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Some Implications of GM Food Technology Policies for Sub-Saharan Africa

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Abstract

The first generation of genetically modified (GM) crop varieties sought to increase farmer profitability through cost reductions or higher yields. The next generation of GM food research is focusing also on breeding for attributes of interest to consumers, beginning with ‘golden rice’, which has been genetically engineered to contain a higher level of vitamin A and thereby boost the health of unskilled labourers in developing countries. This paper analyses empirically the potential economic effects of adopting both types of innovation in Sub-Saharan Africa (SSA). It does so using the global economy-wide computable general equilibrium model known as GTAP. The results suggest the welfare gains are potentially very large, especially from golden rice, and that – contrary to the claims of numerous interests – those estimated benefits are diminished only slightly by the presence of the European Union’s current barriers to imports of GM foods. In particular, if SSA countries impose bans on GM crop imports in an attempt to maintain access to EU markets for non-GM products, the loss to domestic consumers due to that protectionism boost to SSA farmers is far more than the small gain in terms of greater market access to the EU.

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

Key words: Biotechnology, GMOs, trade policy, regulation, computable general equilibrium, Sub-Saharan Africa

1. Introduction

Over the 13,000 years since humankind began to move beyond just hunting and gathering, one of the most important micro contributors to economic progress has been innovation in food production (Diamond 1998). Even as recently as the period since 1960 the world has seen a major example of that in the so-called ‘green revolution’. That revolution initially brought higher-yielding semi-dwarf wheat and rice varieties to vast areas of Asia and other developing regions that had access to irrigation or reliable rainfall, but then it extended to include the adoption of modern varieties also of numerous other grains, root crops and protein crops. The adaption of modern varieties to local conditions by national scientists, and the subsequent gradual adoption by farmers of them, was by no means uniform. In particular, Africa lagged far behind Asia and Latin America, contributing importantly to that continent’s relatively slow growth in per capita food production particularly up to the 1990s (Evenson and Gollin 2003). Given that Africa now accounts for one-third of the world’s people living on less than $1 a day (up from one-tenth two decades ago – Chen and Ravallion 2004), and that the vast majority of those poor people in Sub-Saharan Africa are dependent on agriculture for their livelihood and much of their food, this has been an opportunity lost for a whole generation for hundreds of millions of people.

In the latter 1990s another agricultural revolution began, this time involving biotechnology including genetic modification (the so-called gene revolution). Genetically modified (GM) crops have great potential for farmers and ultimately consumers. Benefits for producers could include greater productivity and less occupational health and environmental damage (e.g., fewer pesticides), while benefits to consumers could include not only lower food prices but also enhanced attributes (e.g., ‘nutriceuticals’). While traditional biotechnology improves the quality and yields of plants and animals through, for example, selective breeding, genetic engineering enables direct manipulation of genetic material. In this way the new GM technology has the potential to accelerate the development process by shaving years off R&D programs. Protagonists argue that genetic engineering also entails a more-controlled transfer of genes because the transfer is limited to a single or just a few selected genes, whereas traditional breeding risks transferring unwanted genes together with the desired ones.

This new agricultural biotechnology has been adopted very rapidly where it has been allowed to flourish, but to date that is in just a handful of countries (most notably the US, Canada and Argentina) and so involves only their most important crops (namely maize, soybean and canola) plus cotton.[1] GM varieties of wheat, rice and other food crops would be ready for release were it not for opposition to GM technology by vocal consumer and environmental groups, particularly in Western Europe, concerned about the GM crops' potentially adverse impacts on food safety (e.g., 'Will they cause cancer?') and the environment (e.g., 'Will they lead to herbicide-resistant superweeds?). The EU responded to pressure from these groups by placing in October 1998 a *de facto* moratorium on the production and use of GM varieties other than the tiny number approved to that date. Since April 2004 that moratorium has been replaced by GM labelling laws that are so strict as to have almost the same restrictive effect on trade.

As a result of the EU *de facto* moratorium, the US share of the EU's maize imports has fallen to virtually zero (from around two-thirds in the mid-1990s, close to the US share of world exports), as has Canada's share of EU canola imports (from 54 per cent in the mid-1990s). The fall has been less dramatic in the case of soybean

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[1] China and a few other countries including South Africa also have adopted GM cotton. That crop is ignored in what follows since the focus of this paper is on food.

products, but in all three cases the GM-adopting countries have lost market share to GM-free suppliers. As a consequence, countries exporting food products fear that they will find food-importing countries discounting or denying access to their products if their farmers adopt GM technology or even if they import GM food (because of the risk of contamination of domestically produced non-GM food).

