Genetic Engineering and Trade: Panacea or Dilemma for Developing Countries

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ABSTRACT

Advocates of the use of genetic engineering techniques in agriculture contend that this new biotechnology promises increased productivity, better use of natural resources and more nutritious foods. Opponents, on the other hand, are concerned about potentially adverse implications for the environment and food safety. In response to consumer reactions against genetically modified (GM) foods in some countries - particularly in Western Europe - crop production is being segregated into GM and non-GM varieties. This paper investigates how such changes in the maize and soybean sectors may affect international trade patterns, with particular attention given to different groups of developing countries.

1. Introduction

The current debate about the use of genetic engineering in agricultural production reveals substantial differences in perception of the risks and benefits associated with this new biotechnology. Farmers in North America and a few large developing countries such as Argentina, Mexico, and China are rapidly adopting the new genetically modified (GM) crop varieties as they become available, and citizens in these countries are generally accepting this development. Growing genetically modified crop varieties allegedly provides farmers with a range of agronomic benefits, mainly in terms of lower input requirements and hence lower costs to consumers. However, in other parts of the world, especially Western Europe, people are concerned about the environmental impact of widespread cultivation of GM crops and the safety of foods containing genetically modified organisms (GMOs).

In response to the strong consumer reaction against genetically modified foods in Western Europe, and to a certain extent also in Japan, separate production systems for GM and non-GM crops are emerging in the maize and soybean sectors.[1] To the extent that GMO-critical consumers are willing to pay a price premium for non-GM varieties there may be a viable market for these products alongside the new GM varieties. Developing countries – regardless of whether they are exporters or importers of agricultural crops – will be affected by changing consumer attitudes toward GMOs in the developed world. Some developing countries are highly dependent on exporting particular primary agricultural products to GM-critical regions. Depending on the strength of opposition toward GM products in such regions and the costs of segregating production, the developing countries may benefit from segregated agricultural markets, which will have different prices. In principle these countries may choose to grow GM crops for the domestic market and for exports to countries that are indifferent as to GMO content, and to grow GMO-free products for exports to countries where consumers are willing to pay a premium for this characteristic. Such a market development would be analogous to the niche markets for organic foods. Other developing countries are net importers and can benefit from the widespread adoption of GM technology. Assuming consumers in those countries are not opposed to GM products, they will benefit from lower world market prices.[2] If changing consumer preferences have an effect on world agricultural markets, this latter outcome may also be affected.

This paper offers a preliminary quantitative assessment of the impact that consumers' changing attitude toward GMOs might have on world trade patterns, with emphasis on the developing countries. For this purpose, a multi-regional computable general equilibrium (CGE) model is used. The next section provides a brief overview of the current status of genetically modified crops in agricultural production and some key economic indicators illustrating the importance of the selected GM-potential sectors in the different regions represented in the model. Section three presents the main features of the multi-regional CGE model and describes the scenarios. The empirical results are examined in section four, and a final section identifies areas for future research and concludes.

[1] Another response to the growing concerns about GMOs has been the agreement on the Cartagena Biosafety Protocol, which was concluded in January 2000, but is yet to be ratified. See Nielsen and Anderson (2000) for a discussion of the relationship between this Protocol and the WTO rules, and an empirical analysis of the world trade and welfare effects of a Western European ban on GMO imports.

[2] Although acknowledging the fact that there may be environmental risks and hence externality costs associated with GM crops, they are impossible to estimate at this time and this paper makes no attempt to incorporate such effects in the empirical analysis.

2. Genetic engineering in agriculture[3]

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 is a new biotechnology that enables direct manipulation of genetic material (inserting, removing or altering genes).[4] 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 gene, 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.

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 and representing a considerable expansion from less than 3 million hectares in 1996.[5] Cultivation of transgenic crops has so far been most widespread in the production of soybeans and maize, accounting for 54% and 28% of total commercial transgenic crop production in 1999, respectively. Cotton and rapeseed each made up 9% of transgenic crop production in 1999, with the remaining GM crops being tobacco, tomato, and potato (James, 1999, 1998, 1997). To date, genetic engineering in agriculture has mainly been used to modify crops so that they have improved *agronomic* traits such as tolerance to specific chemical herbicides and resistance to pests and diseases. Development of plants with enhanced agronomic traits aims at increasing farmer profitability, typically by reducing input requirements and hence costs. 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.

The United States holds almost three-fourths of the total crop area devoted to genetically modified crops. Other major GM-producers are Argentina, Canada, and China. At the national level, the largest shares of genetically engineered crops in 1999 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]. The USDA (2000) figures for the United States are similar in magnitude: it is estimated that 40% of maize and 60% of soybean areas harvested in 1999 were genetically modified. 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.[6] 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

[3] The first part of this section draws on Nielsen and Anderson (2000).
[4] 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.
[5] Calculations are based on the FAOSTAT statistical database accessible at www.fao.org.
[6] 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.

and depend on a range of factors such as crop type, location, magnitude of pest attacks, disease occurrence, and weed intensity.

In developing countries one of the main reasons for low crop yields 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. 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 weather conditions and on poor-quality soils. 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."

GM-potential crops in world production and trade

The data used in the empirical analysis described below are from version 4 of the Global Trade Analysis Project (GTAP) database, which is estimated for 1995 (McDougall, Elbehri & Truong, 1998). As discussed above, the main crops that have been genetically modified to date are soybeans and maize. The sectoral aggregation of this database therefore comprises a cereal grains sector (which includes maize but not wheat and rice) and an oilseeds sector (which includes soybeans) to reflect these two GM-potential crops. The livestock, meat & dairy, vegetable oils & fats, and other processed food sectors are also singled out, since they are important demanders of oilseeds and cereal grains as intermediate inputs to production.

