for different degrees of substitutability between GM & non-GM crops in High Income Asia & Western Europe



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