This new biotechnology therefore raises a number of dilemmas for African countries. Will the resulting decline in international food prices raise or lower national economic welfare in Africa (e.g., because they are net importers or exporters of food)? If the EU were to retain its barriers to imports of GM food, would African food exporters gain more from reduced competition in that market than from trying to develop and adopt new GM crop varieties? If that improved competitiveness required in turn a ban on imports of all food and feed from GM-adopting countries by those African countries so as to avoid contamination (as ostensibly feared by Mozambique, Zambia and Zimbabwe when they were offered food aid from the US in 2002), would the domestic economic loss to net buyers of food outweigh the gains to farmers in those countries? How would a country’s welfare be affected if a neighbouring country (e.g., South Africa) chose to adopt GM varieties of key foods?

This paper attempts to address these empirical questions. It does so by using a well-received simulation model of the global economy known as GTAP in which the South African Customs Union (SACU), the other members of the Southern African Development Community (SADC), and the rest of Sub-Saharan Africa are among the separately identified regions. The model’s base simulation, calibrated to 1997 just before the EU *de facto* moratorium was imposed, is compared with a series of alternative scenarios. After discussing the results, and key caveats including the practicality of GM adoption in Africa, the paper concludes by drawing out welfare and poverty implications for Sub-Saharan African countries under various trade and technology policy scenarios.

2. Model methodology

We use a well-received empirical model of the global economy (the GTAP model) to examine the effects of some countries adopting the new GM technology without and then with government and consumer responses in other countries. Being a general equilibrium model, GTAP (Global Trade Analysis Project) describes both the vertical and horizontal linkages between all product markets both within the model's individual countries and regions as well as between countries and regions via their bilateral trade flows. The GTAP Version 5.4 database used for these applications draws on the global economic structures and trade flows of 1997, the time of the take-off in adoption of GM crop varieties. To make the results easier to digest, the GTAP model has been aggregated to depict the global economy as having 17 regions and 14 sectors (with the focus on the primary agricultural sectors affected by the GM debate and their related processing industries).[2] We have undertaken further sectoral disaggregation of the database by separating golden rice[3] and other GM crop varieties from non-GM varieties of rice, oilseeds, coarse grains and wheat. There are five types of productive factors in the version of the GTAP model used here: skilled labour,

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[2] The GTAP (Global Trade Analysis Project) model is a multi-regional, static, applied general equilibrium model based on neo-classical microeconomic theory assuming perfect competition, constant returns to scale and full employment of all productive factors which are immobile internationally. International goods and services trade is described by an Armington specification, which means that products are differentiated by country of origin. See Hertel (1997) for comprehensive model documentation and Dimaranan and McDougall (2002) for details of the GTAP 5.4 database used here. The model is solved with GEMPACK software (Harrison and Pearson 1996). Welfare decomposition follows Harrison, Horridge and Pearson (1999). Previous uses of the GTAP model in assessing the economic implications of GM crop adoption include Nielsen and Anderson (2001), van Meijl and van Tongeren (2002), Jackson and Anderson (2003) and Huang et al. (2004).

[3] Golden rice is a GM variety that may have no farm productivity attributes but has the potential to improve health significantly in regions where rice is or could be a dietary staple for poor people, through providing pro-vitamin A. The latter characteristic is the result of golden rice being genetically engineered to contain a higher level of beta-carotene in the endosperm of the grain. See Ye et al. (2000) and Beyer et al. (2002).

unskilled labour, agricultural land, other natural resources, and other (non-human) capital. All factors except natural resources (which are specific to primary production) are assumed to be perfectly mobile throughout the national economy but immobile internationally.

We have modified the GTAP model so it can capture the effects of productivity increases of GM crops, consumer aversion to consuming first-generation GM products, and substitutability between GM and non-GM products as intermediate inputs into final consumable foods.

The simulations use a standard, neoclassical GTAP closure. This closure is characterized by perfect competition in all markets, flexible exchange rates and fixed endowments of labour, capital, land and natural resources. One outcome of this specification is that wages are flexible and the labour (and other factor) markets operate at full employment. In addition, investment funds are re-allocated among regions following a shock so as to return to equalized expected rates of return.

Production

Traditionally, to distinguish GM from non-GM productivity, outputs of the GM-adopting sectors are each sub-divided into GM and non-GM product. Except for golden rice, an output-augmenting, Hicks-neutral productivity shock is implemented on the GM varieties of these commodities to capture their higher farm productivity.[4] This assumes that GM technology uniformly reduces the level of primary factors needed per unit of food crop output. When a region does not adopt GM technologies, no regional factor productivity shock is included and there is no distinction between GM and non-GM production in these regions. In the constant-elasticity-of-substitution

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[4] This is an improvement over earlier work by ourselves (e.g. Anderson and Nielsen 2001; Nielsen and Anderson 2001) and others where all production was assumed to switch to GM varieties in the adopting countries.

production nest, producers choose first between imported and domestic inputs according to the model’s Armington (1969) elasticities, and then choose whether or not to use GM or non-GM intermediate inputs in their production of final goods.