In terms of the importance of the two GM-potential crops in total primary agriculture, Table 1 shows that the cereal grains sector accounts for almost 20% of North American agricultural production but less than 7% of agricultural production in all other regions. Oilseed production accounts for 6-7% of agricultural production in low-income Asia, North and South America, and Sub-Saharan Africa, while it's share is small in both Western Europe and high-income Austral-Asia. In the three high-income regions, it is evident from Table 2 that cereal grains and oilseeds are almost entirely used as intermediate inputs (into further food processing or as livestock feed). In the developing regions, a much larger share of output is used for final consumption, and these shares vary substantially across the regions.

Table 1. Agricultural production structures, 1995

	High-income AusAsia	Low-income Asia	North America	South America	Western Europe	Sub-Saharan Africa	Rest of World
Cereal grains*	1.5	4.9	18.5	6.8	5.3	2.8	6.6
Oilseeds	0.5	6.4	7.1	5.8	1.5	6.4	2.3
Wheat	1.6	5.0	5.7	3.5	5.1	4.3	7.6
Other crops	63.6	55.9	23.3	52.6	33.6	69.2	43.9
Livestock	32.7	27.7	45.4	31.3	54.4	17.3	39.7
Total agric.	100.0	100.0	100.0	100.0	100.0	100.0	100.0

* Cereal grains other than wheat and rice (included in 'other crops').
Source: Multi-region GMO model database derived from GTAP version 4 data.

Table 2 also shows that for most regions, production of these two crops is typically sold domestically. An important exception is the North American region, which exports 17% of its cereal grains and 36% of its oilseed production. South America also relies heavily on export markets for sales of its oilseeds. In terms of dependence on imports, Western Europe obtains as much as 50% of its total oilseed use from abroad. The high–income Austral-Asia region is also heavily dependent on imports of both cereal grains and oilseeds. North America is by far the dominant exporter of both crops, although South America also is an important exporter of oilseeds. Furthermore, Western Europe is the main importer of oilseeds and high-income Austral-Asia is the main importer of cereal grains and a large importer of oilseeds.

Table 2. Intermediate demands, trade dependencies and world trade shares, 1995

	High-income AusAsia	Low-income Asia	North America	South America	Western Europe	Sub-Saharan Africa	Rest of World
Share of intermediate demand in total final demand (%)							
Cereal grains*	98.7	47.3	97.0	71.6	96.0	26.8	63.4
Oilseeds	87.8	65.4	96.9	81.8	94.5	57.2	78.2
Share of exports in total production (%)							
Cereal grains*	2.3	0.6	17.4	3.3	7.7	0.5	0.4
Oilseeds	3.4	1.7	35.8	13.2	5.5	1.1	1.1
Share of imports in total absorption (%)							
Cereal grains*	19.2	6.7	0.1	9.1	5.2	8.3	12.3
Oilseeds	66.0	2.0	1.0	7.6	48.0	0.5	12.9
Share of exports in world trade (%)							
Cereal grains*	1.0	1.2	78.2	4.5	12.0	0.6	2.5
Oilseeds	0.5	4.5	68.0	16.7	2.7	1.7	5.9
Share of imports in world trade (%)							
Cereal grains*	43.0	13.8	0.5	13.1	8.2	1.4	20.0
Oilseeds	31.3	5.3	1.2	9.0	45.5	0.2	7.5

* Cereal grains other than wheat and rice (included in 'other crops').
Source: Multi-region GMO model database derived from GTAP version 4 data.

Table 3. Export market shares for cereal grains and oilseeds, 1995

	High-income AuAsia	Low-income Asia	North America	South America	Western Europe	Sub-Saharan Africa	Rest of World	Total
Cereal grains*								
Austral-Asia	0	36.2	0.2	29.0	4.5	0.2	29.9	100.0
Low-incm Asia	45.2	0	0.8	2.2	8.8	1.4	41.6	100.0
North America	50.7	12.2	0	15.2	7.9	0.9	13.0	100.0
South America	4.5	28.7	4.3	0	20.5	1.4	40.6	100.0
West Europe	16.5	15.8	2.4	5.2	0	1.8	58.2	100.0
Sub-Sh Africa	13.5	2.7	0.0	1.1	30.1	0	52.6	100.0
Rest of World	21.0	26.5	0.4	8.6	28.6	14.8	0	100.0
Oilseeds								
Austral-Asia	0	21.1	9.6	0.6	46.1	1.5	21.1	100.0
Low-incm Asia	48.3	0	3.6	0.2	28.8	0.6	18.5	100.0
North America	39.1	6.0	0	12.3	38.8	0.0	3.8	100.0
South America	9.0	4.1	4.5	0	74.5	0.5	7.4	100.0
West Europe	0.4	7.1	2.5	12.8	0	0.4	76.9	100.0
Sub-Sh Africa	25.2	0.3	3.4	0.1	33.0	0	38.0	100.0
Rest of World	10.4	4.9	1.5	5.1	77.5	0.7	0	100.0

* Cereal grains other than wheat and rice (included in 'other crops').
Source: Multi-region GMO model database derived from GTAP version 4 data.

The bilateral export flows show that half of North American cereal grain exports are destined for the high-income Austral-Asian region, and only 8% go to Western Europe (Table 3).

Eighty percent of North American exports of oilseeds are split equally between these two destination regions, while South American exports of oilseeds are dominated by Western Europe as the receiving region. In both crops, imports into Austral-Asia come largely from North America (Table 4). For Western Europe, 76% of this region's cereal grains imports and 58% of oilseed imports are from North America – the rest coming mainly from South America and the 'Rest of World'.

