Review

Economic impacts of policies affecting crop biotechnology and trade

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Agricultural biotechnologies, and especially transgenic crops, have the potential to boost food security in developing countries by offering higher incomes for farmers and lower priced and better quality food for consumers. That potential is being heavily compromised, however, because the European Union and some other countries have implemented strict regulatory systems to govern their production and consumption of genetically modified (GM) food and feed crops, and to prevent imports of foods and feedstuffs that do not meet these strict standards. This paper analyses empirically the potential economic effects of adopting transgenic crops in Asia and Sub-Saharan Africa. It does so using a multi-country, multi-product model of the global economy. The results suggest the economic welfare gains from crop biotechnology adoption are potentially very large, and that those benefits are diminished only very slightly by the presence of the European Union's restriction on imports of GM foods. That is, if developing countries retain bans on GM crop production in an attempt to maintain access to EU markets for non-GM products, the loss to their food consumers as well as to farmers in those developing countries is huge relative to the slight loss that could be incurred from not retaining EU market access.

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Introduction

Up until the 19th century, the pace of improving the productive efficiency and quality of the world's food crops had been slow [1]. Then, following a century of wheat improvements [2], hybrid varieties dramatically increased average corn yields from the 1940s [3], and dwarf varieties of high-yielding wheat and rice caused what became known as the green revolution in Asia and elsewhere from the 1960s [4,5]. Those technological developments

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of the past six decades contributed to an acceleration of the long-term decline in real international food prices so that, by the late 1980s, they were below 1930s' levels,[1] which in turn led to complacency about the need for further agricultural research. As a result, growth in public funding for such research fell substantially in both rich and poor countries [6] – despite overwhelming evidence that this is a very high payoff investment area [7]. In particular, the aid agencies and foundations reduced their support for the Consultative Group on International Agricultural Research (CGIAR) and for complementary national agricultural research systems in developing countries – which quickly led to fears that food crop productivity growth would slow [8].

The emergence in the 1990s of new agricultural biotechnologies, and in particular transgenic crop varieties, seemed to offer new hope that the private sector might fill this lacuna. But to those early hopes were added three other concerns. One was that a small number of huge biotech firms would capture most of the gains from the new agricultural biotechnology. This ignores the fact that competition among those firms forces down the selling price of new seeds, and that farmers will only adopt the new technology if they perceive a net benefit to themselves.

A second concern was that those firms would not invest in poor countries where profits would be slim because of poor protection of intellectual property rights, the high cost of getting over national regulatory barriers, and small commercial seed markets [9]. In so far as these characteristics prevail, the solution lies in improving property rights, streamlining the regulatory processes and opening up the seed market to more competition.

The third concern was that Europeans and others would reject the technology because of environmental and food safety concerns, thereby thwarting export market prospects for adopters of the transgenic crops [10–12]. That third concern was vindicated by the European Union's imposition, in late 1998, of a *de facto* moratorium on the production and importation of food products that might contain genetically modified organisms (GMOs), which helped to constrain widespread adoption to just three GM food/feed crops (maize, soybean and canola) in three countries where production had already taken off by 1998, namely the United States, Argentina and Canada. Even when the other important GM crop is added (cotton), those three countries continue to dominate [13].

In May 2004 the European Union (EU) replaced its moratorium with new regulatory arrangements, but they involve such onerous and laborious segregation, identity preservation and labelling requirements as to be almost as restrictive of exports of GM products as was the moratorium. With several other countries also imposing strict labelling regulations on GM foods [14], and even private importing firms seeking GM-free foods [15], biotech firms are diverting more of their R&D investments away from food. At the same time, the public agricultural research system has been shy about investing heavily in this technology – including the CGIAR which depends heavily on rich-country grants from EU member states.

How are these events affecting food security in developing countries, where food security can be thought of as everyone having access to the minimum amount of basic food that is necessary for survival, that is, having the wherewithal to grow or to purchase a minimum basket of food? Transgenic crops can boost food security in either of two ways: by improving a farm household's net real earnings (including not only the implicit value of subsistence food production but also earnings from cash crops such as cotton), or by lowering the price or improving the quality of the food brought by a non-farm household. The real price of food in international markets would be lowered because of farm productivity growth in any trading countries that adopt the new technology, and that would reduce food prices in the domestic market of all countries that are at least somewhat open to trade.