However, as discussed in more detail elsewhere (Anderson, Jackson and Nielsen 2004), second-generation GM varieties such as golden rice require a treatment different from first-generation GM varieties. We assume there is no net difference between producing second-generation GM crops and their non-GM counterpart in terms of farm productivity: any input saving is assumed to be absorbed in the cost of segregation and identity preservation. The motivation for developing country farmers to adopt nutritionally enhanced varieties has to come from their higher valuation in the domestic market in competition with other GM and traditional varieties, net of the extra cost of segregation and identity preservation of these superior varieties when they are marketed outside the farm household.

Data on global adoption of GM technologies reveal a wide divergence in adoption across countries. In the first simulation, we assume that 75 per cent of oilseed production in the US, Canada and Argentina is GM and that 45 per cent of US and Canadian and 30 per cent of Argentinean rice, wheat and coarse grain production is GM. (Since these countries are already GM adopters in coarse grain and oilseeds, we assume they would also be the earliest adopters of GM rice and wheat once they are ready for commercial release. Those countries’ farmers have shown no interest in golden rice, so it is assumed their adoption is restricted to other GM rice varieties.) In the scenarios involving GM rice adoption in developing countries, we consider two cases: one in which 45 per cent of the rice crop is grown with GM seed that enhances farm productivity, and the other in which 45 per cent of the rice crop uses golden rice seed. The latter set of adopting farmers is assumed to be able to segregate their golden rice from other rice in order to market this product based on its enhanced nutritional composition.[5] We also consider a case where some developing countries adopt GM varieties of coarse grains, oilseeds and wheat that are assumed to account for 45 per cent of their production of those crops.

Productivity shocks

The simulations assume GM technical change in grain and oilseed production is Hicks-neutral, involving an output-augmenting productivity shock of 7.5 per cent for coarse grain, 6 per cent for oilseeds and 5 per cent for wheat and rice (Table 1). Alternative simulations were conducted to assess the importance of altering these assumptions to allow for biased technical change, but because the welfare results are not substantially different we retained the simpler Hicks-neutral assumption.[6]

While GM rice and wheat has not yet been commercialised, around the world several varieties have been approved for field trials and environmental release. A recent study found that, even under conservative adoption and consumption assumptions, introducing golden rice in the Philippines could decrease the number of disability-adjusted life years (DALYs) lost due to Vitamin A deficiency by between 6 and 47 per cent (Zimmermann and Qaim 2003). That is equivalent to an increase in unskilled labour productivity of up to 0.53 per cent. Based on those findings, Anderson, Jackson and Nielsen (2004) represent these health impacts with an assumed 0.5 per cent improvement in unskilled labour productivity in all sectors of golden rice-adopting Asian developing economies. Given the low nutrition levels of poor workers in Africa, and the fact that if golden rice were to be adopted in Asia and

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[5] The cost of segregation would be smaller, the more rice is consumed by the producing household or sold to local consumers, as is common in developing countries. This situation is thus qualitatively different from that analyzed by Lapan and Moschini (2004) where the costs of segregation and identity preservation are assumed to be significant.

[6] The results from sensitivity analysis are available from the authors.

Africa then nutritionally enhanced GM varieties of wheat and other foods would soon follow, we assume the productivity of unskilled labour would rise by 2 per cent following adoption of second-generation GM crops. We also assume no direct impact on the productivity of skilled labourers, who are rich enough to already enjoy a nutritious diet.[7] And to continue to err on the conservative side, we assume second-generation GM crop varieties are no more productive in the use of factors and inputs than traditional varieties net of segregation and identity preservation costs, even though there is evidence to suggest they may indeed be input-saving.[8]

Consumption

In order to capture consumer aversion to GM products in OECD countries, elasticities of substitution between GM and non-GM products in those regions are set at low levels.[9] Once nutritionally enhanced GM grain varieties are introduced, consumers in Sub-Saharan Africa are assumed to have a preference for them over their traditional counterparts. For simplicity and to continue to be conservative, we ignore the possibility that consumers of inferior grains might shift to these new grains and instead just represent the consumer response as involving demand for traditional rice or wheat shrinking by 45 per cent so that the nutritionally enhanced variety accounts for 45 per cent of total demand for that cereal in adopting countries. And we

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[7] There would also be non-pecuniary benefits of people feeling healthier, and less expenditure on health care, but these too are ignored so as to continue to err on the conservative side. For more on this and other aspects of golden rice and other biotech R&D outcomes, see Conway (2003).

[8] Bouis (2002) and Welch (2002) suggest nutritionally enhanced rice and wheat cultivars are more resistant to disease, their roots extend more deeply into the soil so they require less irrigation and are more drought resistant, they release chemical compounds that unbind trace elements in the soil and thus require less chemical inputs, and their seeds have higher survival rates.