Table 4. Import market shares for cereal grains and oilseeds, 1995

	High-income AuAsia	Low-income Asia	North America	South America	Western Europe	Sub-Saharan Africa	Rest of World	Total
Cereal grains*								
Austral-Asia	0	1.3	92.2	0.5	4.6	0.2	1.2	100.0
Low-incm Asia	2.5	0	69.4	9.3	13.8	0.1	4.9	100.0
North America	0.4	2.0	0	38.3	57.4	0.0	1.9	100.0
South America	2.1	0.2	91.1	0	4.8	0.1	1.7	100.0
West Europe	0.5	1.3	75.9	11.2	0	2.1	8.9	100.0
Sub-Sh Africa	0.1	1.2	50.3	4.5	16.1	0	27.7	100.0
Rest of World	1.4	2.5	50.6	9.1	34.8	1.5	0	100.0
Oilseeds								
Austral-Asia	0	7.0	84.9	4.8	0.0	1.4	1.9	100.0
Low-incm Asia	2.0	0	76.0	12.9	3.6	0.1	5.4	100.0
North America	4.1	13.9	0	63.9	5.7	4.9	7.4	100.0
South America	0.0	0.1	92.6	0	3.9	0.0	3.3	100.0
West Europe	0.5	2.9	58.0	27.3	0	1.3	10.0	100.0
Sub-Sh Africa	4.5	17.2	3.7	45.9	5.7	0	23.0	100.0
Rest of World	1.4	11.1	34.3	16.5	27.9	8.8	0	100.0

* Cereal grains other than wheat and rice (included in 'other crops').
Source: Multi-region GMO model database derived from GTAP version 4 data.

3. Global CGE model and scenarios[7]

The modeling framework used in this analysis is a multi-region computable general equilibrium (CGE) model consisting of seven regions, which are inter-connected through bilateral trade flows: High-Income Austral-Asia, Low-Income Asia, North America, South America, Western Europe, Sub-Saharan Africa and the Rest of World. [8] For the purpose of describing the model, it is useful to distinguish between the individual regional models and the multi-region model system as a whole, which determines how the individual regional models interact. When the model is actually used, the *within* region and *between* region relationships are of course solved simultaneously. Each regional CGE model is a relatively standard trade-focused CGE model, with ten sectors: five of which are primary agriculture, three are food-processing industries, and the remaining two comprise aggregate manufactures and services. Each regional model has five factors of production: skilled and unskilled labor, capital, land, and natural resources. For each sector, output supply is specified as a constant elasticity of substitution (CES) function over value-added, and intermediate inputs are initially demanded in fixed proportions. Profit-maximization behavior by producers is assumed, implying that each factor is demanded so that marginal revenue product equals marginal cost, given that all factors are free to adjust. Each regional economy contains domestic market

[7] The model description draws in part on Lewis, Robinson and Thierfelder (1999).
[8] Note that the bilateral trade figures that link these regions are net of trade within the region, and that in the model intra-regional trade is treated as another source of domestic demand.

distortions in the form of sectorally differentiated indirect consumption and export taxes, as well as household income taxes. There is a single representative household in each economy, which demands commodities according to fixed expenditure shares, maximizing a Cobb-Douglas utility function.

As in other CGE models, it is only relative prices that are determined – the absolute price level is set exogenously. In this model, the aggregate consumer price index in each sub-region acts as the *numeraire*. A convenient consequence of this specification is that solution wages and incomes are in real terms. The solution exchange rates in each region are also in real terms and can be seen as equilibrium price-level-deflated exchange rates, using the country consumer price indices as deflators. The international *numeraire* is defined by fixing the exchange rate for North America. World prices are converted into domestic currency using the exchange rate, including any tax or tariff components. Cross-trade price consistency is imposed, so that the world price of country A's exports to country B are the same as the world price of country B's imports from country A.

Sectoral export-supply and import-demand functions are specified for each region. As is common in other CGE models, the multi-regional model used in this analysis specifies that goods produced in different countries are imperfect substitutes. On the supply side, sectoral output is a constant elasticity of transformation (CET) aggregation of total supply to all export markets and supply to the domestic market. The allocation between export and domestic markets is determined by the maximization of total sales revenue. On the demand side the assumption of product differentiation is combined with the almost ideal demand system (AIDS) to determine the input aggregation equation. Although not used in this application, this specification allows for non-unitary income elasticities of demand for imports and pairwise substitution elasticities that vary across countries (unlike the more typical CES specification). The macro closure of the model is relatively simple. First of all, aggregate real investment and government consumption are assumed to be fixed. Secondly, since the trade balances in each region also are assumed fixed with the real exchange rates adjusting to equilibrate aggregate exports and imports, the macro closure of the model is achieved by allowing domestic savings for each region adjust to achieve macro equilibrium.

The model applied here differs from the "standard" GTAP model (Hertel, 1997) in a number of aspects. First, the present model uses CET functions to explicitly treat the export side symmetrically with the import side, so that goods destined for export markets are imperfect substitutes with goods supplied to the domestic market. The standard GTAP model only assumes imperfect substitutability on the import side, which implies that the domestic prices of exportables are very sensitive to foreign demand and other changes in world markets. Second, the AIDS rather than CES import demand functions principally allows for a more flexible treatment of substitutability between goods originating from different types of regions. A third difference is that the GTAP model is specified as a linear approximation to a nonlinear CGE model and is most often solved in terms of rates of change. In contrast, the model applied here is solved in levels and hence involves no approximation error.

Model extensions

The model is amended by splitting the maize and soybeans sectors into GM and non-GM varieties, thereby allowing for a choice between the two in production and consumption. In the base data, it is assumed that all regions in the model initially produce some of both the GM and non-GM varieties of oilseeds and cereal grains. Specifically, the assumed shares are as shown in Table 5, adapted from estimates provided in James (1999) and USDA (2000).

Table 5. Assumed initial shares of GM varieties in total GM-potential production

	High-income AusAsia	Low-income Asia	North America	South America	Western Europe	Sub-Saharan Africa	Rest of World
GM grains*	10	40	40	40	10	10	10
GM oilseeds	15	60	60	90	10	10	10

* Cereal grains other than wheat and rice (included in 'other crops').

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. The destination structures of exports are also initially assumed to be the same. In the model we endogenize the decision of producers and consumers to use GM vs. non-GM varieties in their production and final demand, respectively. 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 cereal grains, 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 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 as well.