What has been the impact on developing country welfare of the limited adoption of GM varieties so far and of the EU's reaction to that, and what would be the impacts of wider adoption of GM crops? This question is addressed in this paper by considering first-generation corn and oilseed GM crops, then the prospective adoption of 1st or 2nd generation (nutritionally enhanced) rice and wheat, and finally the adoption of GM cotton. This is done by drawing on empirical data and some simulation results from a multi-country, multi-product model of the global economy. The paper concludes with some policy implications that follow from the results of this analysis.

China and India are the most significant developing countries to consider, in the sense that they house the majority of the world's poor [16], they comprise almost one-third of the world's production and consumption of grain (and even more of cotton), and they (especially China) have the potential to rapidly apply and disseminate this new biotechnology. But Sub-Saharan Africa is also of crucial concern, given its extreme poverty and strong dependence still on agriculture for employment and export earnings and, in some cases, on food aid imports (which can be problematic if food provided as aid is not GM-free, as was the case for US shipments to southern Africa in 2002).

How has national welfare been affected to date in GM-adopting countries, in the EU, and in non-adopting developing countries?

To estimate the welfare consequences of policies affecting GM crop adoption, we have employed a model of the world economy known as GTAP (see [17]) and report several sets of simulation results.[2] We begin with GM adoption for just coarse grains and oilseeds but then add rice and wheat, and then cotton, to get a feel for the relative economic importance to different regions and the world as a whole of current versus prospective GM crop technologies. The impacts of GM food crop adoption by just the United States, Canada and Argentina are considered first, without and then with policy reactions by the EU. The simulation is then re-run with the EU added to the list of adopters, to explore the tradeoffs for the EU between productivity growth via GM adoption and the benefits of remaining GM-free given the prior move to adopt in the Americas. A change of heart in the EU would reduce the reticence of the rest of the world to adopt GM food crop varieties, so the effects of all other countries then adopting is explored as well.

Specifically, the base case in the GTAP model, which is calibrated to 1997 just before the EU moratorium being imposed, is compared with an alternative set of simulations whereby the

[1] The other key contributor was the post-war growth of agricultural protectionism in developed and newly industrialising countries [29,30].

[2] This section draws on results presented in [31], which in turn has been inspired by earlier global modelling analysts including [32–34].

TABLE 1

Estimated economic welfare effects of GM coarse grain and oilseed adoption by various countries (equivalent variation in income, 1997 US$ million per year)Source: [31].

	US, CAN and ARG adopt		All countries adopt	
	Without policy response	With EU moratorium	Without policy response	
	Sim 1a	Sim 1b	Sim 1c	EV as % of GDP (sim 1c)
Argentina	312	247	287	0.11
Canada	72	7	65	0.01
US	939	628	897	0.01
EU-15	267	−3145	595	0.01
Southern African Customs Union	3	7	9	0.01
Rest of Sub-Saharan Africa	−2	14	60	0.03
Rest of the world	700	1027	2204	0.02
World	2290	−1243	4047	0.013

effects of adoption of currently available GM varieties of maize, soybean and canola by the first adopters (Argentina, Canada and the US) is explored without and then with the EU *de facto* moratorium on GMOs in place.[3] Plausible assumptions about the farm productivity effects of these new varieties and the probable percentage of each crop area that converts to GM varieties are taken from the available literature including [18–20].[4]

The estimated national economic welfare effects of the first set of these shocks are summarized in Table 1. 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 1) 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-SACU countries of Sub-Saharan Africa (SSA) 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 1 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 because of its import restrictions on those crops from GM-adopting American countries. For SSA other than SACU, however, welfare would be $46 million p.a. greater than in Sim 1b because in Sim 1c African farmers are able to sell into the EU with less competition from the Western Hemisphere. As a proportion of GDP, those economies gain three times as much as SACU (see final column of Table 1).

However, if by adopting the technology in the EU the rest of the world also became uninhibited about adopting GM varieties of these crops, global welfare would be increased by nearly twice as much as it would when just North America and Argentina adopt, and almost all of the extra global gains would be enjoyed by developing countries. If one believes the EU's policy stance is determining the rest of the world's reluctance to adopt GM varieties of these crops, then the cost of the EU's moratorium to people outside the EU15 has been up to $0.4 billion per year for the three GM-adopting countries (compare columns 2 and 3 of Table 1) and $1.1 billion per year for other developing countries.