[9] Elasticities of substitution are included in the computation of the distribution of GM and non-GM consumption of coarse grains, oilseeds, wheat and rice within each region. Systematic sensitivity analysis indicates that varying the elasticities of substitution for these commodities has minimal impact on the model solution. Again, details are available from the authors.

assume the consumer health benefits of second-generation GM varieties are confined to the adopting countries.

3. Scenarios

The base simulation in the GTAP model, which is calibrated to 1997, is compared with four sets of simulations. The first set examines the effects of adoption of currently available GM varieties of maize, soybean and canola[10] by the current adopters (Argentina, Canada and the US) without and then with the EU *de facto* moratorium on GMOs in place, before examining what impact adoption in South Africa would have, and then the benefits from adoption elsewhere in Africa, and then in the rest of the world as well:

Sim 1a: The US, Canada and Argentina adopt GM varieties of coarse grain and oilseeds that raise farm productivity there

Sim 1b: As for Sim 1a + the EU bans imports of those crops from GM-adopting countries

Sim 1c: As for Sim 1a + SACU adopts GM varieties of coarse grain and oilseeds

Sim 1d: As for Sim 1b + SACU adopts GM varieties of coarse grain and oilseeds

Sim 1e: All countries adopt GM varieties of coarse grain and oilseeds.

The second set of simulations involves a repeat of the first set except that China and India are assumed to join America in adopting, and GM (non-golden) rice and wheat are assumed to be made available to those adopting countries' farmers:

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[10] This has to be done in a slightly inflating way in that the GTAP model is not disaggregated below 'coarse grains' and 'oilseeds'. However, in the current adopting countries (Argentina, Canada and the US), maize, soybean and canola *are* the dominant coarse grains and oilseed crops.

Sim 2a: The US, Canada and Argentina plus China and India adopt GM varieties of coarse grain, oilseeds, rice and wheat (without EU moratorium)

Sim 2b: As for Sim 2a + the EU bans imports of those crops from GM-adopting countries

Sim 2c: As for Sim 2a + SACU adopts GM varieties of coarse grain, oilseeds, rice and wheat

Sim 2d: As for Sim 2b + SACU adopts GM varieties of coarse grain, oilseeds, rice and wheat

Sim 2e: All countries adopt GM varieties of coarse grain, oilseeds, rice and wheat.

The third set of simulations focuses on what difference it would make if SADC countries other than SACU members either banned imports of GM varieties or allowed their farmers and consumers access to them:

Sim 3a: As for Sim 1d + Rest of SADC also bans imports of those crops from GM-adopting countries

Sim 3b: As for Sim 2d + Rest of SADC also bans imports of those crops from GM-adopting countries

Sim 3c: As for Sim 2d + Rest of SADC adopts GM varieties of coarse grain, oilseeds, rice and wheat.

Finally, the fourth set of simulations repeats some of the second set except the GM rice and wheat is nutritionally enhanced and so it boosts all unskilled labour productivity in Sub-Saharan Africa by 2 per cent instead of boosting just farm productivity:

Sim 4a: As for 2a + Sub-Saharan Africa adopts second-generation GM rice and wheat that enhances health and thereby the productivity of unskilled labour in the region

Sim 4b: As for 4a + the EU bans imports of those crops from GM-adopting countries.

These simulations, which are summarized in Table 2, are clearly only a small subset of possible simulations, but they are chosen to illustrate the main choices facing Sub-Saharan Africa.

4. Results

The estimated national economic welfare effects of the first set of these shocks are summarized in Table 3. Assuming no adverse reaction by consumers or trade policy responses by governments, the first column shows that the adoption of GM varieties of coarse grains and oilseeds by the US, Canada and Argentina would have benefited the world by almost US$2.3 billion per year, of which $1.3 billion is reaped in the adopting countries while Asia and the EU enjoy most of the rest (through an improvement in their terms of trade, as net importers of those two sets of farm products). The only losers in that scenario are countries that export those or related competing products. Australia and New Zealand lose slightly (not shown in Table 3) because their exports of grass-fed livestock products are less competitive with now-cheaper grain-fed livestock products in GM-adopting countries. But so too do the non-SADC countries of Sub-Saharan Africa as a group, although again only slightly. South Africa gains slightly as a net importer of coarse grains and oilseeds, while the net welfare effect on the rest of SADC is negligible.

Column 2 of Table 3 shows the effects when the EU’s moratorium is taken into account. The gains to the adopting countries are one-third less, the EU loses instead of gains (not accounting for the value EU consumers place on being certain they are not consuming food containing GMOs), and the world as a whole would be worse off (by $1.2 billion per year, instead of better off by $2.3 billion, a difference of $3.5 billion) because the gains from the new technology would be more than offset by the massive increase in agricultural protectionism in the EU due to its import restrictions on those crops from GM-adopting American countries. For SSA, however, welfare would be $20 million p.a. greater than in Sim 1a because in Sim 1b African farmers are able to sell into the EU with less competition from the Western Hemisphere.