In the following the modeling of the endogenous input-output choice is illustrated. The endogenous final demand choice is incorporated into the model in an analogous manner for the representative household. The input-output choice is endogenized for four demanders of cereal grains and oilseeds: livestock, meat & dairy, vegetable oils & fats, and other processed food sectors. The choice between GM and non-GM varieties is determined by a CES function (here shown for intermediate demand for oilseeds, *osd*):

$$IO(osd,j,k) = a(osd,j,k) \cdot \left[a_G(gm\_osd,j,k) \cdot IO(gm\_osd,j,k)^{-r_G(osd,k)} + a_G(ng\_osd,j,k) \cdot IO(ng\_osd,j,k)^{-r_G(osd,k)} \right]^{-1/r_G(osd,k)}$$

where *IO(osd,j,k)* is sector *j* in region *k*'s intermediate demand for oilseeds, and *a(osd,j,k)* is the CES intermediate demand shift parameter. The exponent is defined by the elasticity of substitution between GM and non-GM varieties, $\sigma_G(osd,j,k)$: $\rho_G(osd,j,k) = [1/\sigma_G(osd,j,k)] - 1$. The CES function share coefficients are $\alpha_G(gm\_osd,j,k)$ and $\alpha_G(gm\_osd,j,k)$. In the model, the following first-order conditions are included for the four GM-using production sectors mentioned above in all regions – one set of equations for oilseeds (shown here as *osd*) and another for cereal grains:

$$\frac{IO(gm\_osd,j,k)}{IO(ng\_osd,j,k)} = \left[\frac{PC(ng\_osd,k)}{PC(gm\_osd,k)} \cdot \frac{a_G(gm\_osd,j,k)}{a_G(ng\_osd,j,k)} \right]^{1/(1+r_G(osd,k))}$$

The adding-up constraints are included as follows (again, shown here for *osd*):

$$IO0(gm\_osd,j,k) + IO0(ng\_osd,j,k) = IO(gm\_osd,j,k) + IO(ng\_osd,j,k)$$

The input-output coefficients in all other sectors are assumed fixed, as are the input-output coefficients for the four above-mentioned sectors vis à vis other intermediate inputs.

Design of experiments

The available estimates of agronomic and hence 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, Josling, Bullock, Unnevehr, Rosegrant & Hill (1999), for example, suggest that glyphosate-resistant soybeans may generate a total production cost reduction of 5%, and their scenarios have genetically modified corn increasing yields by between 1.8% and 8.1%. For present purposes, the GM-adopting sectors are assumed to make more productive use of the primary factors of production as compared with the non-GM sectors. I.e., the same level of output can be obtained using fewer primary factors of production, or a higher level of output can be obtained using the same level of production factors. In our scenarios, the GM oilseed and GM cereal grain sectors in all regions are assumed to have a 10% higher level of factor productivity as compared with their non-GM (conventional) counterparts.

We introduce the factor productivity shock in the GM sectors against five different base models, which differ in terms of the degree to which consumers and producers in Western Europe and High-Income Austral-Asia find GM and non-GM products substitutable. To start with, it is assumed that the elasticity of substitution between GM and non-GM varieties is high and equal in all regions. Specifically, σ_G(“oilseeds”, k) = σ_G(“cereal grains”, k) = 5.0 for all regions k. Then, in order to reflect the fact that citizens in Western Europe and High-Income Austral-Asia (particularly in Japan) 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 poor 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 those production systems. Table 6 provides an overview of the setup of experiments.

Table 6. Stepwise design of scenarios: substitutability between GM and non-GM

High-Income Austral-Asia and Western Europe	All other regions
Base models	***Base models***
The high substitutability between GM and non-GM varieties in production in the first base model run: σ_G(“oilseeds”, k) = σ_G(“cereal grains”, k) = **5.0** is reduced step-wise in four subsequent base model runs, with the last base run having σ_G(“oilseeds”, k) = σ_G(“cereal grains”, k) = **1.0**	High substitutability between GM and non-GM varieties in production in all base model runs: σ_G(“oilseeds”, k) = σ_G(“cereal grains”, k) = **5.0**
Experiment	***Experiment***
Total factor productivity in GM cereal grain and oilseed sectors increased by **10%**.	Total factor productivity in GM cereal grain and oilseed sectors increased by **10%**.

Expected results

Initially, the more effective GM production process will cause labor, 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 responsive to this price reduction, this cost-reducing technology will lead to increased production and potentially higher returns to factors. 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 (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 will 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, applying genetic engineering techniques to wheat breeding is apparently more complex compared with 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.

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, and is computed empirically in this 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, producers and 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 *per se* (using an appropriate welfare measure).

4. Results of empirical analysis

The expected increase in production of the genetically modified crops is borne out in the empirical results for all regions of the model as a direct consequence of the assumed increase in factor productivity and hence lowers costs of production. Due to the increased supply of GM commodities, demand and production of conventional cereal grains and oilseeds declines. In the following the effects on bilateral trade flows will be examined to provide an indication as to how the developing countries will be affected by the segregation of global oilseed and cereal grain markets in the light of changing preferences in Western Europe and High-Income Austral-Asia. Three developing country regions are in focus: South America, Sub-Saharan Africa, and Low-Income Asia. The first two regions are initially net exporters of oilseeds and net importers of cereal grains (other than rice and wheat). Low-Income Asia is a net importer of both crops.

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. Exports are directed away from the GM critical regions and spread evenly over the other importing regions. Oilseed exports from South America are initially more dependent on the GM critical regions as compared with oilseed exports from Sub-Saharan Africa. Therefore, Figures 1 and 2 show that the adjustment in total GM oilseed exports is relatively larger in the first region. 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 in 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. This is because a higher price is obtained on non-GM products relative to GM varieties, and given a high but not perfect substitutability between the two varieties, there is scope for selling both in the North American market.