Those estimates understate the global welfare cost of the EU's policy in at least four respects, however. First, the fact that the EU's stance has induced some other countries to also impose similar moratoria on GM food crops (if not cotton) has not been taken into account. Sri Lanka was perhaps the first developing country to ban the production and importation of GM foods. In 2001 China did the same (with some relaxation in 2002), having been denied access to the EU for some soy sauce exports because they might

[3] 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.

[4] We assume 45% of US and Canadian coarse grain production is GM and, when they adopt, all Latin American countries and Australia are assumed to adopt GM coarse grains at two-thirds the level of the US while all other countries are assumed to adopt GM coarse grains at one-third the level of US adoption. For oilseeds, we assume that 75% of oilseed production in the US, Canada and Argentina (and Brazil when we allow it) is GM. Again Other Latin American countries and Australia are assumed to adopt at two-thirds the extent of the major adopters and the remaining regions adopt at one-third the extent of the major adopters. For the prospective rice scenarios, major assumed adopters, including the US, Canada, China, India, and all other Asian countries are assumed to produce 45% of their crop using GM varieties. All other regions adopt at two-thirds this rate. Prospective GM wheat adoption is assumed to occur to the same extent as coarse grain adoption for all regions. The GM varieties are assumed to enjoy higher total factor productivity than conventional varieties to the extent of 7.5% for coarse grains, 6% for oilseeds and 5% for wheat and rice. The simulations are able to estimate the equivalent variations in income, measured in 1997 US dollars, that would result from these assumed degrees of adoption and productivity growth for the GM potion of each crop and its consequence effect on markets.

TABLE 2

Estimated economic welfare effects of GM coarse grain, oilseed, rice and wheat adoption by various countries (equivalent variation in income, 1997 US$ million per year)Source: [31].

	US, CAN, ARG, CHN and IND adopt		All countries adopt	
	Without policy response	With EU moratorium	Without policy response	
	Sim 2a	Sim 2b	Sim 2c	EV as % of GDP (sim 2c)
Argentina	350	285	312	0.12
Canada	83	−23	63	0.01
US	1045	754	1041	0.01
China	841	833	899	0.25
India	669	654	669	0.14
EU-15	355	−4717	810	0.01
Southern African Customs Union	7	11	15	0.01
Rest of Sub-Saharan Africa	5	27	187	0.11
Rest of the world	964	1322	3509	0.03
World	4308	−892	7506	0.024

have been produced using GM soybeans imported by China from the US. Second, these are comparative static simulations that ignore that fact that GM food R&D is on-going and that investment in this area has been reduced considerably because of the EU's extreme policy stance as biotech firms redirect their investments towards pharmaceuticals and industrial crops instead of food crops. Third, the gains to the biotech firms that produce GM seeds are ignored in these results (and all subsequent simulations reported below). And fourth, the above results refer to GM adoption just of coarse grains and oilseeds. The world's other two major food crops are rice and wheat, for which GM varieties have been developed and are close to being ready for commercial release.

How might GM rice and wheat adoption affect developing countries?

The above numbers refer to adoption only of GM foodcrop varieties currently in production. If 1st generation (i.e. farm productivity enhancing) GM rice and wheat adoption also were to be allowed at the rates assumed in footnote 4 above, global welfare would be increased by nearly twice as much (compare bottom row of column 3 of Tables 1 and 2: $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. Comparing columns 2 and 3 of Table 2, these results suggest SSA would be better off by more than $130 million per year if the world were to embrace 1st generation GM technology for all four groups of foodcrops rather than for just coarse grains and oilseeds.

While 2nd generation (nutritionally enhanced) GM rice and wheat has not yet been commercialised, several varieties have been approved for field trials and environmental release in various parts of the world. An early 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 because of Vitamin A deficiency by between 6 and 47% [21]. That is equivalent to an increase in unskilled labour productivity of up to 0.53%. On the basis of those findings, Anderson *et al.* [22] represent these health impacts with an assumed 0.5% 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 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% following adoption of 2nd 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.[5] And to continue to err on the conservative side, we assume 2nd 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 might indeed be input-saving.[6]

Table 3 suggests this 2nd generation GM technology could have a major impact on poor people's welfare: if it were to be adopted in SSA, for example, its estimated gain is 18 times as great as it would be if the GM varieties were just farm productivity enhancing (compare Sims 2c and 3a). And again, this startling result is independent of whether the EU maintains its current moratorium (compare Sims 3a and 3b). Needless to say, adopting these 2nd generation GM varieties in the developing countries of Asia would add far more, given the large population of rice and wheat consumers in Asia. Anderson *et al.* [22] show that even Golden Rice on its own could add $3.2 billion per year to developing country economic welfare.