Columns 3 and 4 of Table 3 are the same as columns 1 and 2 except that SACU is assumed also to adopt GM coarse grains and oilseeds. In the absence of the EU moratorium this would benefit SACU an extra $6 million p.a. while helping the rest of SSA by $1 million (compare Sims 1a and 1c). However, in the presence of the EU ban, SACU would be $2 million worse off and the rest of SSA $3 million better off (compare Sims 1b and 1d).

Column 5 of Table 3 assumes the world relaxes about GMOs and all countries adopt the technology. Global welfare in that case is almost double what it is with just the current three adopters (compare with Sim 1a). South Africa’s welfare is the same in this as in Sim 1c, but welfare in the rest of SSA is enhanced considerably (by $46 million p.a. compared with the current situation as depicted in Sim 1b) and, as a proportion of GDP, those economies gain three to four times as much as SACU (see final column of Table 3).

The above numbers are small, but recall they refer to adoption only of GM varieties currently in production. If GM rice and wheat adoption also were to be allowed, global welfare would be increased by nearly twice as much (compare bottom right-hand corners of Tables 3 and 4: $7.5 versus $4.0 billion), because the market for those two crops is even larger than for coarse grains and oilseeds. Again, though, SSA economies would gain little if they do not participate, with the benefit in terms of enhanced competitiveness from abstaining in the presence of the EU moratorium being very minor relative to the foregone productivity benefits from adopting the new technology.[11]

This last point is reinforced in Table 5 where, in Sims 3a and 3b, SADC members other than SACU place a ban on imports of products that may contain GMOs, while in Sim 3c they embrace the technology. In the first two cases SACU is made slightly worse off relative to Sims 1d and 2d (by $3-4 million p.a.), while the rest of SADC is hurt even more (by $5-14 million p.a.) assuming consumers there are indifferent to consuming food that may contain GMOs; and other SSA welfare remains virtually the same. By contrast, if the rest of SADC were to adopt GM varieties along with SACU, as in Sim 3c, its welfare would be boosted by $26 million instead of reduced by $10 million and SACU’s would be up by a further $4 million annually – despite the assumed continuance of the EU moratorium.

It is instructive to focus also on the impacts on domestic food prices and quantities in the Rest of SADC in this third set of simulations. Table 6 reveals the extent to which domestic food production would be greater but by more in Sim 3b where the Rest of SADC chooses not to adopt, and to ban GM imports, than in Sim 3c

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[11] In this as in all the simulations, there is an implicit assumption that, if government policies allowed, the technology would be developed by biotech corporations for each of the regions concerned and the GM seed varieties would be sold to adopting farmers to provide the net productivity gains reported in Table 1. Those seed firms are too small a fraction of the global economy to include in the model.

where it embraces the new technology. This is the standard consequence of increasing agricultural protectionism, reflected also in the greater decline in net imports of food in Sim 3b than 3c, and in the increase in domestic food prices in Sim 3b compared with their decline in Sim 3c.

Finally, consider the situation where the GM varieties of rice and wheat that are adopted in Sub-Saharan Africa are nutritionally enhancing to the extent of boosting the health and hence productivity of unskilled workers regardless of occupation, rather than raising farm productivity as with first-generation GM varieties. Table 7 suggests this second-generation GM technology could have a major impact on poor people's welfare: its estimated gain is 18 times as great as it would be if the GM varieties were just farm productivity enhancing (compare Sims 2e and 4a). And again, this startling result is independent of whether the EU maintains its current moratorium (compare Sims 4a and 4b).

The welfare results for all of these simulations are decomposed for Sub-Saharan African regions in Table 8, to show the extent to which they derive from productivity growth, from a change in the region's international terms of trade, or from a change in the economic efficiency of resource allocation in the region given its policy distortions. All three elements play a role in determining the overall welfare impacts, but the contribution of productivity growth dominates in all regions where GM adoption occurs – especially in the case of nutritionally enhancing varieties.

5. Caveats

As with all CGE modelling results, the above are subject to a number of qualifications. One has to do with the way consumer preferences are handled. The estimated market and welfare effects vary with the elasticities of substitution assumed between GM and non-GM varieties of a product. Anderson, Nielsen and Robinson (2002) examine this issue and show that this is unlikely to be an important issue because results do not vary much as those elasticities (which are set very low for Europe and Northeast Asia and moderate elsewhere) are altered.