Both South America and Sub-Saharan Africa depend on imports for 8-9% of their total cereal grain absorption. However, in terms of origins, South America depends almost entirely on North America for its imports, while imports into Sub-Saharan Africa come from both North America (50%), Western Europe (16%), and the Rest of World (28%). Because citizens in these regions are assumed to be uncritical of GMO content, *total* GM cereal grain imports increase as preferences in Western Europe and High-Income Austral-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. Imports 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 non-GM import prices as preferences shift.

Low-Income Asia is a net importer of both oilseeds and cereal grains and the bulk of these foreign crops come from North and South America. Figures 9 and 10 show that total imports of GM crops into this region increase as preferences turn against GMOs in Western Europe and High-Income Austral-Asia. This is because the redirection of GM export crops means increased supplies on fewer markets and hence prices drop 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 come from the Americas. In terms of bilateral flows, there are marginal increases in non-GM imports from Western Europe and High-Income Austral-Asia since imports from these regions must compete with GM crops in a GM-indifferent market.

In sum, the bilateral trade results show that trade diversion is significant. As preferences in High-Income Austral-Asia and Western Europe turn against GM varieties, trade flows are diverted so that *all* markets – whether GM-indifferent or GM-critical – are served appropriately. 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 3.9% and 6.6%, varying across regions, crops, and degrees of demand substitutability in Western Europe and High-Income Austral-Asia. Figures 13 and 14 show that for both crops, the price differential is higher in the developing country regions as compared with the three developed country regions when substitutability is high in all regions. In the GMO critical regions, the price wedges widen 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. Furthermore, in an effort to retain access to the GM critical markets, production of non-GM varieties increases in North America as citizens of those 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 Austral-Asia. Thus it is mainly the productivity differential that seems to be determining the price wedge, not preference shifts in the GM critical regions. With the exception of South American and Sub-Saharan African exports of oilseeds this is because for these particular crops the developing countries are initially net importers. Being indifferent to the GMO content of agricultural products (whether produced domestically or imported) as well as obtaining most of their import from countries that are extensive adopters of GM crops, they gain substantially from lower import prices. Preference shifts in Western Europe and High-Income Austral-Asia do not have much impact on this effect.

Global absorption increases by USD 12 billion when GM cereal 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 Austral-Asia turn against GM varieties, this increase is reduced to USD 11 billion. As Figure 15 shows, three regions are by far the main beneficiaries: South America, North America, and Low-Income Asia. They are all assumed to be intense adopters of the productivity-increasing crop varieties. North America gains as the major producer and exporter of both crops. However, the total absorption gain in this region is reduced by 5% from the high substitutability experiment as a consequence of changing preferences in its important export markets in Western Europe and High-Income Austral-Asia. However, the 'costs' of the preference changes are borne mainly by the GM critical regions themselves, with the gains made in High-Income Austral-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. 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 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.

5. Further research and conclusion

Further research

The present analysis relies on simplifying assumptions about the productivity impact of adopting GM crops. It has been assumed that factor productivity increases by 10% in sectors cultivating GM rather than conventional crops. Improved data would ideally provide information about how the GM productivity effects differ across sectors and regions. Furthermore, some preliminary studies (e.g. Pray, Ma, Huang & Qiao, 2000) indicate that it is a reduction in pesticide and herbicide use that is the main cost-reducing impact of using the prevailing types of GM crops, and hence the modeling of the productivity impact of GM crops should be amended to take account of a more specific effect both in terms of intermediate use and factor use. By assuming that it is only primary factor use that is more efficient and not (perhaps input-specific) intermediate input use, the results presented here may in part be driven by excessive factor re-allocation effects.

The segregation of production and marketing of GM and non-GM varieties of cereal grains and oilseeds in this analysis 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 labeling requirements at national borders. Experience from identity preservation of specialty crops today reveals that this can potentially increase the price of such products by between 5 and 15% (Buckwell, Brookes & Bradley 1999). It is argued by e.g. Frandsen and Nielsen (1999) and Runge and Jackson (1999) that such a cost-price premium will – in a free market, and in the absence of unsympathetic political reactions – emerge on the guaranteed non-GM products. Whether consumers in Western Europe and elsewhere are in fact willing to pay such a premium is yet to be determined empirically. Moreover, consumers may demand supplies of *processed* foods that are guaranteed free from genetically modified organisms. To the extent that testing methods and accompanying labeling 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 the empirical model – that processed foods would also have to be identified as either GMO-inclusive or GMO-free.

Conclusion

The very different perceptions – particularly in North America and Western Europe – concerning the benefits and risks associated with the cultivation and consumption of genetically modified foods are already leading to the segregation of soybean and maize markets and production systems into GM and non-GM lines. By using a global CGE model, this analysis has shown that such a segregation of markets may have substantial impacts on current trade patterns. The model distinguishes between GM and non-GM varieties in the oilseed and cereal grains sectors, and GM crop production is assumed to have higher factor productivity as compared with conventional production methods. The North and South American regions and Low-Income Asia are assumed to be particularly in favor of using GM crops. The effects of this factor productivity increase in the GM sectors are then investigated in an environment where there are increasingly strong preferences *against* GM crops in Western Europe and High-Income Austral-Asia. This change in preferences is modeled by making GM and non-GM crops increasing poor substitutes in demand in these regions.

The empirical results indicate that global markets are able to adjust to this 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-favorable 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 the GM-varieties. An important result of this empirical analysis is that the developing countries are also responsive to these GM preference changes, and redirect their trade flows among partners accordingly. Furthermore, given the existing bilateral trade patterns for these particular crops, the price wedges that arise in the developing countries mainly reflect productivity differences, not preference changes in the developed world. Overall, the regions most receptive to the productivity-enhancing technology gain most in terms of aggregate absorption. It is the citizens of Western Europe and High-Income Austral-Asia that pay the 'costs' of their non-GMO preferences.