[5] 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.

[6] Bouis [35,36] and Welch [37] 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.

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TABLE 3

Estimated economic welfare effects of GM crop adoption with Sub-Saharan Africa's being 2nd generation, nutritionally enhanced rice and wheat (equivalent variation in income, 1997 US$ million per year)Source: [31].

	US, CAN, ARG, CHN, and IND adopt first-generation GM coarse grains, oilseeds, rice and wheat and SSA adopts 2nd generation rice and wheat	
	Without EU moratorium Sim 3a	With EU moratorium Sim 3b
Southern African Customs Union	1786	1789
Rest of Sub-Saharan Africa	1824	1846
All Sub-Saharan Africa	3610	3635

What difference can GM cotton make to developing country welfare?

The spread of GM cotton to developing countries is beginning to pick up speed. As of 2009, it accounted for one-eighth of the world's total area of GM crops, and GM varieties accounted for 49% of all land sown to cotton [13]. The United States and China account for much of that. The only other countries with high GM adoption rates as of 2004 were Australia and South Africa, both with slightly more than four-fifths of their cotton areas under GM varieties, but in barely half a decade India has gone from zero to five-sixths of its cotton crop being GM.

What impact has that adoption by those first four countries had on global welfare, and how much greater would be that impact if India is added and other producing countries were to promote widespread adoption of GM cotton varieties? To answer that question, results are drawn from global simulation modelling in Anderson *et al.* [23]. They suggest that world cotton output had hardly changed up to 2001. This is because the output gains in the first four GM-adopting countries were offset by output losses in the non-adopting countries, which were driven by the downward pressure on the average price of cotton in international markets (which fell by 2.5% as a result of this initial adoption, according to that study).[7] Globally, both value added by cotton farmers and the value of cotton exports were reduced by about 1% and by more than that in most non-adopting regions. The largest regional changes in value added in cotton production are in Sub-Saharan Africa, with a rise in South Africa of 3.5% and a fall in the rest of Sub-Saharan Africa of 4.4% by 2001. Among the GM cotton adopters, estimated value added in cotton production fell in both the United States and China, in part because of the decline in export prices. This is not to say individual farmers in those countries were irrational in adopting GM cotton, because had they not they would have still suffered from the product price fall, following adoption by other farmers, but would not have had a productivity improvement to partly offset it.

The net economic welfare effects of this initial adoption of GM cotton are summarized in Table 4. For all four adopting countries this was positive despite the loss because of their terms of trade deterioration, while welfare improved in all non-adopting regions but one. This is because they are net importers of cotton and so enjoy an improvement in their terms of trade and a greater flow of imports. The exceptional non-adopting region is Sub-Saharan Africa (excluding South Africa) which as a net exporter of cotton faces lower cotton export prices and also has resources move to sectors in which it had a lesser comparative advantage. Globally, annual economic welfare is estimated to have been enhanced by more than $0.7 billion from GM cotton adoption as of 2001, plus whatever net profits accrued to the biotech and seed firms (which are not explicitly modelled).

In the next scenario, in which all other countries then adopt GM cotton, cotton output in the early-adopting countries falls in response to the output expansion in newly adopting regions. If Sub-Saharan Africa continues to procrastinate, its cotton output, value added and exports would fall even further; but if it also were to embrace this technology, its cotton industry would expand more than any other region's and would more than make up its losses to 2001 from adoption by the first four adopters. Global welfare is boosted very much more with greater adoption by developing countries. Even without Sub-Saharan Africa adopting, it would jump to $2.0 billion per year. But adoption by Sub-Saharan Africa would raise that global benefit to $2.3 billion, with two-thirds of that extra $0.3 billion being enjoyed by Africa (more than offsetting its earlier loss because of adoption by others up to 2001), and the rest by cotton-importing regions. Asia's developing countries that are net importers of cotton gain even if they grow little or no cotton, not only because of greater imports but also because the international price of that crucial input into their textile industry would be lowered further, by an average of 4.1% when Sub-Saharan Africa also adopts, as compared with 2.5% from GM adoption by just the first four adopting countries. With complete catch-up as in this third scenario, the gains to Central Asia, Sub-Saharan Africa and South Asia are 10, 13 and 23 times greater than the global gains when expressed as a percentage of regional GDP (last column of Table 4). South Asia's are especially large because it is a large producer of both cotton and textiles.