Of more importance is that we have no satisfactory way of valuing any loss of welfare for consumers who would like to avoid consuming foods containing GMOs but cannot if such foods are introduced into their marketplace without credible labelling. Since we have assumed that loss to be zero, we are overstating the gains from adopting this technology to that extent. An alternative way to cope with this issue is to introduce a cost of segregation and identity preservation. We did that implicitly by choosing conservative cost savings due to the new technology, saying they were net of any fees charged for segregation and identity preservation. According to Burton et al. (2002) such fees may be as high as 15 per cent of farm gate price, which would make it unprofitable to market many GM varieties if that was a required condition of sale. Others suggest those costs could be miniscule – at least in developed economies – on the grounds that such segregation is increasingly being demanded by consumers of many conventional foods anyway (e.g., different grades or varieties or attributes of each crop) so the marginal cost of expanding such systems to handle GM-ness would not be great, at least in countries that have already shown a willingness to pay for product differentiation.

The version of the GTAP database used in the above modelling does not include tariff preferences enjoyed by Africans exporting to the EU. In so far as they enjoy preferences on the products considered above, then African exporters are currently receiving the domestic EU price minus trading costs (including the share of the tariff rent enjoyed by the importing firms). That price would be raised by the EU moratorium, but whether that rise would be greater or less than the rise in the international price of GM-free varieties sold to the EU under MFN conditions is unclear. In practice this issue is likely to be of minor importance though, for two reasons. On is that the EU's MFN tariffs on coarse grains and oilseeds are low and hence so is the margin of preference. The other is that many exporters find the rules of origin so complicated that it is cheaper for them just to pay the MFN import duty rather than try to take advantage of preferences.

In all these simulations we assume for simplicity that there are no negative environmental risks net of positive environmental benefits associated with producing GM crops, and that there is no discounting and/or loss of market access abroad for other food products because of what GM adoption does for a country's generic reputation as a producer of 'clean, green, safe food'.

We have ignored the owners of intellectual property in GM varieties, and simply assumed the productivity advantage of GM varieties is net of the higher cost of GM seeds. In so far as that intellectual property is held by a firm in a country other than the GM-adopting country, then the gain from adoption is slightly overstated in the adopting country (and very slightly understated for the home regions of the relevant multinational biotech companies).

It is difficult to know how close to the mark is our assumed boost to unskilled labour productivity following adoption of second-generation GM varieties. But even if it is a gross exaggeration, discounting heavily the massive magnitude of the estimated welfare gain from adopting such varieties would still leave us with a large benefit – particularly bearing in mind that developing countries are being offered this technology at no cost by its private sector developers, and that we have included no valuation of the non-pecuniary gain in well-being for sufferers of malnutrition. The cost of adapting the off-the-shelf technology to local conditions in Africa may well be non-trivial, however, and may require a better-functioning agricultural research system than has operated in the past four decades (as evidenced by Africa's relatively poor take-up of the previous green revolution – see Evenson and Gollin 2003).

Finally, and perhaps most importantly, the above comparative static modelling assumes first-generation GM technology delivers just a one-off increase in total factor productivity (TFP) for that portion of a crop's area planted to the GM varieties. But what is more likely is that, if/when the principle of GM crop production is accepted, there would be an increase in the *rate* of agricultural TFP growth into the future. Similarly, second-generation GM varieties with additional health attributes such as those associated with golden rice would be quicker in coming on stream the more countries embraced the technology. And biotech firms would be encouraged to invest more in non-food GM crop varieties too (adding to the success already achieved with GM cotton) if there was an embracing of currently developed GM crop varieties by Sub-Saharan African and other developing countries. Hence the present value of future returns from GM adoption may be many times the numbers shown above. For that reason, care is needed in interpreting cases where our results suggest that when rich countries introduce trade barriers against GM products, food-importing developing countries benefit. This is because our analysis does not take into account that moratoria have slowed the investment in agricultural biotechnology, and so reduced future market and technological spillovers to developing countries from that prospective R&D.

6. Conclusions

From the viewpoint of Sub-Saharan Africa, the above results are good news. The GM crop technology promises much to the countries willing to adopt these new varieties. The first-generation, farm-productivity enhancing GM varieties alone will boost welfare in the adopting countries, and those welfare gains could be multiplied – perhaps many fold – if second-generation GM varieties such as golden rice were also to be embraced. Those estimated gains are only slightly lower if the EU's policies continue to effectively restrict imports of affected crop products from adopting countries. More importantly, Sub-Saharan African countries do not gain if they impose bans on GM crop imports even in the presence of policies restricting imports from GM-adopting countries: the consumer loss net of that protectionism boost to Sub-Saharan African farmers is more than the small gain in terms of greater market access to the EU.

The stakes in this issue for Sub-Saharan Africa are thus very high, with welfare gains that could alleviate poverty directly and substantially in those countries willing and able to adopt this new GM food crop technology. African countries need to assess whether they share the food safety and environmental concerns of Europeans regarding GMOs. If not, their citizens in general, and their poor in particular, have much to gain from adopting GM crop varieties and especially second-generation ones. Unlike for North America and Argentina, who are heavily dependent on exports of maize and oilseeds, the welfare gains from GM crop adoption by Sub-Saharan African countries would not be jeopardised by rich countries banning imports of those crop products from the adopting countries.