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Figure 1. Changes in exports from South America by destination: GM oilseeds

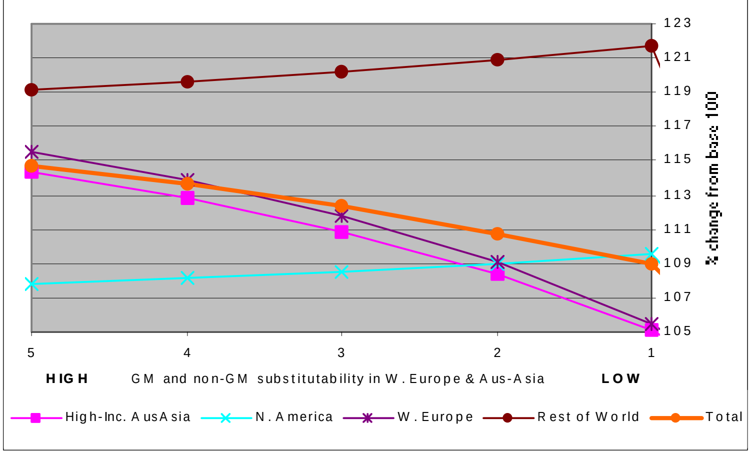


Figure 2. Changes in exports from Sub-Saharan Africa by destination: GM oilseeds

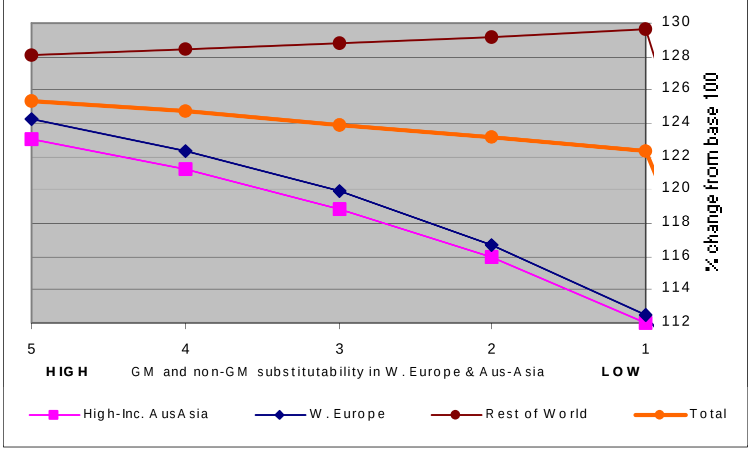


Figure 3. Changes in exports from South America by destination: Non-GM oilseeds

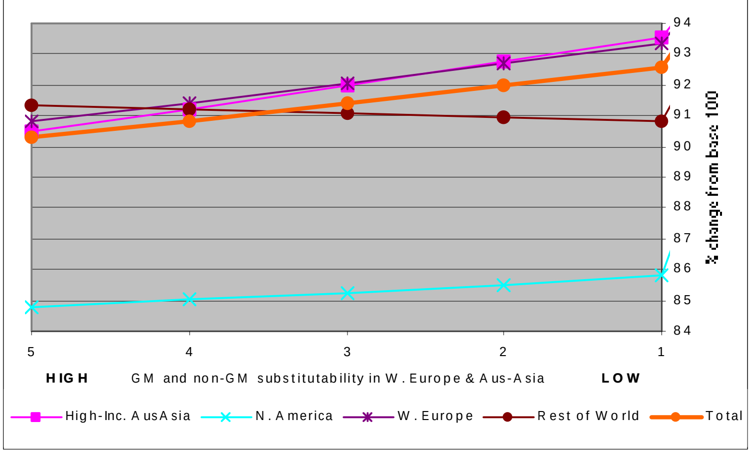


Figure 4. Changes in exports from Sub-Saharan Africa by destination: Non-GM oilseeds

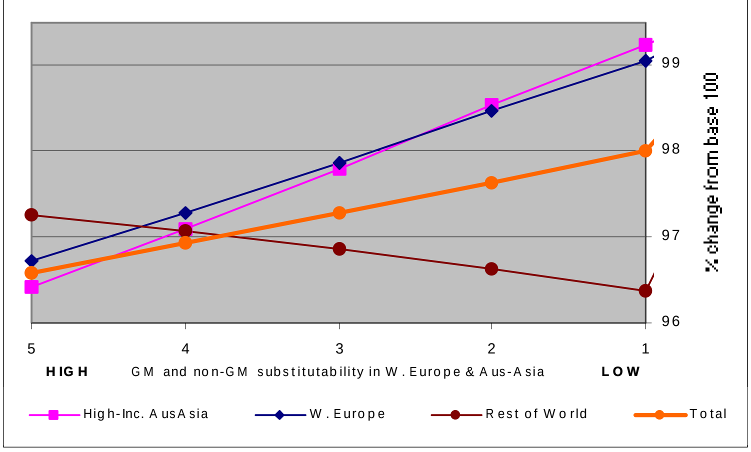


Figure 5. Changes in imports into South America by source: GM cereal grains

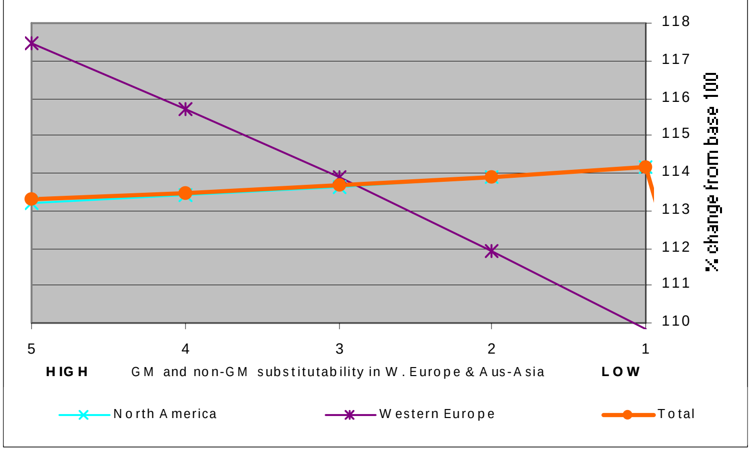
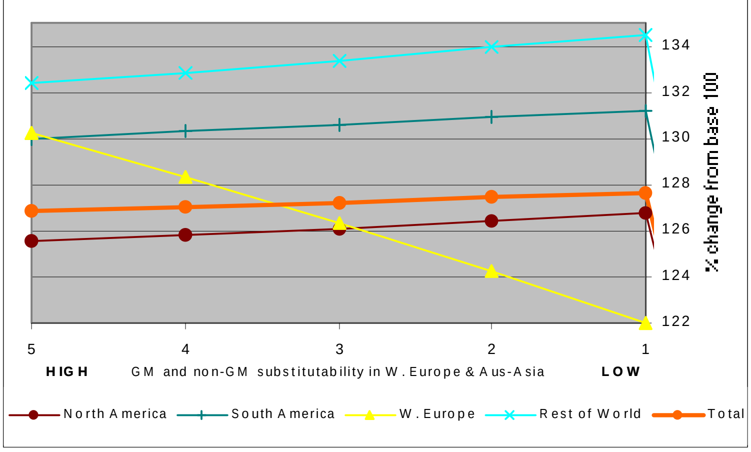