Caveats

As with all CGE modelling results, the above are subject to several 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 *et al.* [24] 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 at moderate levels 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 (following [25]), 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 because of the new technology, saying they were net of any fees charged for segregation and

[7] That estimated price fall would have been somewhat less had we also included GM corn and soybean adoption at the same time, since that would have reduced the extent of diversion of resources to cotton.

TABLE 4

Effects of GM cotton adoption on national economic welfare as of 2001 (equivalent variation in income, 2001 US$ million)Source: [23].

	4 countries adopt		All but SSA adopt		All including SSA adopt		
	TFP Shock (%)[a]	Welfare change ($m)	TFP Shock (%)	Welfare change ($m)	TFP Shock (%)	Welfare change ($m)	Welfare change (% of GDP)
Adopters as of 2001							
United States	−5	324	0	61	0	57	0.001
China	−2.5	162	2.5	113	2.5	100	0.009
Australia	−5	26	0	−14	0	−28	−0.008
South Africa	−5	2	0	5	0	12	0.010
Non-adopters as of 2001							
Other high-income countries	0	147	5	271	5	337	0.003
Eastern Europe and Central Asia	0	5	5	325	5	317	0.048
Southeast Asia (ex China)	0	36	5	31	5	63	0.009
South Asia	0	14	5[b]	964	5[b]	970	0.158
Middle East and North Africa	0	14	5	157	5	175	0.020
Sub-Saharan Africa (excluding S. Africa)	0	−17	0	−18	15	187	0.091
Latin America and Carib.	0	29	5	124	5	135	0.007
World		742		2018		2323	0.007

[a] By applying a negative TFP shock to cotton production we examine how the world would have been had that productivity gain from cotton GM adoption not taken place in these countries (but for comparative purposes we express the welfare results with the opposite signs).
[b] Except for India, where the TFP is 15%.

identity preservation. If such fees were a high share of the farm gate price, it would be unprofitable to market many GM varieties if that was a required condition of sale. But some 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 on GM products, 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 non-preferential conditions is unclear. In practice this issue is probably to be of minor importance though, for two reasons. One 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 regular import duty rather than try to take advantage of tariff 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'. In fact some GM crops (e.g. cotton) will reduce not only negative environmental externalities but also farmers' health risks associated with spraying pesticides (see [26]).

It is difficult to know how close to the mark is our assumed boost to unskilled labour productivity following adoption of 2nd generation GM varieties (see [27]). 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 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 might well be non-trivial, however, and might 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 [4]).

Finally, and perhaps most importantly, the above comparative static modelling assumes 1st generation GM technology delivers just a one-off increase in total factor productivity for that portion of a crop's area planted to the GM varieties. But what is more probable is that, if/when the principle of GM crop production is accepted, there would be an increase in the *rate* of agricultural factor productivity growth into the future. Similarly, 2nd 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 might 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.

Conclusions

From the above results it is clear that the new agricultural biotechnologies promise much to the countries willing to adopt GM crop varieties. Moreover, the gains from farm-productivity enhancing GM varieties could be multiplied – perhaps many fold – if 2nd generation biofortified GM varieties such as Golden Rice were also to be embraced. The estimated gains to developing countries are only slightly lower if the EU's policies continue to effectively restrict imports of affected crop products from adopting countries. Importantly, developing countries would not gain if they imposed 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 Asian and Sub-Saharan African farmers is far more than the small gain in terms of greater market access to the EU.[8]

The stakes in this issue are thus very high, with welfare gains that could alleviate poverty directly and substantially in those countries willing and able to adopt this new biotechnology. Developing 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 those gains will increase as climate change proceeds and requires adaptation by farmers to changes in weather patterns and in particular to increased weather volatility and higher costs of water for irrigation. Unlike for North America and Argentina, who are heavily dependent on exports of maize and oilseeds, the welfare gains from GM crop adoption by Asian and Sub-Saharan African countries would not be greatly jeopardised by rich countries banning imports of those crop products from the adopting countries.

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[8] This is consistent with the finding [38] that African exports of food crops in general to the EU that might be affected adversely by GM adoption represent a very small share of the region's exports. See also [39].