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Table 1: Assumed impact of adoption of first-generation GM crop technology on factor productivity for GM varieties relative to current non-GM varieties, by sector

(per cent difference)

	GM coarse grains	GM oilseeds	GM wheat	GM rice (non-golden)
Land	7.5	6	5	5
Skilled labour	7.5	6	5	5
Unskilled labour	7.5	6	5	5
Capital	7.5	6	5	5
Natural Resources	7.5	6	5	5

Source: Authors' assumptions, based on literature reviews by Marra, Pardey and Alston (2002), Qaim and Zilberman (2003), Huang, Hu, van Meijl and van Tongeren (2004), Huang, Hu, Rozelle and Pray (2004) and FAO (2004).

Table 2: Simulation scenarios considered

Scenario:	US, CA + ARG adopt GM coarse grain and oilseeds	US, CA, ARG, CHINA + INDIA adopt GM coarse grain, oilseeds, rice and wheat	SACU adopts GM coarse grain and oilseeds	SACU adopts GM coarse grain, oilseeds, rice and wheat	EU bans imports of affected crops from GM adopters	SADC – SACU bans imports of affected crops from GM adopters	All SADC adopts GM coarse grain, oilseeds, rice and wheat	All Sub-Saharan Africa adopts GM coarse grain and oilseeds + 2nd generation rice and wheat	All countries adopt GM coarse grain and oilseeds	All countries adopt GM coarse grain, oilseeds, rice and wheat
1a	X									
1b	X				X					
1c	X		X							
1d	X		X		X					
1e									X	
2a		X								
2b		X			X					
2c		X		X						
2d		X		X	X					
2e										X
3a	X		X		X	X				
3b		X		X	X	X				
3c		X			X		X			
4a		X						X		
4b		X			X			X		

Table 3: Estimated economic welfare effects of GM coarse grain and oilseed adoption by various countries (US$ million per year)

	US, CAN and ARG adopt		US, CAN, ARG + SACU adopt		All countries adopt	
	Without policy response	With EU moratorium	Without policy response	With EU moratorium	Without policy response	
	Sim 1a	***Sim 1b***	***Sim 1c***	***Sim 1d***	***Sim 1e***	***EV as % of GDP (sim 1e)***
Change in economic welfare (equivalent variation in income, $m)						
SACU	3	7	9	5	9	0.01
Rest of SADC	0	2	0	3	18	0.04
Rest of SSA	-2	12	-1	14	42	0.03
Argentina	312	247	312	246	287	0.11
Canada	72	7	72	7	65	0.01
US	939	628	939	627	897	0.01
EU-15	267	-3145	269	-3179	595	0.01
Rest of World	700	1027	225	1001	2204	0.02
WORLD	**2290**	**-1243**	**2300**	**-1276**	**4047**	**0.013**

Source: Authors' GTAP model simulation results

Table 4: Estimated economic welfare effects of GM coarse grain, oilseed, rice and wheat adoption by various countries
(equivalent variation in income, US$ million)

	US, CAN, ARG, CHN and IND adopt		US, CAN, ARG, CHN, and IND + SACU adopt		All countries adopt	
	Without policy response	With EU moratorium	Without policy response	With EU moratorium	Without policy response	
	Sim 2a	***Sim 2b***	***Sim 2c***	***Sim 2d***	***Sim 2e***	***EV as % of GDP (sim 2e)***
Change in economic welfare (equivalent variation in income, $m)						
SACU	7	11	13	10	15	0.01
Rest of SADC	0	4	0	4	22	0.05
Rest of SSA	5	23	6	24	165	0.12
Argentina	350	285	350	285	312	0.12
Canada	83	-23	83	-23	63	0.01
US	1045	754	1045	754	1041	0.01
China	841	833	841	832	899	0.25
India	669	654	669	654	669	0.14
EU-15	355	-4717	358	-4754	810	0.01
Rest of World	964	1322	953	1285	3509	0.03
WORLD	**4308**	**-892**	**4319**	**-928**	**7506**	**0.024**

Source: Authors’ GTAP model simulation results

Table 5: Estimated economic welfare effects of GM adoption with SADC other than SACU either banning or adopting GM varieties

(US$ million per year)