Figure 6. Changes in imports into Sub-Saharan Africa by origin: GM cereal grains



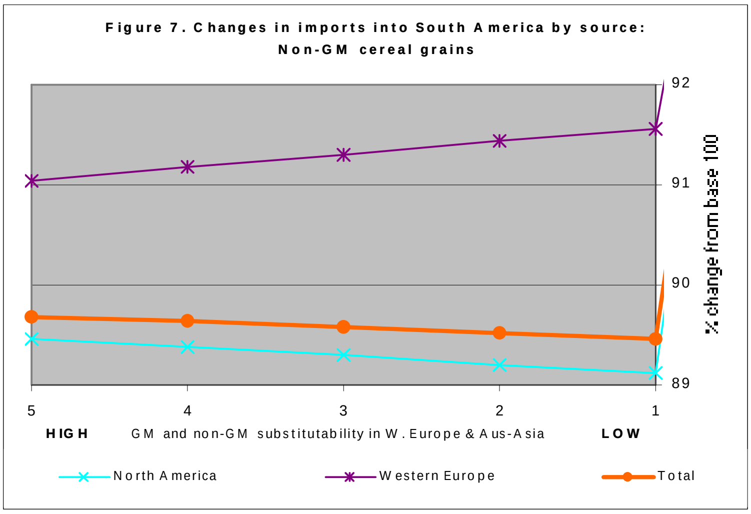


Figure 7. Changes in imports into South America by source:
Non-GM cereal grains
92
91
90
89
% change from base 100
5
4
3
2
1
HIGH
GM and non-GM substitutability in W. Europe & Aus-Asia
LOW
North America
Western Europe
Total

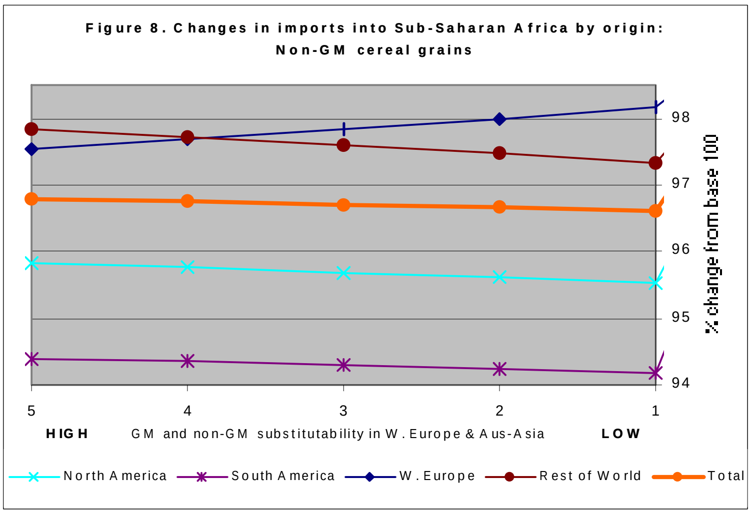


Figure 8. Changes in imports into Sub-Saharan Africa by origin:
Non-GM cereal grains
98
97
96
95
94
% change from base 100
5
4
3
2
1
HIGH
GM and non-GM substitutability in W. Europe & Aus-Asia
LOW
North America
South America
W. Europe
Rest of World
Total

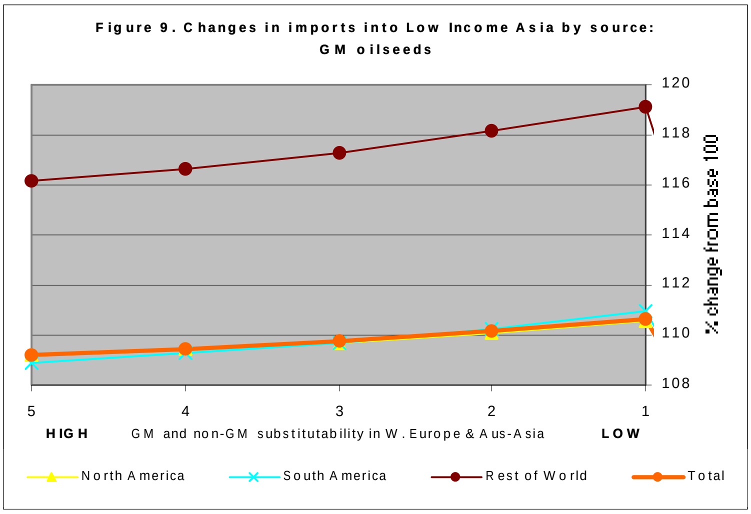


Figure 9. Changes in imports into Low Income Asia by source:
GM oilseeds
120
118
116
114
112
110
108
% change from base 100
5
4
3
2
1
HIGH
GM and non-GM substitutability in W. Europe & Aus-Asia
LOW
North America
South America
Rest of World
Total