	US, CAN, ARG and SACU adopt GM coarse grains and oilseeds	US, CAN, ARG, CHN, IND and SACU adopt GM coarse grains, oilseeds, rice and wheat	As for 3b + Rest of SADC adopts same GM commodities
	With EU and SADC (excl SACU) moratoria	With EU and SADC (excl SACU) moratoria	With EU moratorium
	Sim 3a	***Sim 3b***	***Sim 3c***
Change in economic welfare (equivalent variation in income, $m)			
SACU	2	6	10
Rest of SADC	-2	-10	26
Rest of SSA	14	25	25
Argentina	246	284	285
Canada	7	-24	-23
US	626	756	754
China	111	833	833
India	3	654	654
EU-15	-3181	-4760	-4750
Rest of World	889	1290	1286
WORLD	**-1287**	**-946**	**-900**

Source: Authors' GTAP model simulation results

Table 6: Trade and domestic production, price and trade impacts in SADC other than SACU (Rest of SADC) of GM adoption, with Rest of SADC either banning or also adopting GM varieties

(percentage changes)

	US, CAN, ARG, CHN, IND, SACU adopt GM coarse grains, oilseeds, rice and wheat	US, CAN, ARG, CHN, IND, SACU adopt GM coarse grains, oilseeds, rice and wheat + *Rest of SADC adopts*
	With EU *and Rest of SADC Moratoria*	With EU Moratorium
	Sim 3b	***Sim 3c***
Production		
Coarse grains	1.0	0.4
Oilseeds	5.8	1.8
Rice	1.5	0.9
Wheat	15.6	0.7
Meat	0.0	0.3
Domestic market prices		
Coarse grains	0.3	-0.8
Oilseeds	0.3	-1.2
Rice	0.3	-1.0
Wheat	0.4	-0.3
Meat	0.2	0.0
Imports		
Coarse grains	-25.7	-2.2
Oilseeds	-52.5	-0.6
Rice	-6.9	-4.1
Wheat	-21.2	-0.2
Meat	-0.4	-0.9
Exports		
Coarse grains	1.2	4.2
Oilseeds	9.2	12.0
Rice	7.0	11.7
Wheat	1.7	-0.3
Meat	0.6	1.4

Source: Authors' GTAP model simulation results.

Table 7: Estimated economic welfare effects of GM crop adoption with Sub-Saharan Africa's being second-generation, nutritionally enhanced rice and wheat

(US$ million per year)

	US, CAN, ARG, CHN, and IND adopt first-generation GM coarse grains, oilseeds, rice and wheat and SSA adopts second-generation rice and wheat	
	Without EU moratorium	With EU moratorium
	Sim 4a	***Sim 4b***
Change in economic welfare (equivalent variation in income, $m)		
SACU	1786	1789
Rest of SADC	403	407
Rest of SSA	1421	1439

Source: Authors' GTAP model simulation results

Table 8: Decomposition of national economic welfare effects due to GM adoption under various simulations[a]

(equivalent variation in income, US$ million)

	Allocative efficiency impact	Terms of trade impact	Productivity growth impact	**Total impact**
SACU				
Sim 1a	3	1	0	3
Sim 1b	2	5	0	7
Sim 1c	2	0	7	9
Sim 1d	-2	-1	7	5
Sim 1e	3	0	7	9
Sim 2[a]	4	3	0	7
Sim 2b	3	9	0	11
Sim 2c	3	2	9	13
Sim 2d	-1	3	8	10
Sim 2e	4	3	8	15
Sim 3a	-3	-3	7	2
Sim 3b	-3	1	8	6
Sim 3c	-1	3	8	10
Sim 4a	216	22	1549	1786
Sim 4b	215	28	1549	1789
Rest of SADC				
Sim 1a	0	0	0	0
Sim 1b	0	3	0	2
Sim 1c	0	0	0	0
Sim 1d	0	3	0	3
Sim 1e	2	-3	19	18
Sim 2a	0	0	0	0
Sim 2b	0	4	0	4
Sim 2c	0	0	0	0
Sim 2d	0	4	0	4
Sim 2e	2	-2	22	22
Sim 3[a]	-9	7	0	-2
Sim 3b	-21	12	0	-10
Sim 3c	0	-1	22	22
Sim 4a	43	-22	382	403
Sim 4b	43	-18	382	407

continued …

Table 8: (cont)

Rest of SSA

Sim 1a	0	-2	0	-2
Sim 1b	1	9	0	12
Sim 1c	1	-2	0	-1
Sim 1d	2	9	0	14
Sim 1e	2	-5	45	42
Sim 2a	3	1	0	5
Sim 2b	4	16	0	23
Sim 2c	3	2	0	6
Sim 2d	5	17	0	24
Sim 2e	7	-5	163	165
Sim 3a	2	10	0	14
Sim 3b	5	17	0	25
Sim 3c	6	17	0	25
Sim 4a	-11	-396	1887	1421
Sim 4b	-8	-383	1888	1439

[a] See the previous four tables for the descriptions of each of the simulations. The welfare decomposition follows Harrison, Horridge and Pearson (1999).

Source: Authors' GTAP model simulation results

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