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

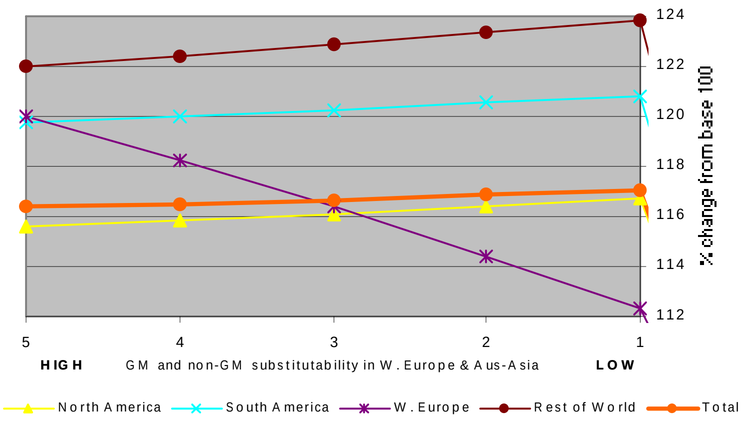


Figure 11. Changes in imports into Low Income Asia by source: Non-GM oilseeds

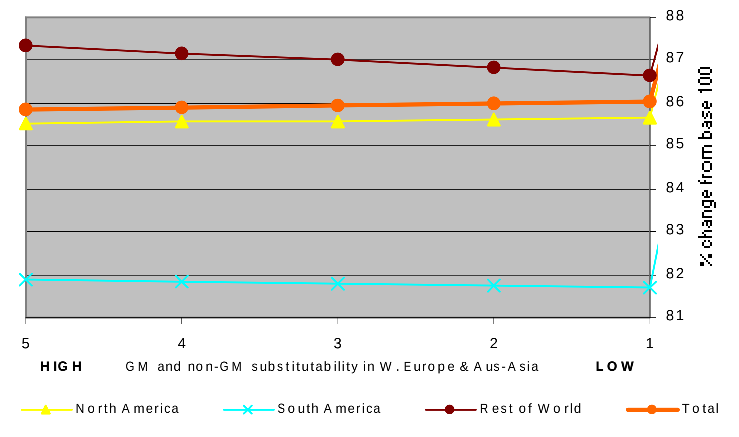


Figure 12. Changes in imports into Low Income Aisa by source: Non-GM cereal grains

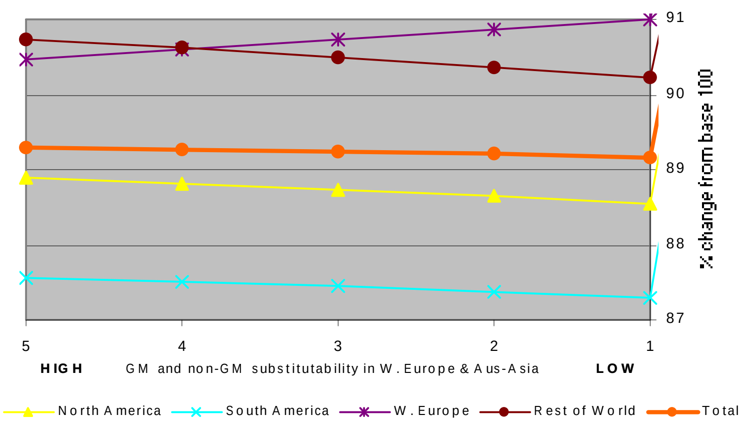


Figure 13. Price differentials between Non-GM and GM oilseeds

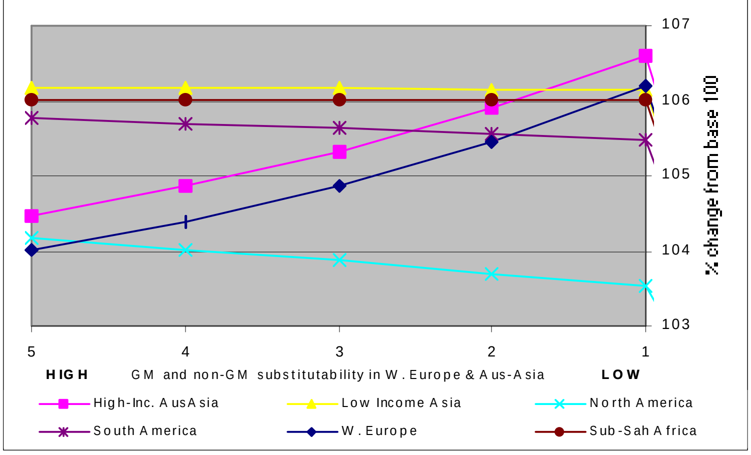


Figure 14. Price differentials between Non-GM and GM cereal grains

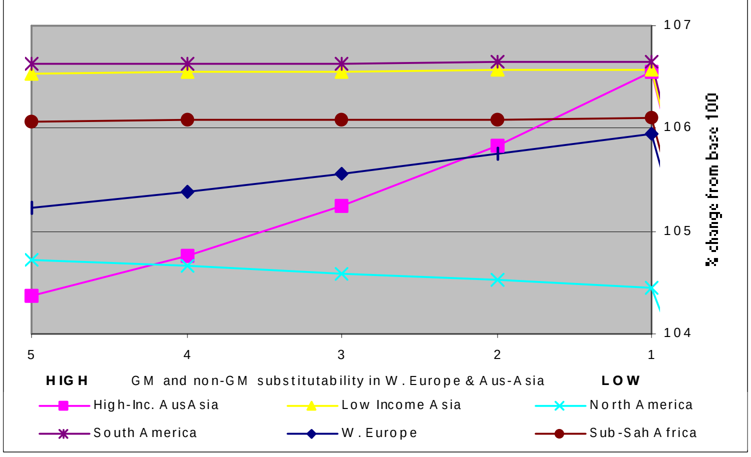


Figure 15. Changes in total absorption for different degrees of substitutability between GM & non-GM crops in AusAsia & W. Europe